

**SEDIMENTATION, LIVESTOCK, AND FARMERS'
WILLINGNESS TO MAINTAIN SMALL SCALE
IRRIGATION SCHEMES IN ETHIOPIA**

HANAN TADELE DESSALEGN

SEDIMENTATION, LIVESTOCK AND FARMERS' WILLINGNESS TO MAINTAIN SMALL-SCALE IRRIGATION SCHEMES IN ETHIOPIA

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Propositions

1. The sustainability of small-scale irrigation schemes is highly dependent on the farmers' willingness to maintain the irrigation systems.
(this thesis)
2. Current measures to reduce sedimentation are unsuccessful because they address only one source.
(this thesis)
3. Young mothers need more than a scholarship to succeed in their Ph.D.
4. Writing science in your own mother tongue is more difficult than writing in English.
5. For a successful Ph.D. trajectory, emotion management is needed than intelligence.
6. Limited attention for transdisciplinary learning at Ethiopian Universities hampers solving the country's complex problems.

Propositions belonging to the thesis, entitled.

Sedimentation, Livestock and Farmers' Willingness to Maintain Small Scale-irrigation schemes in Ethiopia.

Hanan Tadele Dessalegn

Wageningen, 21 February 2023

**Sedimentation, Livestock and Farmers' Willingness to
Maintain Small-Scale Irrigation Schemes in Ethiopia**

Hanan Tadele Dessalegn

Thesis Committee

Promotor

Prof. Dr. Charlotte de Fraiture

Professor of Hydraulic Engineering for Land and Water Development

IHE Delft Institute for Water Education and Wageningen University & Research

Co-promoters

Dr. Ir. Alex Bolding

Assistance professor, Water Resource Management

Wageningen University and Research

Dr. Mekonen Ayana Gebul

Associate professor, Department of Water Resources Engineering

Adama Science and Technology Institute

Other Members

Prof. dr.ir.C (Cees) Leeuwis, Wageningen University and research, The Netherlands

Prof. Tena Alamirew, Senior researcher at Addis Ababa University, Ethiopia

Dr. Hermen Smit, Senior Water policy officer at Westland Municipality, The Netherlands

Dr. Frank van Steenberg, Meta-Meta Enterprise, Netherlands.

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Hanan Tadele Dessalegn

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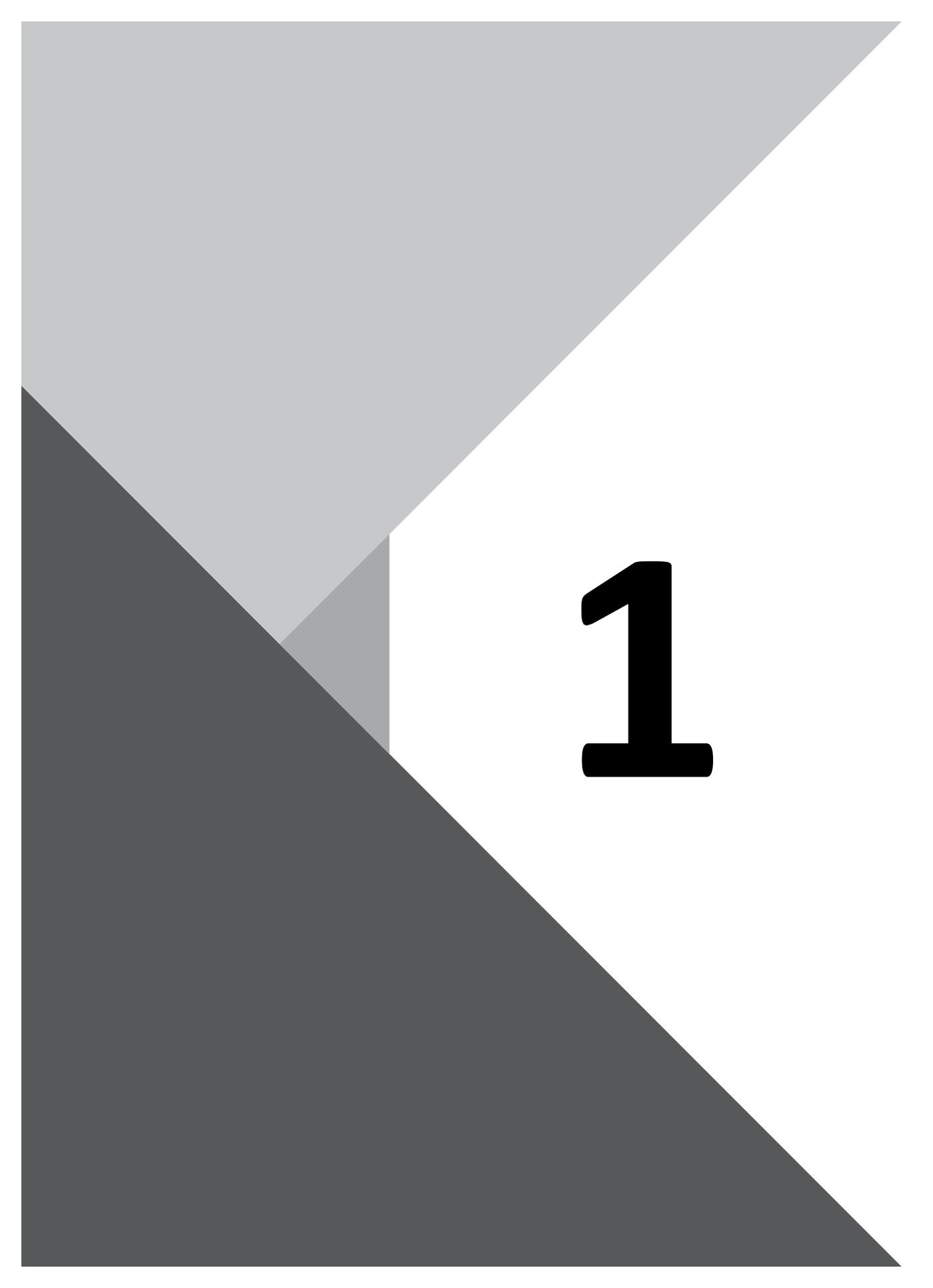
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The image features a white background with a large, bold, black number '1' centered on the right side. The background is divided into several geometric sections by diagonal lines. A dark gray triangle occupies the bottom-left corner. A light gray triangle occupies the top-left corner. A vertical gray bar is positioned to the left of the number '1'.

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CHAPTER 1.

Introduction

1. Introduction

1.1. Introduction and Background

1.1.1. Irrigated Agriculture and Its Contribution to Global Food Security

Irrigation has been used by humans for over 8,000 years as a technique to grow crops in areas or seasons where otherwise they would be unable to do so. Irrigation has played a very important role in increasing global agricultural production and improving global food security in the past decades. From 1961 to 2009, the global area equipped for irrigation increased by 117%. Currently, more than 40 percent of global agricultural products are produced on irrigated land, which is less than 20 percent of global arable land area. To meet the requirements of the world population, which is projected to be more than 9 billion by 2050, food production needs to be increased by 70 percent globally and by 100 percent in developing countries, and irrigation is expected to be a major contributor (Alexandratos & Bruinsma, 2012). Nevertheless, in Africa, only about 5% of agriculture is irrigated even though the region has an irrigation potential covering 43 million hectares (Ringler, Mekonnen, Xie, & Uhumamure, 2020). For a continent where much rainfall is highly seasonal, this remains a huge barrier to improved food security and better incomes for farmers. In most African countries, including Ethiopia, there is still untapped irrigation potential that can be developed to boost agricultural production for ensuring food security and poverty alleviation.

Investment in irrigation infrastructure and the maintenance of existing irrigation schemes are key to improve agricultural productivity and fast-track economic growth for practical poverty reduction (Hanjra & Gichuki, 2008).

1.1.2. Irrigation in sub-Saharan Africa (SSA)

Most of the people in Sub-Saharan Africa (82% according to (Beegle, Christiaensen, Dabalén, & Gaddis, 2016)) live in rural areas, earning most of their income through agriculture and struggling to secure food. The region has the highest prevalence of hunger, more than 66% of the population of Africa has been affected by moderate to severe food insecurity (UNICEF, 2021). Around 92% of rural households in SSA are to some extent involved in farming, and a median African rural household earns about three-quarters of its income from agriculture (Davis, Di Giuseppe, & Zezza, 2017). Despite farmers in SSA being vulnerable and food insecure, they can be the engine for growth and poverty alleviation. Empirical evidence shows that agricultural growth in SSA can be eleven times as effective in reducing extreme poverty as growth in other sectors (FAO 2012; Ringler et al., 2020). Irrigation has been identified as a key investment to end hunger by 2025 as part of the Malabo Declaration (AUC 2014). Hence, the African Union launched a framework for Irrigation Development and Agricultural Water Management in Africa in 2019. The irrigated area in SSA is projected to double by 2030 (World Bank, 2008) increasing both the food supply and sector productivity since irrigation produces twice the yield of rainfed agriculture (De Fraiture & Giordano, 2014).

Estimates of the number of small-scale farmers and how much they contribute to food production vary according to the definition of a small-scale farm, which in turn is context dependent. The size of the landholding is often cited, but the scale varies tremendously from one country to another. For instance, irrigation schemes in Ethiopia are classified into three types based on the size of their command area, namely, small-scale (< 200 hectares), Medium-scale (200-3,000 hectares), and large-scale irrigation systems (>3,000 hectares) (Makombe et al., 2011).

A large body of empirical research (Fan & Rue, 2020) argues that smallholders are key to global food security and nutrition. The smallholders in developing countries play a key role worldwide in this food security equation. More than 84% (513 million) of the world's farms operate on less than two hectares of land. Although these farms account for only 12% of the world's farmland, they provide livelihoods for more than 2 billion people and produce about 80% of the food in SSA and Asia (FAO, 2015). Smallholders contributed up to 30 % of the gross domestic product (GDP) of SSA and employed 67% of the labour force (Tushaar shah, 2020). One of the reasons why SSI is attractive for food security purposes is that the estimated SSI potential in sub-Saharan Africa is 6.6 Mha, much bigger than the irrigation potential for large-scale irrigation schemes of 1.3Mha (You et al., 2011). The simple design, easy operation and management, low cost, and higher rate of return relative to large-scale schemes make SSI promising for increasing agricultural productivity (De Fraiture & Giordano, 2014). Moreover, studies show that small-scale irrigation schemes perform better than large-scale irrigation ventures (Bjornlund, Bjornlund, & Van Rooyen, 2020; Gebul, 2021).

1.1.3. History Of Small-Scale Irrigation in Ethiopia

All three government changes in Ethiopia have been accompanied by some restructuring of land tenure policy, including the imperial regime (prior to 1974), the Derg regime (from 1974 to 1991), and the current government steering the Federal Democratic Republic of Ethiopia (from 1991 to date). Traditional irrigation development in Ethiopia has a long history that was practiced before centuries (Bekele, Tadesse, & Konka, 2012) probably pre-dating the Axum of empire more than 2,000 years ago (Kloos, 1991). Moreover, in the highlands of Ethiopia, irrigation practices have long been in use since ancient times for producing subsistence food crops. Spate irrigation has also been used traditionally.

During the imperial regimes (prior to 1974), local resources (human, land, water, and other natural) were "owned" by a few powerful individual agents affiliated with the royal court: landlords, army officials, or local tax collectors who used to work on behalf of the central kingdom. Irrigation planning and management were undertaken by the owners or their representatives. Peasants who were working with local landowners on "sharecropping" basis did not have any entitlements unless the landowner (i.e. the scheme owner) allowed them to use water.

During this regime, the main purpose of irrigation was to provide industrial crops to the growing agro-industries in the country, many of which were controlled by the interest of

foreign companies and fostered to boost export earnings (Gebul, 2021). Spate irrigation has also been used traditionally.

During the era of the socialist Derg regime (from 1974-1991), the dominant motto was empowering the socially disfavoured peasants in the imperial regime by organizing and making them “owners” of the resources. The irrigation and agricultural development schemes were then transferred to peasant cooperative unions. Ownership was secured by joining Agricultural Producer Cooperatives (PAC) which constituted peasants from the local peasant association (PA) and managed the scheme to produce food crops. Maintenance of ownership was secured through participation in the production processes of the PAC. Kloos (1991) argued that during the Derg regime, the government-funded initiatives of irrigation development were unsustainable partly due to the social instability created during the national villagization program that led to the resettlement of peasants and abandonment of irrigated lands in the old settlement areas. Also tenure insecurity and the peasants' dissatisfaction with cooperative farming negatively affected by irrigation performance (Gessese, 1990) as cited by (Kloos, 1991). Since the 1975 land reform, ongoing land fragmentation and a reduction in farm size have been major factors in the reappearance of insecure tenure (Gebre-Kiros, 1980). Insecure land tenure has hindered peasants from investing time and money in irrigated agriculture.

During the current FDRE regime (from 1991 to date); the period between 1991 and 1995 was considered a transitional period (to federalism) during which no significant irrigation development activity was carried out. There has been no major change in core property (land) policies between the Derg and the current government; hence changes concerning irrigation schemes were not as radical as that between the imperial and the Derg regime. Ownership of the SSI scheme has remained communal, while the management system has been changed in many respects. Under the current government, “democracy” and devolving power to the people (whether it is practiced or not) through decentralization dominate public policy discourses and discussions in Ethiopia. The political atmosphere of such a governance system is manifested - at least in theory - in the day-to-day communications of irrigation management. Institutional hierarchies are decentralized and major decisions at least in principle are supposed to be made at an individual, local level. The present regime is focused on the articulation and implementation of a series of national economic development plans and programs. In all these plans, irrigation development has progressively received greater attention. Hence, in the past decades, small-scale irrigation received considerable attention through a national plan for expansion as well as many state-funded efforts to foster rehabilitation and modernization of existing irrigation schemes (Mastewal Yami, 2013). The growing interest in enhancing rural livelihoods through improving agricultural water management has led to an increase in investment in SSI development by donors, and governmental and non-governmental organizations (NGOs).

Small-scale irrigation is classified into three categories, modern, traditional, and modernized small-scale irrigation schemes. Modern schemes usually have fixed or improved water

control/ diversion structures and are generally constructed by the government or NGOs. Traditional irrigation schemes on the other hand differ from modern schemes because their diversion weirs are usually made from local material and need reconstruction every year. They are constructed by local people and have often been functional for a relatively long period. The management of small-scale irrigation is similar, usually involving local leadership and water users' association with the government providing extension support. Studies are showing that local water management institutions are stronger in traditional irrigation schemes compared to modern schemes (Hagos, Makombe, Namara, & Awulachew, 2009). Modernized small-scale irrigations are comprise existing traditional irrigation systems that have been upgraded by concrete diversion structures and concrete lining part of the irrigation canals (Haile & Kasa, 2015).

Even though irrigation schemes are considered key in eradicating poverty, the irrigation sector also represents the largest freshwater consumer in many countries. Irrigation accounts for approximately 70 percent of total global fresh water withdrawals, including from groundwater, and account for more than 80 percent of consumptive water use (FAO, 2016; Makarigakis & Jimenez-Cisneros, 2019). Livestock watering and freshwater aquaculture are additional forms of growing agricultural water use. According to the World Water Assessment Programme (UNESCO, 2015), irrigated water withdrawals have tripled over the last 20-50 years, and these were expected to increase at 0.6% per year from 1998 until 2030, resulting in 36% more food production at the cost of 13% more water consumption.

1.1.4. Available Water Resources and Irrigation Potential of Ethiopia

Ethiopia is blessed with an abundance of natural resources, especially water, it is known as the water tower of Africa. The annual rainfall varies from 2,000 mm in southwest Ethiopia to 100 mm in the northeast of the country, in the arid Afar lowland. Besides the availability of a huge volume of freshwater – Ethiopia has 12 river basins with an annual runoff volume of 122 billion m³ and an estimated annual renewable groundwater volume of more than 6.5 billion m³, most of its rivers are not perennial, with about 70% of the total runoff obtained from the month June to August (S. B. Awulachew & Ayana, 2011; RVO/NWP, 2015). Water is a limiting factor in the irrigation potential.

Ethiopia's irrigation potential estimates differ from one source to the next due to a lack of standard or agreed-upon criteria for estimating irrigation potential in the country. Awulachew and Ayana (2011) estimated that there was 3.7 million ha of irrigation potential, and 197,000 ha are actually irrigated, but Hagos et al. (2009a) reported that there was an irrigation potential of 3.5 million ha and 626,116 ha are actually irrigated. However, according to (MoA, 2011), traditional and modern irrigation schemes are currently used to irrigate between 10 and 12 percent of the total irrigable potential. According to Tilahun and Paulos (2004), traditional irrigation schemes cover 138,339 ha, while modern small-scale irrigation covers 48,074 ha and modern large- and medium-scale irrigation covers 61,057 ha, making up for a total irrigated land of is 247,470 ha. One of the characteristics of Ethiopian agriculture and

the national economy is the country's inability to produce sufficient food (Gebreselassie, 2006). The challenge that Ethiopia faces in terms of food insecurity is associated with both inadequate food production, even during good rain years (a problem related to the inability to cope with the growth of population), and natural failures due to erratic rainfall (aggravated by climate change) that increased the vulnerability to periodic droughts and food insecurity. Ethiopia has a history of famines caused by a combination of high population pressure, resource depletion, but also war and social disruption and droughts that have a significant impact on rain-fed agriculture. Low farm production and productivity as a result of backward technology and a lack of other productivity-enhancing modern inputs have been documented as major causes of rural poverty and food insecurity (Gebreselassie, 2006). As a result, increasing total available arable land or attempting to increase agricultural yield by, for example, growing higher-yielding crop varieties has limited potential to provide food security in Ethiopia. With the advent of rapid population growth in recent years, local population displacement, deforestation, frequent land redistribution, soil erosion, and sedimentation have begun to threaten the very resource base of the dominant farming system. Unless the overall natural resource management and its governance is improved, food security will remain challenging to achieve.

1.1.5. Challenges of SSI in Ethiopia

Awulachew and Ayana (2011) argue that the failure to achieve the planned national targets is caused by many operational problems. Several studies (Abera et al., 2019; Agide et al., 2016; S. B. Awulachew & Ayana, 2011; Zeleke, Bart, & Laszlo, 2012) indicate that the performance of irrigation schemes is low, measured with several applicable indicators; While the causes for low performance are diverse, one of the major constraints is excessive sedimentation in the headworks and canal network and a lack of funds and labour for operation and maintenance (S. B. Awulachew & Ayana, 2011; Gebul, 2021). It is largely attributed to inadequate management of schemes. S. B. Awulachew and Ayana (2011) argued that the operational and management problems that affect the irrigation systems are due to a lack of strong national institutions. Hence, not only are the productivity and efficiency of schemes low but also the areas irrigated are far below the potentially irrigable areas created by project implementation. Reports indicate that currently, about 50% of the irrigation schemes are considered as providing functional services, 34% of the implemented schemes are not utilized at full capacity, and 16% are non-functional (Gebul, 2021).

The succession of water resources and irrigation management policies is characterized by the frequent restructuring that also involves the movement of human and physical resources. Institutional instability causes high levels of staff turnover and the loss of institutional memories and data that hinder effective knowledge and skill transfers (Gebul, 2021). Irrigation development and management in Ethiopia is highly dominated by a top-down approach and could not benefit from the golden opportunity of existing local knowledge (Yohannes, Ritsema, Solomon, Froebrich, & Van Dam, 2017). A lack of ownership feeling by the local community toward those schemes that are planned, implemented, and operated by

government support constitutes of the key reasons for the unsustainable irrigation system operation. In general users community are not actively consulted during the various stages of irrigation schemes design and construction.

The consistent focus on the expansion of new construction of irrigation schemes while those previously operationalized are underperforming or abandoned, shows the lack of regard for or access to lessons learnt from past efforts. Generally, irrigation development in Ethiopia has been largely focused on infrastructure construction. The important role of irrigation management and governance is largely overlooked. There has been little attention paid to the rehabilitation of deteriorated schemes.

Recognizing the shortcomings of technical top-down measures and the importance of social interaction in managing sediment and maintaining irrigation infrastructure, another set of solutions emphasizes the establishment of effective formal and informal institutions (Beyene, 2009) and collective action (Chun, 2014). Collective action is considered the most promising solution for the sustainable management of common property resources (Gebremedhin, Pender, & Tesfay, 2004; Ostrom, 1990).

1.1.6. Sedimentation in SSI

Sedimentation was pointed out as one of the main causes of underperformance and abandonment of irrigation scheme. Excessive sedimentation in irrigation schemes can cause clogging of the intake, filling the headworks and canals, and jamming of the sluice gates, which in turn causes inequity and inadequacy in water supply (Fayisa Ertiro, 2017; Munir, 2011; Theol, C. de Fraiture, & Surya, 2016). The management of sedimentation in irrigation schemes requires a considerable budget and/or manpower to keep up the canals. However, problems related to the accessibility of funds or labour often cause a considerable delay in maintenance, and may ultimately lead to the abandoning of the schemes (Munir, 2011). Therefore, the planned food security improvement may be under threat unless relevant preventive measures are put in place.

1.2. Problem Statement

The continuing underperformance of irrigated agriculture in sub-Saharan Africa has set a negative impact on the returns on investments in the irrigation sector. The failure and underperformance of the irrigation systems undermine the region's ambition to obtain food security despite the high prevalence of hunger and acute poverty. Irrigation expansion in sub-Saharan Africa has experienced an endless loop, with new systems being constructed while many of all the existing systems underperform. There are many reasons for irrigation scheme underperformance, however, a primary factor causing underperformance and abandonment is excessive sedimentation and inadequate maintenance (S. B. Awulachew & Ayana, 2011; Gebul, 2021). Sedimentation causes several performance issues including conveyance capacity reduction of up to 40% (Belaud & Paquier, 2001), inequity and inadequacy in water

supply, and a large number of resources that have to be mobilized to maintain the canals. Particularly in SSI it has proven difficult to mobilize sufficient funds and especially labour force to perform proper maintenance. Considerable delays in maintenance may occur ultimately leading to scheme abandonment in the face of excessive labour demands.

The mitigation measures for sediment management in small-scale irrigation that are in place have not been effective for two reasons: First, previous policies were directed at minimizing sedimentation either through measures aiming at upstream catchment conservation or technical measures to deal with suspended sediments entering the scheme from the main intake. Both sets of measures overlook the problem of in-season sedimentation caused by livestock-irrigation interactions. Second, none of the past policies achieved effective forms of user governance and participation, precipitating SSI scheme collapse and abandonment.

1.3. Research Objectives and Questions

The study aims to assess the causes and extent of sedimentation, unravel the livestock-irrigation conundrum and understand the complexity of collective action in a multi-use irrigation system and illustrate the key factors influencing farmers' willingness to maintain the small-scale irrigation.

Specific objectives of this study are to:

1. Identify the causes and extent of sedimentation in four small-scale irrigation schemes.

Hence Research Question 1 is: What are the major causes of sedimentation during the irrigation season?

2. Disentangle the livestock-irrigation conundrum, explore the various causes for sedimentation and the challenges of coming up with effective solutions.

This translates into Research Question 2: What factors inhibit the emergence of effective and sustainable collective action?

3. Show that Farmers' Willingness to Maintain (FWM) better explains the sustained operation of SSIs in Ethiopia than a singular, snapshot analysis using either Ostrom's eight design principles or Coward's hydraulic property relations framework.

Research Question 3 respond to this objective by wondering: when farmers give up on their irrigation system that is subjected to heavy sedimentation? When do SSIs collapse, and what factors play a decisive role in that?

4. Provide policy recommendations to reduce sedimentation and improve the governance and sustainability of irrigation systems in Ethiopia.

Hence the Research Question 4 is: What are the policy recommendations that could enhance SSI sustainability?

1.4. Conceptual Approach

1.4.1. Governance of Common Pool Resource (CPR) Research

The study used the "socio-technical" approach to the study of collective governance CPRs (multi-use irrigation system) by using Ostrom's (1990) eight Design principles and Coward's (1986) "property rights creation" theory to assess the schemes' performance on their empirical validity. After studying long-lasting user-governed common-pool resources (CPRs), Elinor Ostrom developed her well-known design principles (DPs) (Ostrom, 1990). These DPs have been widely used to evaluate the functionality of CPR institutions all over the world that rely on various types of natural resources. She identified some significant common features of these CPRs that characterized their governance system and contributed to their long-term existence (robustness). Although the operational rules of these strong CPR institutions differed, they all shared some characteristics that Ostrom categorized as the eight DPs. (Ostrom, 1990) defines a DP as an important element or condition that contributes to understanding institutions' success.

Table 1.1. Ostrom's Design Principles

Ostrom's design principles	Operationalization
Clearly defined boundaries	Individuals or households who have rights to use the common resource are clearly defined.
Congruence with local conditions	Rules restricting the time, place, technology, and/or quantity of resource are well adapted to local conditions.
Collective choice arrangements	Most individuals affected by rules can participate in modifying them
Monitoring	Monitors who actively audit CPR conditions and appropriate behavior are accountable to the appropriators or are appropriators themselves
Graduated sanctions	Users who violate operational rules are subject to graduated sanctions (depending on the seriousness and context of the offense) by other users, officials accountable to these appropriators, or both
Conflict-resolution mechanism	Appropriators and their officials have rapid access to low-cost local arenas to resolve conflicts among appropriators or between appropriators and officials.
Minimal recognition of rights to organize	The rights of users to devise their own institutions are not challenged by external governmental authorities.

Nested enterprises	Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises
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Coward (1986) hypothesized that in constructing irrigation infrastructure, farmers transform and reinforce their social relationships and establish property relations. These so-called 'hydraulic property rights are essential for the sustained maintenance of irrigation infrastructure.

The concept of (re)creation of hydraulic property can be used to explain the entire process of acquiring and negotiating water rights. The first step in acquiring water rights, according to Coward (1986), is to invest in irrigation infrastructure. The structures and the water that flows through them will be regarded as belonging to the farmers who invested in their construction. Other users who want to use the water may be given several options by the owners of the hydraulic property, including they can either pay the "owners" a fee for the water they use, or in some cases, buy a share and become co-owners. This share could be provided through in-kind or cash investments. Because the process of obtaining water rights is ongoing, water rights are constantly recreated and redefined often annual water right can only be reproduced through a proportional contribution to collect maintenance activities. Ownership and responsibility for irrigation work are thus inextricably linked. This means that clear concepts of ownership will be central to good Operation and Maintenance practices. External intervention in an irrigation system, whether new or existing (modernizing or expanding), might have a number of consequences for the development of hydraulic property relations, sometimes leading to their extinction or redefinition. This in turn often negatively affects the collective action around their maintenance.

The study used these theoretical frameworks to analyse the sustainability or collapse of collective action for the multi-use irrigation systems that are subjected to contextual rather than generic principles. The study actively participates in a socio-technical approach that focuses on how water, technology, and social actors who use and manage SSIs interact. To determine the tipping point beyond which farmers decide to quit maintaining their system at the individual and collective level, it is critical to gather information on the factors impacting farmers' collective willingness to maintain.

1.5. Methodology

The empirical work for this PhD can be divided into three stages. The first phase was used to review literature and write the proposal, while the second and third phases were used to collect primary data in four small-scale irrigation schemes. I conducted a literature review on the sedimentation problem in irrigation schemes and potential mitigation measures during the first phase (December 2017-June 2018). This laid the groundwork for understanding the

scope of the sedimentation problem and its impact on irrigation system sustainability, as well as the peculiarities of small-scale irrigation. Due to the scarcity of available online information about schemes, I visited 22 small-scale irrigation schemes in close proximity to Addis Abeba, Ethiopia, during a second phase (June to October 2018). Based on site selection criteria such as proximity, accessibility, sedimentation level (light versus heavy), and functionality (functional versus abandoned), I chose four small-scale irrigation schemes (Figure 1.1). During the second phase, I collected qualitative data from all four schemes through semi-structured in-depth interviews, focus group discussions, and field observation. I measured the accumulated sediment before the start of the irrigation season in the canal for lightly and heavily sedimented schemes using a staff-rod with a flat sheet at the bottom of the rod to measure the depth of accumulated sediment and depth of both lined and unlined canals. The canal profile was created by measuring the canal's width and length with a measuring tape. Using the volume equation, the volume of the accumulated sediment is then calculated.

During the third phase (in 2019), Sediment inflow was measured in the Ejersa (heavily sedimented) scheme during one irrigation season from October 2019 to February 2020, starting when the irrigation season resumed after conclusion of the rainy season. These measurements considered changes in discharge caused by inflow or outflow from the canal, control structure operation, changes in canal geometry along its length, changes in roughness when the canal's surface material changed, and changes in bed level. Within the 1.85 km length of the main canal from the intake, eight data collection points were marked. At each section, all required data (water flow, cross-section, sediment concentration sample, top and bottom bed level, water depth) were measured once a week. A DH-48 depth-integrating sampler was used to collect water samples at the eight marked points, and a digital current meter was used to measure velocity. Using a measuring tape, the canal cross-section and water depth were determined. I used pre-weighed glass fiber filters (Whatman GF/C) to determine suspended sediment concentration. After filtering a one-liter volume, the filters are dried and weighed to determine the suspended sediment concentration. To determine the particle size distribution, the pipette laboratory analysis method was used.

As a general methodological approach, we used a “follow the water” approach to identify the water users and their networks, to map all relevant infrastructure and institutions. Following the livestock was also used to track the owners of livestock, irrigation users, and grazing areas. Mapping, open-ended and semi-structured in-depth interviews, field observations, and focus group discussions were all part of the fieldwork period. Snowball sampling was used to identify key informants from the top, middle, and bottom of the user pyramid. In phases two and three of the research, I interviewed 75 people: 18 women and 45 men from the four schemes' head, tail, and middle-reach users, including Water User Association and Livestock Farmers committee members, five irrigation development agents, four government officials, and three engineers (The interviewees varying in age from 14 to 79 years).

The number of interviewees was increased until the collected information reached a point where no new insights could be gleaned beyond those already expressed (Glaser and Strauss, 2017; Bernard and Bernard, 2013). Following that, nine focus-group discussions with 6-8 members in each of the four schemes were held. Field observations and semi-structured interviews with older farmers', WUA committee members, irrigation users, livestock farmers (LF), selected professionals, and responsible government officials provided first-hand information on the irrigation schemes' operation and maintenance practices, as well as the irrigation schemes' interaction with livestock and livestock farmers. To stay focused on my research puzzles, I kept day-reports of each day, noting interviews, film and observations, meetings, and any remaining questions that I could bring with me the next day. Interviews were triangulated by comparing them to field observations. Birhanu Angea, a translator, assisted me in translating interviews from Afaan Oromo to Amharic, and I translated from Amharic to English. In addition to translating, he provided feedback on my observations and interpretations, and we discussed the operation of the irrigation system to understand the details. Secondary data was gathered from the district and a regional office that had a stake in the respective schemes. After reading each transcription line by line, the qualitative data analysis was carried out. Field notes and observations helped triangulate findings and interpret results.

1.6. Study Area Description

Four small scale irrigation schemes have been included in the study:

- The Ejersa small-scale irrigation scheme was modernized with government assistance, but it is now a heavily sedimented scheme that serves two kebeles (the lowest administrative unit in the country), Dembeleketa and Bedesa Koricha. It is situated 114 kilo meters from Addis Ababa along the highway to Jimma, at an elevation of 2120 meters above mean sea level, with 96 hectares of command area supplying water for 120 households.
- Boye-1 and 2 began as two separate traditional small-scale irrigation schemes that were merged and modernized by the government without the consent of the irrigation users. Improvements to the new main intake and the lining of the main canal were part of the modernization. This scheme was chosen as an example of a lightly sedimented scheme. It is located 110 kilometers from Addis Ababa, at an elevation of 2123 meters above mean sea level. The current scheme is divided into two parts: Boye-1, which serves 56 households, and Boye-2, which serves 65 households, irrigating a total command area of 56 hectares.
- Meri-Megari is a non-functional modern small-scale irrigation scheme that has been abandoned. Sedimentation and excessive seepage loss along the canal were the primary reasons for its abandonment. It is located 158 kilometers from Addis Ababa and has an elevation of 1902 meters above mean sea level. Prior to its abandonment, it covered 200 hectares of command area supplying water to 234 households.

- The Kulit traditional small-scale irrigation scheme is a new scheme that was established in response to the abandonment of the Meri-Megari scheme. A traditional weir in Kulit was built 5.3 kilometers downstream of the Meri-Megari abandoned scheme weir. It is situated at 151 kilometers from Addis Ababa, at an elevation of 1834 meters above mean sea level, with 17 hectares of command area providing water for 29 households.

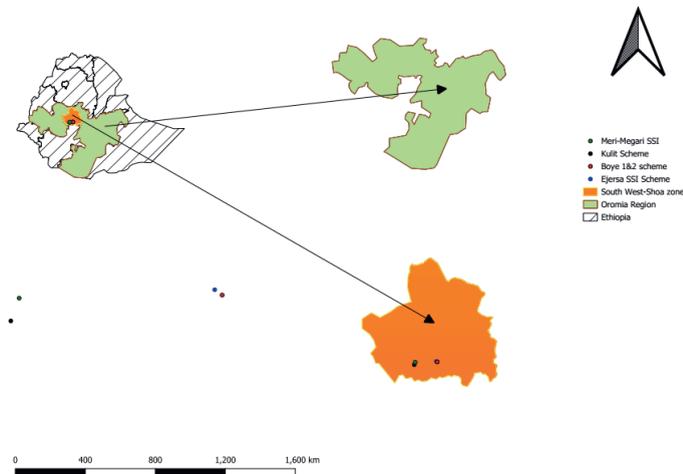


Figure 1.1 Location of the study area with the three case-study irrigation schemes

1.7. Structure of the Thesis

The thesis is structured in Six parts, which will be outlined below.

Chapter 1: -Provides the background to this study and introduces the research objectives and methodology.

Chapter 2: - Identifies the causes and extent of sedimentation in the four small-scale irrigation schemes included in the study. It is argued that livestock-irrigation interactions are the main sediment source during the irrigation season. Before the irrigation season (during the rainy season) the bulk of sedimentation may originate from the upstream catchment through in-flow and overland flow.

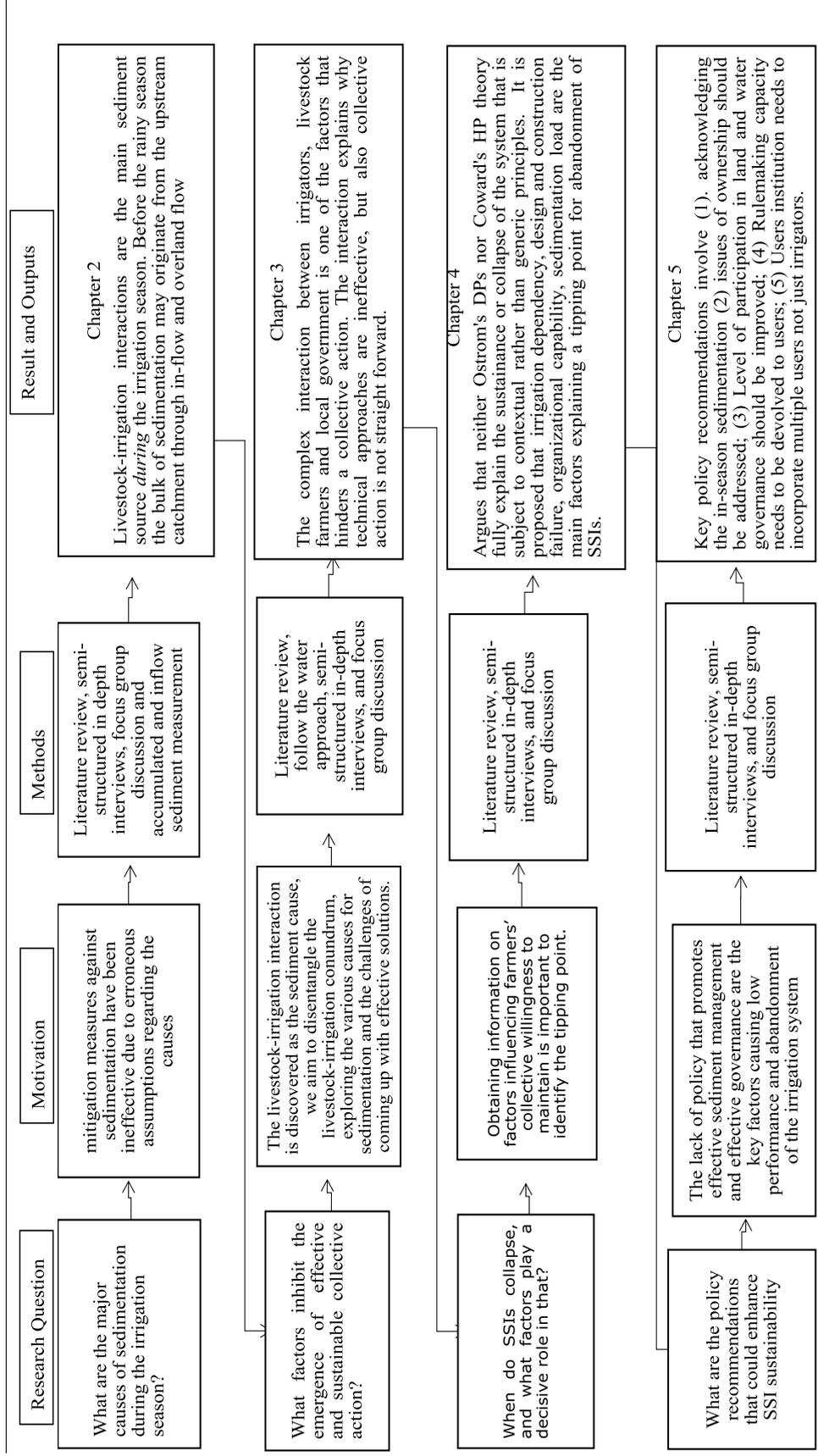
Chapter 3: -Builds on the findings of Chapter 2 by digging deeper into the phenomenon of livestock-irrigation interaction. It investigates why sediment management mitigation measures are ineffective by unravelling the intricate interactions between irrigators, livestock farmers, and local governments. These interactions explain why technical approaches are ineffective, but also why collective action to remedy its effects is difficult to achieve, as demonstrated by three small-scale irrigation systems in Ethiopia.

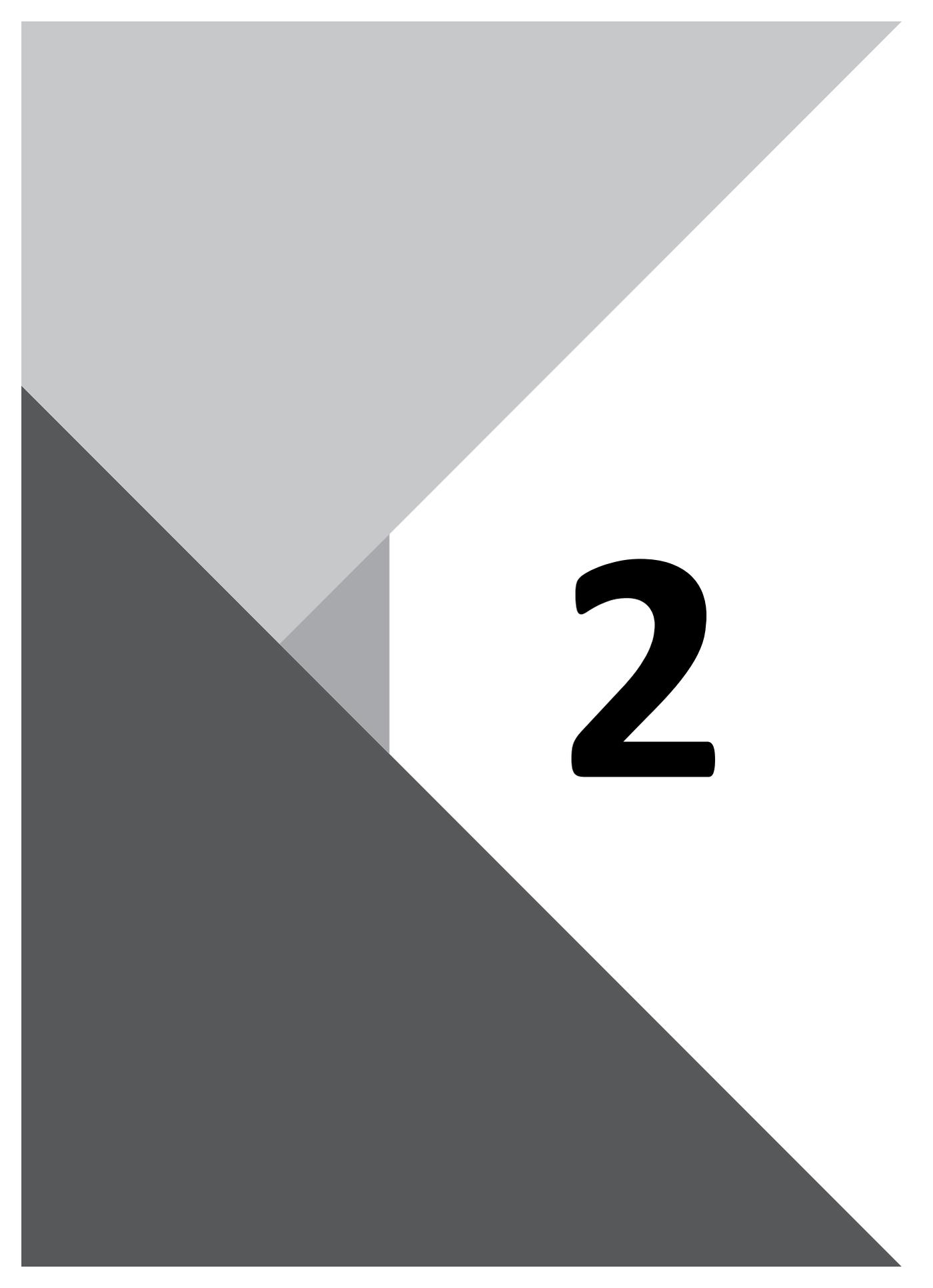
Chapter 4: - Demonstrates that an empirically based concept, such as Farmers' Willingness to Maintain (FWM), better explains the sustained operation of SSIs in Ethiopia than a single,

snapshot analysis based on either Ostrom's eight design principles or Coward's hydraulic property relations framework. Rather, we studied the willingness to maintain in a process-oriented manner to examine the sustenance or collapse of collective action subject to contextual rather than generic principles. Obtaining information on the factors influencing farmers' collective willingness to maintain is critical in determining the tipping point beyond which farmers decide to quit maintaining their system on an individual and collective level.

Chapter 5: - Examines past policies, identifying the key reasons for their ineffectiveness in addressing sedimentation in SSIs. It summarizes key challenges related to the conundrum of sedimentation in Ethiopian small-scale irrigation systems based on four case study schemes; and provides policy recommendations to reduce sedimentation, improve governance, and ensure the sustainability of Ethiopian irrigation systems.

Chapter 6: - Contains the synthesis and reflection of this study. It provides a brief overview of the entire dissertation before providing summary answers to the research questions, followed by a reflection on the methodology used and the research's scientific and societal relevance. The positionality of the researcher and potential biases are discussed. The study's limitations are followed by suggestions for future research.



The image features a large, bold, black number '2' centered on a white background. The background is composed of several geometric shapes: a light gray triangle in the top-left corner, a dark gray triangle in the bottom-left corner, and a small gray trapezoidal shape positioned to the left of the number. The overall composition is minimalist and modern.

2

CHAPTER 2.

Livestock and Small-Scale Irrigation Scheme Interactions; As a Key Source for Sedimentation during the Irrigation Season: four case studies from South-West Shoa, Ethiopia

This chapter is based on:
Dessalegn H.T., Bolding A., Fraiture, C.d., and Ayana, M. (2021)

Livestock and Small-Scale Irrigation Scheme Interactions; As a Key Source for Sedimentation during the Irrigation Season: four case studies from South-West Shoa, Ethiopia.

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2. Livestock and Small-Scale Irrigation Scheme Interactions; As a Key Source for Sedimentation during the Irrigation Season: four case studies from South-West Shoa, Ethiopia

Abstract: Small-scale irrigation (SSI) development can play a major role in Ethiopia's economic development, but sedimentation is a major threat to its sustainability. The focus of the dominant discourse around the sedimentation of SSI schemes lies in upstream catchment protection during the rainy season, neglecting both protection against erosion through overland flow along the margins of the canal network and sedimentation caused by livestock disturbances. Remedies against the latter causes of sedimentation during the irrigation season have been ineffective due to erroneous assumptions regarding its cause. This study aimed to identify the sources and extent of sedimentation in SSI schemes. The accumulated sediment in the canal pre-irrigation season was measured from four SSI schemes and suspended sediment samples *during* irrigation season were collected from one SSI scheme. The accumulated sediment in the canal pre-irrigation season was measured from four SSI and suspended sediment samples *during* irrigation season were collected from one SSI scheme. The extent of sedimentation in the canals during the pre-irrigation season in relation to canal capacity was 100% of lined and unlined canals in abandoned, 68% in a lined, and 84% unlined canals in heavily sedimented and 38% in a lined and 46% of unlined canals lightly sedimented schemes. Livestock interactions with the SSI schemes were found to be the major sediment source before and during the irrigation, hence, attention should be given to integrating livestock as a part of the system.

Keywords: small-scale irrigation scheme; sedimentation; livestock access; sediment cause

2.1. Introduction

Irrigation development plays a major role in Ethiopia's economic development program (Makombe et al., 2011). Investment in irrigation infrastructure and the maintenance of irrigation schemes are key to improve agricultural productivity and fast-track economic growth for practical poverty reduction (Hanjra & Gichuki, 2008). Irrigation schemes in Ethiopia are classified based on the size of the command area, in three types (Makombe et al., 2011). Namely, small-scale (< 200 hectares), Medium scale (200-3,000 hectares), and large-scale irrigation systems (>3,000 hectares). Small-scale irrigation plans have been identified as vital to ensure the food security of the nation because of their simplicity to develop and operate, relatively small investment, and cheap operation and maintenance (Lambisso Wamiso, 2008). Despite the huge ambitions, 80% of the proposed irrigation development in Ethiopia falls within the small-scale irrigation category.

In Ethiopia, most irrigation schemes do not operate at full capacity and many of the schemes failed to serve the purpose for which they are intended (S. B. Awulachew & Ayana, 2011; Fayisa Ertiro, 2017; Lambisso Wamiso, 2008). In Oromia Regional State alone, 109 (18%) of the modern irrigation schemes and 8,508 (13%) of the pump schemes were reported to be inoperative or semi-functional in 2017 (Gurmu, Ritzema, de Fraiture, & Ayana, 2019). In the Tigray region, most of the reservoirs, that feed the small-scale irrigation schemes, are filled with sediment within less than 50% of their intended service time (Tamene, Park, Dikau, & Vlek, 2006).

Improvement of this low performance is high on the policy agenda and the prime motivation of the government to keep investing in the sector. The causes of underperformance and abandonment of the schemes are often diverse and complex; one of the major constraints is excessive sedimentation in the headworks and canal network and a lack of available funds and skilled manpower for operation and maintenance (S. B. Awulachew & Ayana, 2011; Kidane & Alemu, 2015). In a developing country like Ethiopia, rapid population growth, deforestation, uncontrolled land use, and overgrazing have resulted in accelerated soil erosion (Gelagay & Minale, 2016). Soil erosion and soil loss are the major challenges for sustainable irrigated agricultural development.

Excessive sedimentation in irrigation schemes can cause clogging of the intake, filling the headworks and canals, and jamming of the sluice gates, which in turn causes inequity and inadequacy in water supply (Fayisa Ertiro, 2017; Munir, 2011; Shaimaa A. Theol). The management of sedimentation in irrigation schemes requires a considerable budget and/or manpower to keep up the canals. However, problems related to the accessibility of funds or labour often cause a considerable delay in maintenance, and may ultimately lead to the abandoning of the schemes (Munir, 2011). Therefore, the planned food security improvement may be under threat unless relevant preventive measures are put in place.

Most of the existing studies point at the erosion in the upper and middle river catchment as a prime cause of sedimentation, whereby high sediment loads pass through the intake structure of irrigation schemes, and accumulate in the (unlined) canal network, thus resulting in excessive sedimentation (Dereje & Yusuf, 2015; Haregeweyn et al., 2017; Kassie, 2019; Wolancho, 2012). Other studies have documented that the causes of sedimentation vary according to different stakeholders' perceptions (Gurmu et al., 2019) some ascribing sedimentation to design problems, most of the engineers identifying erosion in the upstream river catchment and a lack of appropriate technology and materials as prime causes, and farmers seeing poor operation and maintenance as a major cause.

Some scholars argue that cattle accessing streams, grazing, and trampling of stream banks cause an increase in erosion, destruction of in-stream banks, and changes to stream morphology (Katrien Descheemaeker, Tilahun Amede, & Amare Hailelassie, 2010; O'Callaghan et al., 2019; Wilson, 2007). Even though some studies point to livestock accessing the grazing land on the canal bank as potential sediment sources, most literature focuses on the causes of sedimentation during the rainy season. In Ethiopia, the sediment management strategy, put in place in irrigation schemes, is ineffective because it considers only the sediment source during the rainy season. It focuses on watershed management as a solution whereas sedimentation during the rainy season is not the only cause. Identification of the main cause of sedimentation year-round is the first step in determining effective solutions. Therefore, this study aims to identify the causes and extent of sedimentation in four small-scale irrigation schemes. It is argued that livestock-irrigation interactions are the main sediment source before and during the irrigation season.

The paper consists of seven sections; the next section introduces different discourses of sediment causes. Section three introduces the key features of the study areas. Section four describes the study methods. Section five presents the results on the extent and origin of sedimentation in the four study schemes while delving deeper into the dynamics of sedimentation during one whole irrigation season in one case study scheme. Section six assesses the importance of different causes for sedimentation, identifying livestock interactions as the key in-season cause, and delving deeper into the drivers behind livestock-irrigation interactions. The last section presents the overall conclusion and some policy recommendations for tackling sedimentation during the irrigation season.

2.2. Discourses on the Causes of Sedimentation in SSIs

There are two dominant discourses on the causes of sedimentation in small-scale irrigation schemes: erosion in the upstream watershed and improper design of small-scale irrigation. Many authors identify the upstream catchment erosion and the high rates of soil erosion and land degradation in Ethiopia as major drivers of sedimentation in irrigation systems. An estimated 25% of the highland area is affected by large volumes of soil eroded annually. Soil erosion and soil loss are major challenges for sustainable agricultural development in the

Ethiopian highlands. Inappropriate agricultural practices, high population pressure from humans and livestock, high rainfall intensity, and rugged topography have been reported as the main facilitators of severe erosion and sedimentation (Kidane & Alemu, 2015). Erosion in the upper and middle catchment is the main source of sedimentation during the rainy season (Wolancho, 2012). The sediment-laden river water that comes from the upstream eroded catchment is one of the sediment sources in irrigation systems (Dereje & Yusuf, 2015). Deforestation also contributes to upstream soil erosion and watershed management is the fundamental step to reduce sedimentation (Tamene et al., 2006).

The second discourse around causes of sediment problems in irrigation highlight poor design of small scale irrigation schemes without considering adequate baseline data (Tolera; Wolancho, 2012) faulty design; the location of the intake; mild longitudinal slopes; poor layout of the main canal; and poor operation and maintenance (Gurmu et al., 2019). One of the causes of sedimentation is the erosion of the unlined canals due to the erosive potential of the irrigation water coming from the main canal. (Dereje & Yusuf, 2015). This discourse implies that proper design of the infrastructure and better operation and maintenance is needed to reduce the sedimentation.

The two domain discourses are propagated by different professional groups, namely policy makers and engineers. Considering the ineffectiveness of the proposed sediment management solutions and the vital role of the mitigation measures, a deeper understanding of the extent and causes of the sedimentation is warranted. Therefore, we researched four small-scale irrigation schemes in different settings and with variables rates of sedimentation. Based on this deeper understanding, we will propose a third discourse that accords a prime role to livestock–SSI interactions, thus allowing us to recommend more effective measures to control and mitigate the problem of sedimentation in SSI schemes in our concluding section.

2.3. Description of the Study Areas

2.3.1. Selection of Case Study Schemes

This study was conducted in the Southwest Shoa zone of Oromia, Waliso, and Ameya districts, which are located between 110 - 158 km from the capital city of Ethiopia, Addis Ababa, along the main road to Jimma. Four small-scale irrigation schemes were purposively selected (Figure 2.1) based on three sets of criteria. Firstly, all schemes have to meet the criteria of proximity and accessibility. Secondly, a variety in the degree of sedimentation varying from light to heavy sediment loads was required, whereby the Boye-1 and 2 merged scheme represents the lightly sedimented category and Ejersa small scale irrigation scheme the heavily sedimented category. Thirdly, this study probed what happens when a scheme gets abandoned due to sedimentation, including both an abandoned scheme (Meri-Megari) and a new scheme that was started in response to abandonment (Kulit) in the same location. Hence, four schemes were selected of which three functional schemes and one non-functional scheme.

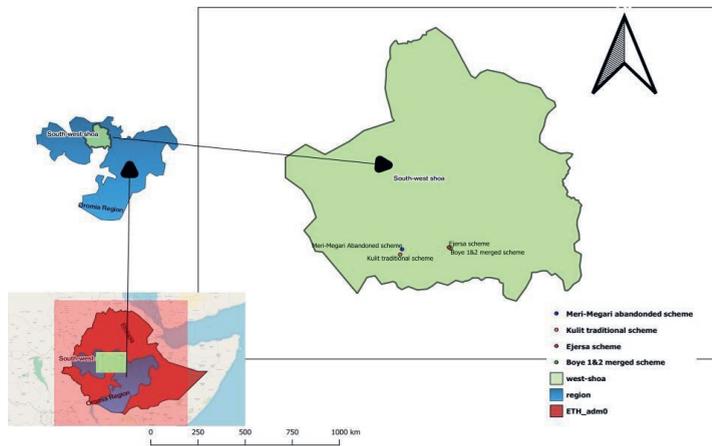


Figure 2.1. Location of the study area with the Four Case-Study Irrigation Schemes. Source: Hanan Tadele, 2021.

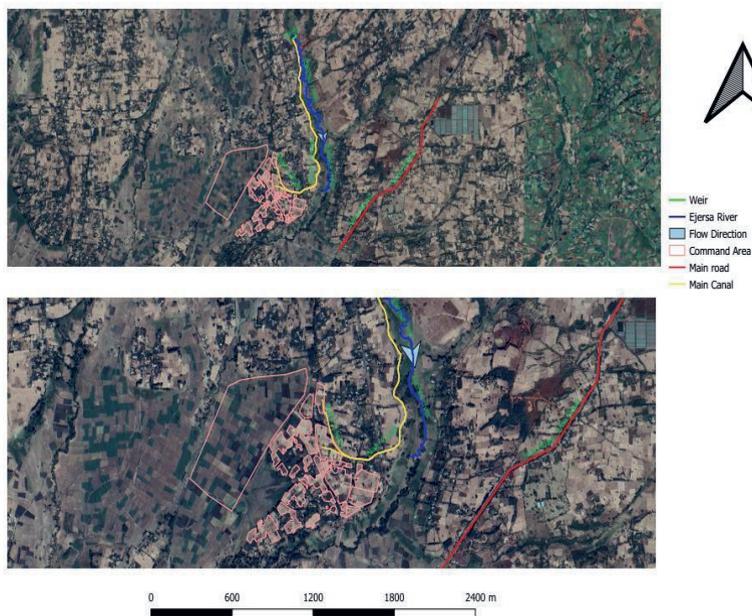
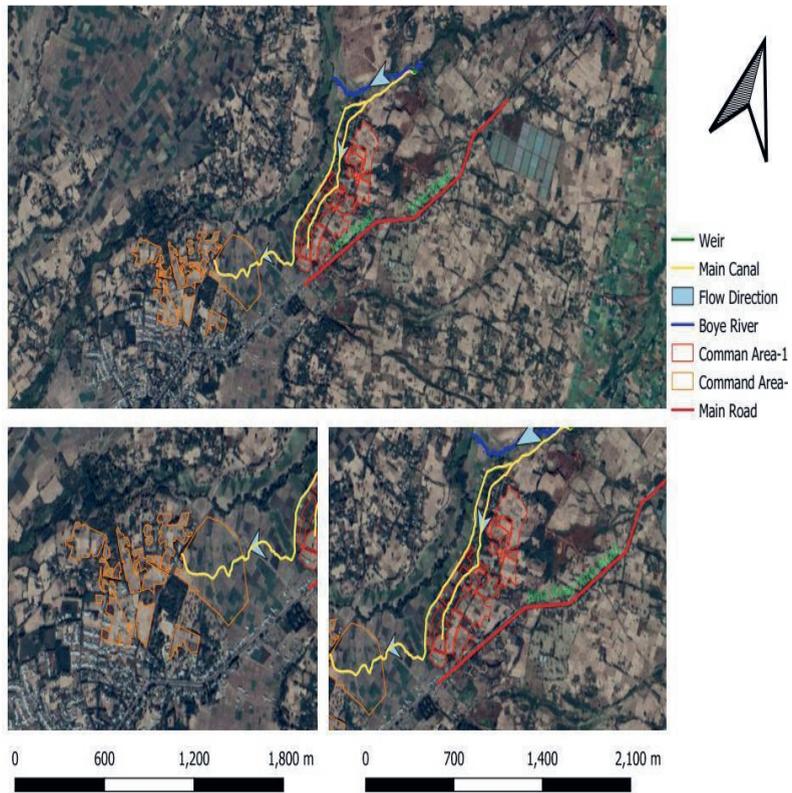


Figure 2.1.A, Ejersa Small-Scale Irrigation Scheme. Source: Hanan Tadele 2021.



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Figure 2.1. B, Boye 1 and 2 Merged Small-Scale Irrigation Schemes. Source: Hanan Tadele, 2021

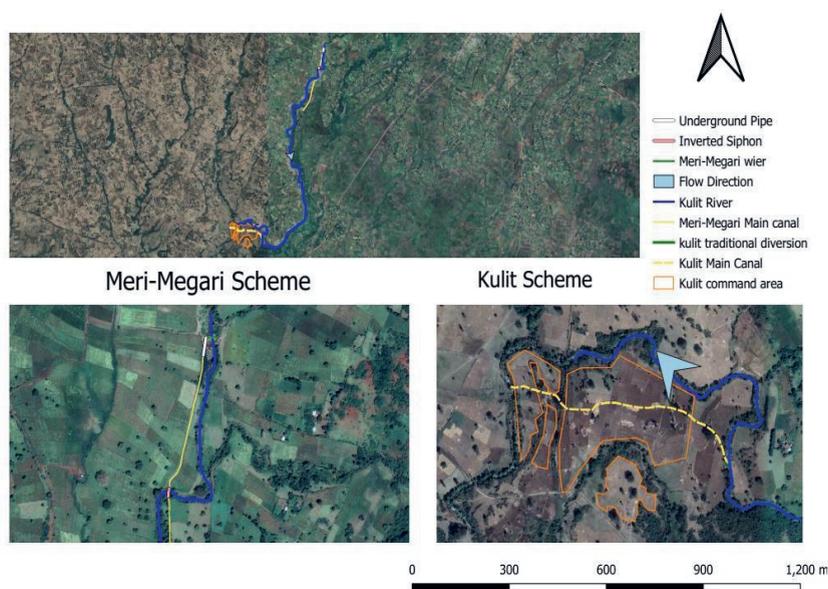


Figure 2.1. C Meri-Megari scheme and Kulit traditional small-scale irrigation scheme.

Source: Hanan Tadele 2021.

2.3.2. Background Information of Each Study Scheme

In Ethiopia, small-scale irrigation schemes are divided into different categories based on the establishment, management, and nature of the structure. Traditional irrigation schemes usually use temporary diversion arrangements or barriers made from local material which need annual maintenance. The canals are usually earthen, and the schemes are managed by the community. Modern schemes are irrigation systems with more permanent diversion weirs made from concrete that don't require annual re-construction. They are mostly community-managed, and the primary and secondary channels are made of concrete. Modernized schemes are traditional schemes that were upgraded after some time with more permanent diversion and concrete canals (Haile & Kasa, 2015).

Ejersa small-scale irrigation scheme was modernized with the support of the Government but is now a heavily sedimented scheme that serves two kebeles (the lowest administrative unit in the country), Dembeleketa and Bedesa Koricha. It is located 114 km from Addis Ababa along the highway to Jimma at an average elevation of 2120 meters above mean sea level, covering 96 hectares of command area, providing water for 120 households (Table 2.1)

Table 2.1 Background information on selected small-scale irrigation schemes

S. No	Irrigation Schemes	Location	Type of scheme	Command area Hectare (ha)	No. of Beneficiaries	Year of First Operation	Mean Annual Rainfall (mm)	Water Sources	Irrigation Methods	State of the scheme
1	Boye 1 & 2 merged scheme	Woliso Woreda	upgraded	56	121	2013	1208	Boye River	Furrow Irrigation	Lightly sedimented
2	Ejersa scheme	Woliso Woreda	Upgraded	96	120	2013	1200	Ejersa River	Furrow Irrigation	Heavily sedimented
3	Kulit scheme	Ameya Woreda	Traditional	17	29	2019	1270	Kulit River	Furrow Irrigation	Lightly sedimented
4	Meri-Megari	Ameya Woreda	Modern	200	234	2000	1270	Kulit River	NA	Abandoned since 2016

Source (Unpublished official document)

Boye-1 and 2 started operation as two separate traditional small-scale irrigation schemes which were merged and modernized by the government without the irrigation users' consent. The modernization entailed improvements to the new main intake and the lining of the main canal. This scheme was selected as representative of lightly sedimented schemes. It is located 110 km from Addis Ababa, at an average elevation of 2123 meters above mean sea level. The present scheme comprises two parts: Boye-1 providing water to 56 households and Boye-2 providing water to 65 households, irrigating a total command area of 56 hectares.

Meri-Megari was a modern small-scale irrigation scheme that is non-functional (abandoned). The main causes of its abandonment are sedimentation and excessive seepage loss along the canal. It is located at 158 km from Addis Ababa, at an average elevation of 1902 meters above mean sea level. It had comprised 200 hectares of command area providing water for 234 households.

Kulit traditional small-scale irrigation scheme was selected as a scheme that was initiated and constructed by the same farmers who were previously using the Meri-Megari modern scheme until its abandonment. The traditional weir in Kulit was constructed at 5.3 km downstream from the Meri-Megari abandoned scheme weir. It is located 151 km from Addis Ababa, at an average elevation of 1834 meters above mean sea level, and comprising 17 hectares of command area providing water for 29 households.

2.3.3. Climate and Weather Condition of the Study Areas

All selected schemes are situated in the mid-highland (Woyna-Dega) agro-ecological zone. Its rainfall pattern is of the unimodal type in which one main rainy season occurs during summer, which lasts from June to August. The mean annual rainfall of the area ranges from 1208 to 1270 mm (design document, unpublished). The average temperature of the study area undulates between 26.7 in summer and 10.3 °C in winter.

2.4. Materials and Methods

2.4.1. Methods of Data Collection.

As a general methodological approach, we used a “follow the water” approach to identify and map the water users and their networks, to map all relevant infrastructure and institutions, along with a “follow the livestock” approach to assess the uses of livestock, the grazing areas around the schemes, track livestock owners, and analyze the problem of the livestock–irrigation interaction. We selected the participants for a qualitative interview using a purposive and snowball sampling technique to identify the key informants from the head, middle, and tail-end users who represent the range of variation expected in the water user population. The fieldwork was conducted during two periods: from June to October 2018 and from September 2019 to February 2020. We conducted open-ended and semi-structured in-depth interviews with older farmers, Water User Association (WUA) committee members,

irrigation users, livestock farmers (LF), selected professionals, and relevant government officials. The number of interviewees was expanded until the collected information reached a certain saturation level, when no new insights could be collected beyond those that had already been expressed (Bernard & Bernard, 2013; Glaser & Strauss, 2017). Field observations provided first-hand information on the irrigation schemes' operation and maintenance practices and the schemes' interaction with the livestock and the livestock farmers. We gathered secondary data from the district and a regional office that have had a stake in the respective schemes, and we conducted nine focus group discussions on the topic with six to eight participants in each session.

We interviewed about 75 persons: 18 women, and 45 men from the head, tail, and middle-reach users of the four schemes, including WUA and LF committee members, five irrigation development agents, four government officials, and three engineers (the interviewees varying in age from 14 to 79 years).

Snowball sampling was used to identify the key informants from the head, middle, and tail-end users, and the open-ended semi-structured in-depth interviews were continued until the collected information reached the saturation level followed by nine focus-group discussions with 6-8 members in all four schemes.

2.4.2. Accumulated Sediment and Sediment Inflow Data Collection

The accumulated sediment in the canals before the beginning of the irrigation season was measured in the Boye 1 and 2 and Ejersa schemes for one season by using a staff rod with a flat sheet at the bottom of the rod to measure the depth of accumulated sediment and depth of both lined and unlined canals. The bottom flat sheet helped to prevent the staff rod from penetrating the surface of the unlined canal. Since the deposited sediment in the canal were non-uniformly distributed, we measured the accumulated depth in three places (left, right, and middle of the canal) in all data collection points and we took the average value. The canal profile was established by using a measuring tape to determine the width and length of the canal. The volume of the accumulated sediment is then calculated by applying the volume equation:

$$V_{rc} = L \times W \times D_{acc} \quad (1)$$

V_{rc} = Volume of accumulated sediment in rectangular canal (m^3)

L = Length of the canal that covered my accumulated sediment (m)

W = Width of the canal (m)

D_{acc} = Accumulated sediment depth (m)

For unlined trapezoidal canal

$$V_{tc} = L * (B + zD_{acc})D_{acc}, \quad (2)$$

Vtc= Volume of accumulated sediment in trapezoidal canal (m³)
L= Length of the canal that covered my accumulated sediment (m)
B= m width of the trapezoidal canal (m)
D= Accumulated sediment depth (m)

z= side slope of trapezoidal canal

To calculate the canal capacity in Volume.

$$V_{cc} = L \times W \times D_c, \quad (3)$$

Vcc= Canal capacity in volume (m³)
L= Canal Length (m)
W= Canal Width (m)
Dc= Canal Depth (m)

$$\text{Percentage of sediment accumulation} = \frac{\text{The volume of accumulated sediment in the canal}}{\text{Canal capacity in volume}} * 100, \quad (4)$$

2.4.3. Sediment in Flow Measurement

Sediment inflow was measured in the Ejersa scheme during one irrigation season from September 2019 to February 2020. These measurements considered the changes in discharge because of inflow in or outflow from the canal, operation of the control structure, changes in canal geometry along its length, changes in roughness when there is a different surface material of the canal, and changes in bed level. Eight data collection points were marked within the 1.85 km length of the main canal from the intake. All required data (water flow, cross-section, sediment concentration sample, top, and bottom bed level, water depth) were measured at each section once a week. Inflow sediment was measured at the eight marked points by using a DH-48 depth-integrating sampler. Depth integrated suspended sediment sampling is carried out at one vertical point most closely representing the centroid of flow for that canal width. We took three samples from each station at a time. All samples were composited into a single container which was then agitated, sub-sampled, and analyzed for suspended sediment concentration (Bartram, Ballance, World Health, & United Nations Environment, 1996), and velocity was measured by using a digital current meter. The canal cross-section and water depth were established using a measuring tape. To determine suspended sediment concentration, we used pre-weighed glass fiber filters (Whatman GF/C). After filtration of a certain volume, the filters are dried and weighed to obtain the suspended sediment concentration. Results and Discussion; Extent and origins of sedimentation in the study schemes.

2.5. Results And Discussion

Below we first present data pertaining to the extent that the four study schemes have been affected by sedimentation (2.5.1); next we identify the origin of this sediment (2.5.2); we describe the livestock-irrigation scheme interaction as a sediment source (2.5.3) and finally we describe the suspended sediment inflow for the Ejersa irrigation scheme during the 2019-20 irrigation season (2.5.4).

2.5.1. The Extent of Sedimentation in All Four SSI Schemes

In the abandoned Meri-Megari scheme, the construction took place between 2001/2001 and 2005/2006, initially with initially the full potential of irrigating 200 hectares. In the first 5 years, it went from irrigating 200 hectares to a significantly reduced area of 40 ha. It was abandoned in 2016, having served only half of its designed lifetime of 20 years. The main reasons for its abandonment were sediment deposition at the intake and canal networks, and the high levels of seepage loss. In 2019, we observed and learned that the entire canal capacity had been 100 percent filled with accumulated sediment. The irrigation water reached the command area after traveling over nine kilometers through a mostly earthen canal (only 0.5 kilometers is lined). It proved impossible for the scheme's beneficiaries to remove the accumulated sediments from the nine kilometers long canals each year. Another complicating factor was formed by the submerged pipe close to the river intake of the scheme. This pipe was prone to blockage by accumulated sediments and proved impossible to clean.

Ejersa scheme comes in the second position regarding its vulnerability to sedimentation. It suffers from a heavy sediment load. However, the Ejersa scheme users are well organized with a strong water user committee capable of keeping the scheme functional. While the scheme is irrigating its full command area, the amount of labor that is required to clean the canals each season is considerable. About 68 percent of the lined canals and 84 percent of the unlined canals were found filled with sedimentation in 2019 before the start of the irrigation season (Figure 2). The farmers removed the accumulated sediment before the beginning of the irrigation season in September. Moreover, the farmers clean the scheme every month to keep it operating at full potential. The accumulated sediment load in the canal network was observed to be heavier at the furthest point from the intake, showing a tendency for suspended sediments to settle as current flow velocity dwindles.

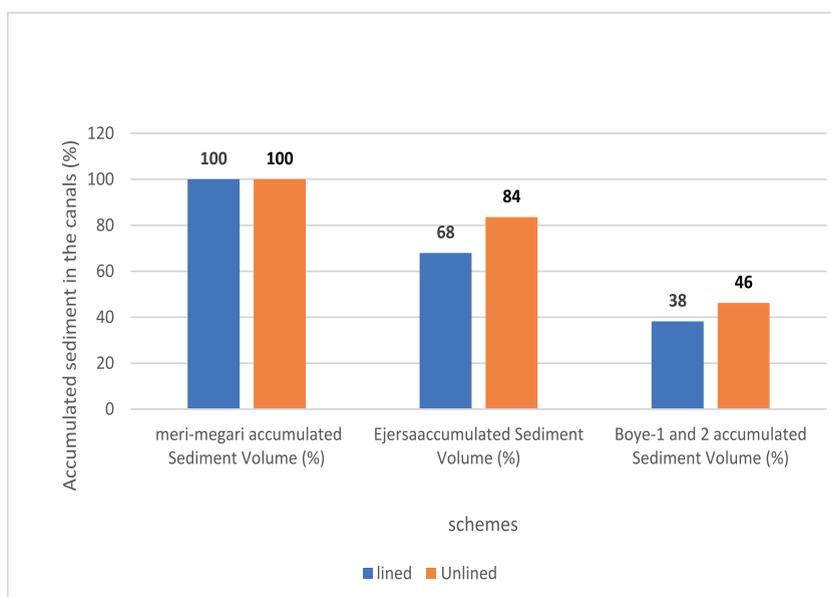


Figure 2.2 Percentage of accumulated sediment in the canal at the start of the irrigation season in three schemes (source: own measurements, 2019)¹

Kulit traditional scheme was constructed on the same river as the abandoned Meri-Megari scheme. The sediment inflow in the canal is such that the irrigation beneficiaries have to clean the canal network at least three times a year. The canal cleaning for the first irrigation season of each year consumes up to a month of labor. Any subsequent cleaning for the other two seasons takes up to 12 days. Some farmers use only two irrigation seasons a year by extending the time that the plant stays on the field and some of the farmers use three irrigation seasons: two seasons to plant different crops and one season to transplant seeds from 45-60 days for the next season. The advantage of this scheme is that during summer when the diversion of the scheme gets washed away the accumulated sediment inside the weir is removed without entering the scheme's canal network. However, the subsequent re-construction of the intake weir at the end of the rainy season is not easy and cheap for the farmers. The re-construction and sediment removal process at the start of the next irrigation season takes a month with almost all 29 members participating.

The merged Boye-1 and 2 schemes were selected as a case study of a lightly sedimented irrigation venture, whereby the sediment inflow through the intake was insignificant during the irrigation season. However, the sediment accumulated still represented 38 percent of the volume of the lined main canal and 46 percent of the unlined canal network before the start

¹ The accumulated sediment in Meri-megari was observed after three years of abandonment. For kulit scheme I couldn't measure the accumulated sediment before irrigation season because of the challenges in the road of access (muddy road) after rainy season.

of the first irrigation season in 2019 (Figure 2.2). Furthermore, the farmers clean the canal length three times a year to remove the sediment that accumulates in the canal network during the irrigation season.

2.5.2. Sources of Sediment in All Study Schemes

In all study schemes, we assessed the sources of sedimentation. I measured the accumulated sediments at the start of the irrigation season due to erosion from the upper river catchment. The overland flow contribution during the rainy season, removed sediment backflow from either side of the canal due to livestock interaction during irrigation season; livestock grazing over the canal bank and drinking water from the canal during irrigation season, and finally the livestock farmers' contribution through trespassing inside and outside the scheme.

The Overland Flow of Agricultural Land

Overland flow contribution on agricultural land during rainy season and erosion in the upper catchment at the beginning of irrigation season was found to be the major sediment source of the small-scale irrigation schemes (Wolancho, 2012). Overland flow in agricultural areas, particularly land that is susceptible to erosion due to livestock trampling during the rainy season, potentially contributes to sediment accumulation. Furthermore, overland flow is one of the causes of the backflow of sediment from the sides of the irrigation canals where removed sediment is deposited on the canal banks.

2.5.2.1. Erosion in The Upper Catchment

Upstream erosion is another sediment source caused by sediment-laden water from the upper catchment entering the canal system through the intake structure at the beginning of the irrigation season (Dereje & Yusuf, 2015). To reduce sediment entering through the intake gate, irrigators delay the canal opening by 2-3 weeks, delaying the growing season (Gurmu et al., 2019).

While these results confirm the existence of the sources of sedimentation that are frequently highlighted in both the neo-Malthusian and technical discourses (as described in section 2), in the next section we will highlight the importance of an often-overlooked third cause.

2.5.3. Livestock-Irrigation Interaction as a Major Sediment Contributor During the Irrigation Season

Before and during the irrigation seasons, livestock grazing and movements in and out of the schemes contribute to sediment in all four irrigation schemes. Livestock production is the second most important economic activity in the area and a key means of livelihood for many. The type and number of livestock holdings of the respondents vary across the study areas from 0 to 33 heads per household and over 70 percent of the livestock are cattle.

The land that was used to construct the irrigation scheme and the remaining grazing land was owned by livestock farmers (LFs). During Ejersa and Boye 1 & 2 schemes upgrading, they made two agreements: one with the irrigators regarding the land that was going to be used for canal construction with adequate compensation for the land and a second agreement with government officials regarding measures in the scheme to facilitate the use for livestock and livestock farmers (LFs). The government agreed to construct cattle-troughs in the canal and a bridge to help the livestock and livestock farmers in exchange for their consent for the construction. The agreed measures implicitly indicate that the livestock was expected to drink from the canal. However, the government representative office did not honor the agreement and the cattle troughs, and the bridge were not constructed. On top of that, during the scheme modernization, the canal route changed its original path, and the canal depth was shallower than in the traditional scheme. Consequently, the water overtops the canal and creates a water stagnation on the grazing land. The livestock farmers were disappointed because promises were not kept. However, the government officials who were in favor of the scheme construction ignored the livestock farmers' objections. In turn, the livestock farmers felt threatened by the government officials who favored irrigation over livestock farming, and they felt they were losing their property right over the water resource.

In the absence of troughs, livestock struggle to drink from the canal when the water level is low. The livestock farmers see the absence of cattle troughs as a denial of water right for their livestock, and they still have a lingering feeling that the land they have already given for the irrigation scheme, belongs to them. Excluding the livestock from the irrigation scheme is extremely difficult because the grazing lands are located along the irrigation canal. The scheme neither has a clear boundary that forbids the livestock farmers to keep their livestock away from the scheme nor a fence that prevents the livestock interaction with the irrigated land.

In all study areas, grazing land is located along the irrigation canals, mostly on the riverbed side. Irrigation water travels a long distance to reach the command area and along the trajectory of the canals, in some cases on both sides of the canal, grazing areas are located, accommodating hundreds of livestock. In most parts of the country, in peri-urban areas drinking water for livestock was never considered in urban planning. Consequently, livestock

is forced to drink canal water or water from the river (Sileshi, Tegegne, & Tsadik, 2003). In all the studied irrigation schemes there are no cattle-troughs along the canal for the livestock to drink in a safe, non-disturbing way and no water supply sources in case the river is low. The absence of the troughs gives the livestock access everywhere along the canal length and as a result, they push the sediment into the canal and destroy the canal bank (Figure 2.3b). Uncontrolled access to the grazing land on the canal bank and cattle trampling all around the scheme make the land more vulnerable to erosion and leads to an increase in sedimentation (Wilson, 2007). The lack of dedicated safe access points for cattle aggravates the vulnerability for erosion (Brits, Van Rooyen, & Van Rooyen, 2002, (P 54); K. Descheemaeker, T. Amede, & A. Hailelassie, 2010, (P 581); O' Sullivan, Huallacháin, Antunes, Jennings, & Kelly-Quinn, 2019, (P 147)). By frequently crossing the irrigation canals (Figure 2.3a) cattle push deposited sediment into the canal, they damage the canal banks and cause bank erosion that leads to sedimentation in the canal (O' Sullivan, Ó hUallacháin, Antunes, Jennings, & Kelly-Quinn, 2019 (P 153)).



Figure 2.3 (a) Cattle grazing and crossing the canal (b) Cattle drinking from the canal
(Source: Ejersa scheme pictures by Hanan Tadele, 2019)

A common practice among the livestock farmers is to put local material in the canal to block and raise the water level for the livestock to drink safely. The herders who constructed the blockage never remove the material once the cattle have had its fill, thus disturbing irrigation water supply and, perhaps more importantly, creating local hubs for sediments to accumulate (Figure 2.4 a and b).



Figures 2.4a and 2.4b. Canals blocked by local material in Ejersa scheme (source; Pictures by Hanan Tadele 2019)

Livestock are owned by three different groups of farmers: 1) livestock farmers who are irrigators in several irrigation schemes; 2) livestock farmers who use the same irrigation scheme and 3) trespassing livestock farmers who do not have land inside the irrigation schemes but whose rainfed farmland is located along the grazing land. Even though some of the livestock farmers are a user of the small-scale irrigation scheme, emerging conflicts over damage caused by livestock are difficult to solve. Livestock farmers belong to different owner groups with different needs and different levels of attachment to irrigated land. Moreover, irrigators and livestock farmers are represented by two different institutions: the irrigation water user association (WUA) and livestock farmers association (LFA), both working for the benefit of their members without considering the damage that they cause to each other. Lastly, boundary issues between the grazing land and the irrigation scheme territory are unsettled. Without a defined boundary between these two communal resources, it remains challenging for the institutions to solve it by themselves.

Livestock owners who gave up land for the construction of the scheme, but do not have land inside the irrigation scheme, feel short-changed. They contributed to the scheme but are excluded from benefits created by the irrigation scheme. They expressed their reluctance of caring for the schemes, and they are not bothered by their contribution to scheme sedimentation or canal bank destruction by livestock. They don't feel ownership of the scheme. Instead, they prefer to freely graze their livestock in all grazing areas. Furthermore, they believe they have nothing to lose if the scheme is damaged. On the contrary, when the system breaks down, they gain access to the entire grazing land and thus they seek to reduce the risk of the livestock getting hurt trying to drink from the canal. In fact, they admitted that they tried to damage the intake gate. However, they did not succeed so far but indicated that they would continue trying to destroy it without being directly responsible to avoid the consequences of destruction of government property. (LF focus group discussion in Ejersa, Woliso, November 2019)

A livestock farmer who also used the same irrigation schemes (Boye and Ejersa) stated in an interview that they preferred not to speak about the problem, as they believed that the problem is complicated for them to solve unless government officials get involved. One of them believed that both parties, livestock farmers and the irrigators, were right because for both groups it was a question of survival. Neither livestock nor crops survive without water, and it is just a conflict of interest that may not be solved easily. Since no solution was in sight, as a livestock owner and irrigation user they neither opposed the consequences of livestock-irrigation interaction, nor did they support the irrigators' effort to limit the interaction. They acquiesced in letting their cattle at the canal bank graze and drink the water, even though they were aware that cattle contribute to sedimentation and canal bank damage. They were willing to contribute the money and labor like other irrigators to maintain the scheme and let their livestock graze as any LF does" (LFs interview, woliso, November 2019)

Both irrigators and livestock farmers have an association that was formed under the acknowledgment of the district office. These two associations have not agreed on any form of co-operation regarding communal resource use. The WUA admits that the LFs are the owner of the grazing land and thus they have decision power over the use of grazing land that includes the verge of irrigation scheme canal bank. However, the irrigators believe that they should at least decide about the irrigation scheme usage, water supply, and any harm that may affect the scheme. Yet, they are not in a position to do so due to the livestock drinking water from canals, that has a negative impact on the irrigation water supply and distribution. The WUA feels it has no means of controlling the situation.

Livestock farmers who do not benefit from the irrigation scheme emphasized that it has been their grazing land: the irrigators are the ones who appropriated the grazing land and created problems for the livestock and livestock farmers. If the scheme had not been constructed, their livestock would have had safe access to drinking water. The existence of clearly defined boundaries of resource systems is often mentioned as a crucial factor for sustainable governance of local commons (Ostrom, 1990). Yet none of the small-scale irrigation schemes in our study have rules and regulations that can be applied to all scheme users, irrigators, livestock farmers, and trespassers. The Ejersa and boye 1&2 LFs demanded that Their presence be acknowledged for them to be able to co-operate with irrigators and contribute to the scheme's sustainability. This can be achieved by constructing a cattle-trough and a bridge. Meri-Megari LFs are using the irrigation canal as a grazing since it is abandoned and filled with grass. Kulit scheme is a traditional scheme and they have not approached by the government office for upgrading the system yet and the cattle drink the water without cattle-through and sometimes by walking in the canal.

Because of the conflict of interest and the boundary issue of the communal resource, the Water User Association (WUA) and Livestock Farmers Association (LFA) were unable to solve their differences. Government officials claim they were unable to help since there is no assigned specific body in the district office that deals with the issue related to boundaries. As a result, damage caused by the livestock interactions with irrigation schemes continued.

Nevertheless, since both associations (WUA and LFA) fall under the district irrigation development office, they are formally responsible to smoothen the relationship between the two groups to reduce the damage. Both WUA and LFA, have been raising their complaints, yet the LFA still believed they were not important enough to warrant the district officers' attention. This neglect slighted them and hardened their unwillingness to co-operate with irrigators.

Complicating matters are the frequent changes in government policy and District office structure: the mandate of those responsible for small-scale irrigation changes, while the officers who have experience in the specific place are getting assigned to different locations frequently. As a result, the district offices are facing a lack of skilled and experienced manpower.

Gaining the trust from irrigators as well as livestock farmers takes a long time. The few officers who did win those farmers' trust often got re-assigned, thus sustaining the communication problem between the farmers and the district office. Moreover, understaffing, missing documents due to the frequent change of the officers, shortage of skilled manpower, a lack of coordination, and a low level of participation and consultation with the schemes make the problem more challenging to handle for the district office.

2.5.4. Quantity of Sediment Deposition in Ejersa Scheme During the Irrigation Season.

The Ejersa scheme is one of the schemes that faces challenge of sedimentation caused by strong livestock disturbance due to livestock grazing along the canal bank. It causes a significant sediment deposition in the canal during the irrigation season. In this scheme, 60 households use the grazing land along the main canal. On average a household has about 11.93 livestock with a standard deviation of 7.4 (Design-Document, 2013) per household involving mostly cattle. On average, over 600 heads of livestock graze along the canal banks every day. They cross the canals frequently pushing the sediment into the canal (Figure 2.3a).

Furthermore, lacking cattle-throughs along the irrigation canal, the canal is the only means of drinking water supply for the livestock when the river is low (Figure 3b). The livestock farmers put blocking barriers consisting of local material inside the canal to raise the water level for the livestock to drink safely. The cattle-farmers raise the water level to 163 % by adding those materials (Figure 2.4 a and b).

The sediment inflow to Ejersa irrigation scheme was measured weekly at 8 points along the 1.85 km of lined main intake canal. The sediment inflow level varies from one data collection point to another. Figure 2.5 shows a variation in sediment concentration across the data collection stations; the maximum and minimum sediment concentrations were found in



different stations due to livestock disturbances. The minimum sediment inflow per cubic meter per second was observed in the fourth station for the first four weeks followed by station two from week four to week eight and from week 8-16, the minimum sediment inflow was observed at the first station or the intake.

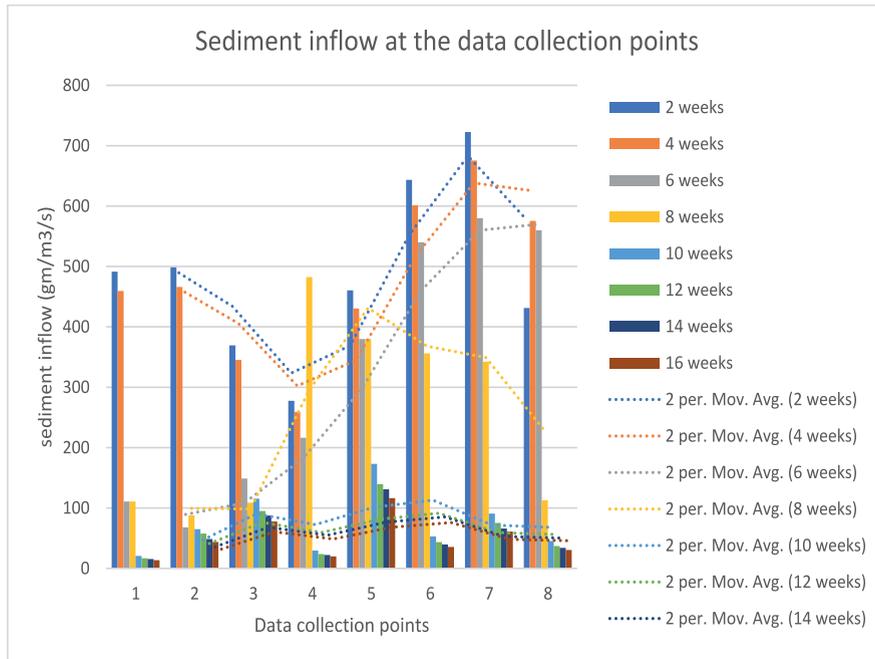


Figure 2.5. Sediment inflow per two weeks at data collection points (from intake (point 1) to most downstream along the main canal (point 8))

However, the maximum Sedimentation inflow per cubic metre per second was observed at the seventh station for the first 6 weeks, followed by station six for the first four weeks. Higher sediment inflow was measured at the point downstream of the livestock grazing and drinking point during the disturbance compared with the upstream of the access point (O' Sullivan et al., 2019). The livestock disturbance was primarily observed at a certain distance from the intake. In some cases, the disturbance occurred at the weir of the scheme: the livestock re-suspends the deposited sediment while drinking the water or crossing the grazing area through the weir. Other times swimming kids at the weir intake re-suspend the sediment and then relatively higher concentrations are found at the intake than other consecutive data collection points.

The trend of Figure 2.6 shows that during the irrigation season, sediment inflow rate per cubic meter increases from the intake to the furthest point and sediment concentration spike was found at the place where there was a disturbance. Moreover, the inconsistency in peaks

demonstrates that rather than sediments originating from upstream catchment erosion, disturbances caused by livestock and swimming kids explain the values at any point along the canal, during the irrigation season. Moreover, it also shows a reduction in sediment concentration over time. The possible reasons might be, the quantity of water that arrives at the Ejersa scheme reduces significantly since the Ejersa scheme is the fifth scheme that is constructed on the same river, as a result, the sediment concentration that is carried by the water would be less. Discharge and sediment concentration show a direct correlation. The other possible reason is that the kids who swim at the intake and resuspend the sediment at some point stop swimming because the water level at the intake is too low to swim in it. As a result, the disturbance would be less and thus sediment concentration in the canal was reduced.

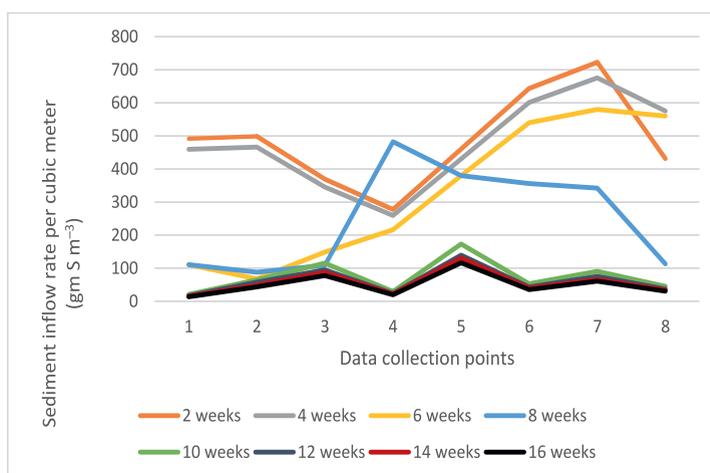


Figure 2.6. Sediment inflow trend lines per 2 weeks at data collection points (from intake (point 1) to most downstream along the main canal (point 8)).

2.6. Conclusion and Recommendations

Since the discourse around sedimentation of SSIs is based on erroneous assumptions regarding its cause, it is unsurprising that the remedies that have been tried in the past proved ineffective. The focus of the dominant discourse lies on upstream catchment protection, neglecting both protection against erosion through overland flow along the margins of the canal network *and* sedimentation caused by livestock drinking from the canals and through disturbances caused by livestock grazing and trespassing. Hence remedies that have been advocated in the past, like the design and construction of silt traps at the start of the main canal and conservation measures in the upstream river catchment, will not be sufficient to deal with on-going sedimentation during the irrigation season.

One of the issues that the schemes are facing as a livestock-scheme interaction is a boundary issue between the grazing area and the SSIs margin of the canal network. It is a complicated matter, especially since there is no specific government body at the small-scale irrigation level that can solve the boundary-related problems. Lacking an easy solution, the problem of sedimentation and damage of SSIs infrastructure caused by livestock interaction during the irrigation season has been sustained. Livestock irrigation interaction contributes to sedimentation and canal bank damage. It also affects the water supply since the livestock is a considerable water consumer, while upstream users also withdraw water for domestic use.

To promote sustainable management of small-scale irrigation infrastructure and improve irrigation water supply; the government has a rule that a water committee must be established before construction of water infrastructure. However, so far this involves irrigators only. It is suggested that involving livestock farmers in the water user committee or creating WUA committees that comprise at least two sub-committees, livestock farmers and irrigators from the beginning of the scheme design and construction, might help to resolve some of the conflicts related to the livestock-irrigation conundrum. Being represented would give livestock farmers a sense of ownership and involvement that might commit them towards resolving the negative impact of livestock-irrigation interactions. Joint rule making by irrigators and livestock owners concerning use of grazing land, use of canals for drinking and movements of livestock across canal infrastructure may help to mitigate the sedimentation as a result of livestock interactions.

Boundary policy efforts that seek to integrate both livestock and irrigation farming systems will be necessary to achieve improvements. This calls for a new institutional approach on the part of government agencies, abolishing established 'silo' structures to facilitate integration of livestock and irrigated production. Improving the sediment management strategy can make an important contribution to increasing overall agricultural water productivity and improve the performances of SSIs that are believed essential to sustainably meeting future human food security needs and reducing poverty.

The image features a large, bold, black number '3' centered on a white background. The background is composed of several geometric shapes: a light gray triangle in the top-left corner, a dark gray triangle in the bottom-left corner, and a small gray trapezoidal shape on the left side of the white area. The number '3' is positioned to the right of these shapes.

3

CHAPTER 3.

Livestock-Irrigation Interaction and Its Influence on the Sustainability of Small-Scale Irrigation Schemes in Ethiopia

This chapter is based on:

Dessaiegn H.T., Bolding A., Fraiture, C.d., and Ayana, M.

Livestock-Irrigation Interaction and Its Influence on the Sustainability of Small-Scale
Irrigation Schemes in Ethiopia

Irrigation and drainage journal (under review)

3. Livestock-Irrigation Interaction and Its Influence on the Sustainability of Small-Scale Irrigation Schemes in Ethiopia

Abstract

Small-scale irrigation (SSI) plays a big role in rural livelihoods and the economy in Ethiopia. Despite considerable investments, overall SSI performance is disappointingly poor. Sedimentation of canals and intakes leads to low performance and abandonment of systems. Roaming livestock in the command area and around riverbanks is an important contributor to sedimentation. Commonly proposed solutions, including technocratic fixes, institutional arrangements between irrigators and livestock farmers; and collective action by irrigators has not yielded satisfactory results. Based on three case studies from Ethiopia, we illustrate why existing solutions are not effective and why the collective action is not straightforward. Using in-depth interviews and focus-group discussions, we examine the complex intertwined relationships between irrigators, livestock farmers, and local government. Without understanding the interrelationship and accounting for the links between irrigation and livestock in the design and governance structures of SSI, the proposed technical and organizational fixes are not likely to be successful. Addressing the conflicting interests and building consensus and trust among irrigators and livestock farmers are prerequisites for solving SSI performance concerns of many Ethiopian SSI.

Keywords; livestock, Small-scale Irrigation, Sedimentation, Water User Association, grazing management, Ethiopia.

3.1. Introduction

Small-scale irrigation is of utmost importance for the rural economy and farmers' livelihoods in Ethiopia. Therefore, the government is investing considerably in the expansion of irrigation. However, small and medium scale irrigation schemes in Ethiopia are underperforming as compared to their designed capacity, and some of them are dysfunctional (S. B. Awulachew & Ayana, 2011). The causes of underperformance and abandonment of the schemes are diverse and complex. One of the major constraints is excessive sedimentation in the headworks and canal network and a lack of funds and labour for operation and maintenance (S. B. Awulachew & Ayana, 2011; Gebul, 2021).

Sedimentation is a big challenge, as it draws on a lot of labour for maintenance before the start of and during the irrigation season. There are three frequently cited causes for sedimentation, each pointing at different solution pathways. The first blames upstream overpopulation and erosion and consequently argues for more catchment protection programs (Wolancho, 2012). A second reason blames faulty design and lack of institutional capacity by users at SSI scheme level and identifies technical solutions and institutional fixes to organize users in irrigation schemes (Gurmu et al. 2022 and 2019). A third reason focuses on the often overlooked cause of sedimentation *during* the irrigation season, namely livestock-irrigation interaction (Dessalegn, Bolding, Fraiture, & Ayana, 2021). Neglecting the irrigation-livestock interaction often renders other measures to reduce sediment ineffective.

In this paper we aim to unravel the livestock-irrigation conundrum. Using the example of three small scale irrigation systems in Ethiopia we explore why the commonly proposed solutions are ineffective by disentangling the complex interactions between irrigators, livestock farmers and local government. These interactions explain why proposed technical approaches are ineffective, but also why collective action is not straightforward.

To do so, we first review existing literature on irrigation-livestock interaction before describing the case study area and study method. Next, we describe and analyse irrigation-livestock interactions in the study schemes by looking into the extent of sedimentation caused by livestock; various forms of collective action controlling livestock movements inside the irrigation perimeter, along its margins and on grazing land; various owner groups of livestock and their motives for interaction with the scheme; and finally, the difficulties of devising effective strategies for institutional control over livestock interactions. In the concluding section we present the major causes and challenges associated with sedimentation caused by livestock-irrigation interactions and present various options to moderate the negative effects of such interactions in the short and long run.

3.2. Irrigation-livestock Interactions

3.2.1. Irrigation is Associated with Higher Livestock Densities

Widgren and Sutton (2004) in their book on islands of intensification in Africa, establish a close link between places in Tanzania and Kenya where irrigated production emerged and the routes of trading caravans from the Indian ocean to the hinterland. This link is not coincidental but based on a mutually beneficial relationship between irrigating agriculturists and nomadic traders (and pastoralists): pack animals (camels, oxen) required watering and stock-feed, whereas irrigating agriculturalists were interested in manure and draught power. Irrigation facilities provide access to water and fodder even during dry seasons and hence attract livestock.

In Africa the highest animal densities are found in irrigation settings (Peden et al., 2006). Cattle provides draught power for farming and transport (McMichael, Powles, Butler, & Uauy, 2007) and also manure, which produces benefits for both farms (fertilizer) and households (fuel and building material). Further, livestock offers a vehicle for wealth accumulation and buffer against income fluctuations.

The beneficial uses of livestock explain why irrigation is associated with high livestock densities. However, higher livestock densities around irrigation also create pressures and problematic effects.

3.2.2. Problems of Livestock-Irrigation Interactions

The problems caused by livestock in an irrigation setting relate to their needs: grazing and water, which often involve movements from the homestead kraal to the place of feeding/watering. Grazing, drinking and regularly moving about produce negative effects, such as sedimentation from erosive, overgrazed pastureland; destruction and sedimentation of irrigation infrastructure; and crop damage. The incisional and erosive forces of cattle hooves, coupled with overgrazing, can reduce stream bank stability, and increase suspended sediment and turbidity, which contributes to in-stream deposited sediment. The trampling effect of cattle is prominent around watering points, where land degradation can be extreme (Brits et al., 2002). Continuous and unrestricted grazing on a riparian margin leads to higher bank erosion and the barring of soils can lead to stream bank deterioration, irrigation infrastructure damage and sedimentation.

3.2.3. Commonly Proposed Solutions to Minimize Livestock-Irrigation Problems

Sedimentation problems due to livestock-irrigation interactions are not new. Already in the colonial period the problem of roaming livestock in the then newly developed irrigation systems in Rhodesia were recognized (Roder, 1965). Solutions were sought in state regulation and top-down measures, such as grazing bans around canal banks and fields, enforced by fencing; and reducing the cattle density according to carrying capacity (Ibid). Realizing that destocking and culling of livestock would lead to strong resistance among the local

population, other proposed approaches comprised a system of rotational grazing and cultivating feed crops such as alfalfa or elephant grass in part of the irrigated area (Ibid).

These technocratic measures are still commonly proposed and implemented. Restricting livestock access to water courses by providing cattle troughs and alternative water sources is an effective way to minimize cattle movement (Wolancho, 2012) and reduce intrusion of suspended sediment in the water body and associated effects on water quality (Madden, Harrison, Finn, & Huallacháin, 2019). Nevertheless, Line, Harman, Jennings, Thompson, and Osmond (2000) found that provision of alternative drinking sources alone was ineffective. Cattle exclusion from the grazing area and water course through fencing proved effective to reduce bank erosion and suspended sediment in the UK (Collins et al., 2010) and the USA (Carline and Walsh, 2007). However, fencing may be too costly in large irrigated areas in developing countries (Pekor et al., 2019).

Zero grazing with cut-and-carry of grasses helps to exclude livestock and can significantly relieve pressure on grazing land (Meul, Van Passel, Fremaut, & Haesaert, 2012). However, the presence of communal grazing areas discourage zero grazing as farmers resort to free-riding strategies (Gebreyohannes & Hailemariam, 2011). Most farmers reject zero grazing on the assumption that they have large grazing lands and can benefit more by having many herds. Others associate zero grazing with confiscation of land. Growing feed crops such as alpha-alpha or elephant grass on irrigated areas as proposed by Roder (1965) likely displaces other crops and hence decreases farmers' income.

Recognizing shortcomings of technical top-down measures and the importance of social interaction in managing sediment and maintaining irrigation infrastructure, another set of solutions emphasizes formal and informal institutions (Beyene, 2009) and collective action (Chun, 2014). Collective action is considered the most promising solution for the sustainable management of common property resources (Gebremedhin et al., 2004; Ostrom, 1990). However, effective collective action between livestock farmers and irrigators is virtually non-existent in Ethiopia and common sediment management strategies in small scale irrigation schemes are ineffective. Our case studies illustrate the underlying reasons.

3.3. Description of the Study Areas

3.3.1. Selection of Case Study Schemes

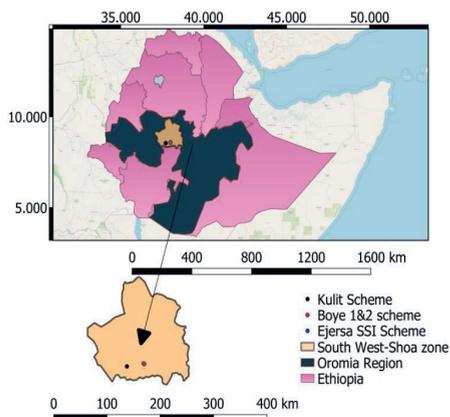
This study was conducted in the Southwest Shoa zone of Oromia, Waliso, and Ameya districts (Figure 1). Three small scale irrigation schemes were identified according to their accessibility and degree of sedimentation varying from light to heavy sediment loads (Table 3.1). The Boye-1 and 2 is a merged and upgraded scheme that represents a lightly sedimented case. It comprises two parts: Boye- 1 providing water to 56 households and Boye-2 with 65 households, irrigating a total command area of 56 hectares (Figure 3.1b).

Table 3.1 Background information on selected small-scale irrigation schemes

S. No	Irrigation Schemes	Type of scheme	Year of first operation	Command area Hectare (ha)	No. of Households	State of the scheme	Average livestock holding per household
1	Boye 1 & 2 merged scheme	Upgraded	2013	56	121	Lightly sedimented	8.25
2	Ejersa scheme	Upgraded	2013	96	120	Heavily sedimented	11.93
3	Kulit scheme	Traditional	2019	17	29	Lightly sedimented	10

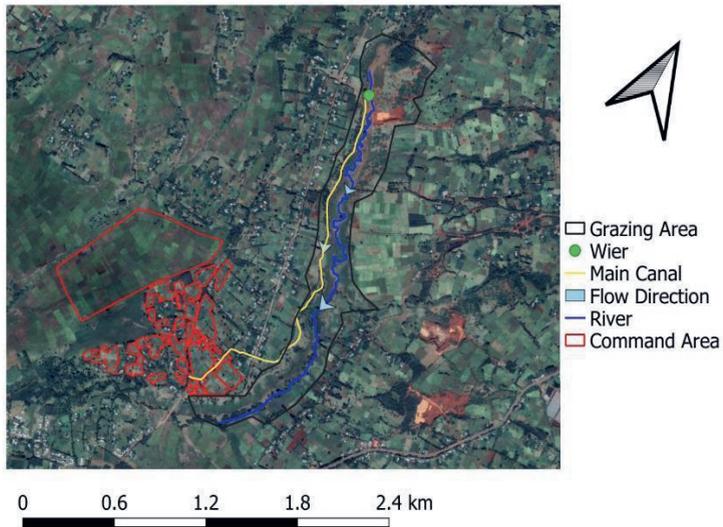
Source: (Unpublished official document)

Ejersa is an upgraded and heavily sedimented scheme serving 120 users from two kebeles, the lowest administrative unit in Ethiopia (Figure 3.1a). The Kulit case represents a new scheme that was started by farmers in response to abandonment of Meri-Megari SSI because of sedimentation. The traditional weir of the Kulit scheme was constructed at 5.3 km downstream from the Meri-Megari abandoned weir. Located at 151 km from Addis Ababa at an average elevation of 1834 meters above mean sea level it comprises 17 hectares and 29 households (Figure 3.1c)



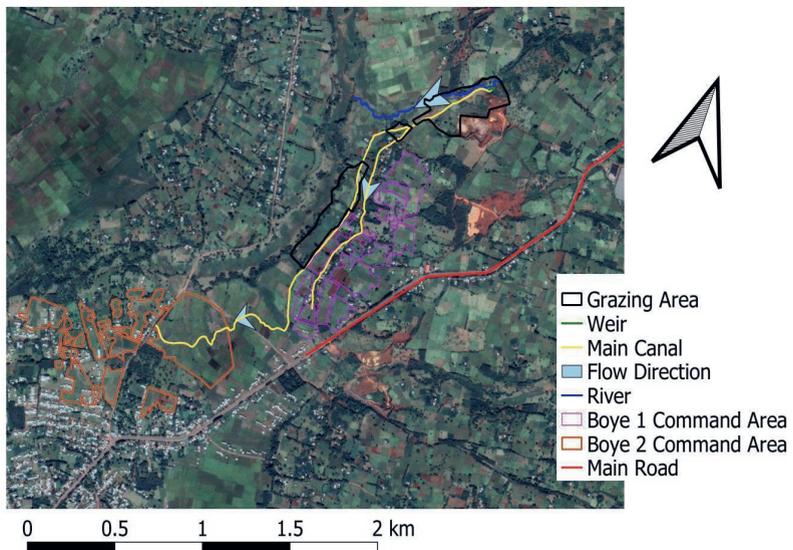
Source: (Own material)

Figure 3.1. Location of the study area with the three case-study irrigation schemes.



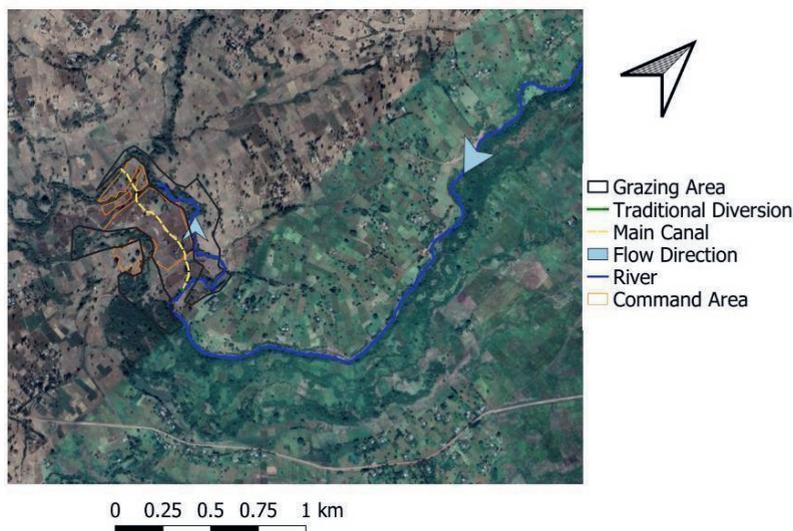
(Source: Own material)

Figure 3.1a. Ejersa irrigation scheme and Part of Grazing land



Source: (Own material)

Figure 3.1b. Boye I & II irrigation Scheme and Part of Grazing land



Source: (Own material)

Figure 3.1c. Kulit traditional irrigation Scheme and Part of Grazing land

3.4. Material and Methods

As a general methodological approach, we used a "follow the water" principle to identify the water users and their networks, to map all relevant irrigation infrastructure, grazing areas and institutions, and to track the livestock owners and reconstruct their interactions with irrigators. Participants for a qualitative interview were selected using a purposive and snowball sampling technique to identify the key informants from the head, middle, and tail-end user representatives. We gathered data during two periods: from June to October 2018 and from September 2019 to February 2020. Open-ended and semi-structured in-depth interviews were conducted with older farmers, the Water User Association committee members, irrigators, livestock farmers, engineers, and relevant government officials. The number of interviewees was expanded until the collected information reached a level where no new insights were added beyond the ones that had already been expressed. Field observations provided first-hand information on the schemes' operation and maintenance practices and the interaction with livestock and the livestock farmers. We gathered secondary data from the district and a regional office that have had a stake in the respective schemes,

and we conducted nine focus group discussions on the topic with 6-8 participants in each session.

We interviewed 63 persons in total. Among the users of the three schemes, we interviewed 15 women and 36 men farmers, spread across the head, tail, and middle-reaches with some of them acting as WUA committee members. Also, twelve officials were interviewed of whom five irrigation development agents (DA); one former DA from Waliso District, two active DAs from Waliso District and two DAs from Ameya District. Of the four Government officials interviewed, one worked for the Oromia irrigation development agency Addis Ababa, one from Waliso District, one from the Ameya District office and one from the south-west Shoa province. A further three engineers were interviewed: one from Oromia irrigation development agency Addis Ababa, and two from south-west Shoa province. The age of the respondents ranged between 14 and 79 years. Interviews were translated and transcribed. The qualitative data analysis was conducted after repeatedly reading each transcription line by line. Field notes and observations contributed to triangulate findings and interpreting the results (Dessalegn et al. 2019).

3.5. Results and Discussion

The problems of the livestock-irrigation interaction in the case study irrigation schemes are driven by the conflicting needs of irrigators and livestock owners: livestock needs grazing and drinking water and often this involves movements from the homestead kraal to the place of feeding/watering. The destruction of irrigation infrastructure is manifested by the main canal of Ejersa SSI which is broken and leaking in many places. The frequency of interactions is high because irrigation farming, livestock grazing, and drinking represent daily activities practiced year-round in all study area schemes. Moreover, because of livestock's gregarious, restless behavior, and their free grazing habits, part of the grazing area in Ejersa and Boye 1&2 study sites was overgrazed despite the Livestock Farmers Associations' efforts to impose grazing management. Compounding the problem is the fact that livestock have unrestricted access to the irrigation systems and cattle need to cross irrigation canals to reach grazing and watering areas along the river (Figures 3.1a and 3.1b).

3.5.1. The Irrigation-Livestock Conundrum: Different Stakeholders, Different Perspectives

Because of the sedimentation and damage to infrastructure, the interaction between irrigators and livestock owners leads to conflicts. The presence of different stakeholders, who have partly over-lapping interests and who are dependent on functional irrigation systems makes the situation more complex. We have categorized the relevant stakeholders into four (partly overlapping) sub-groups: Irrigators, livestock farmers, trespassers, and local government (Figure 3.2). These will be treated in more detail in the section below.

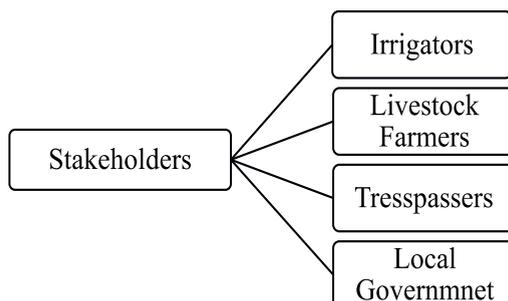


Figure 3.2 Stakeholders in the three SSIs

3.5.2. Livestock Farmers' Perspectives

Livestock farmers (LFs) in Ejersa and Boye claim that irrigation schemes are in the middle of their grazing areas (figures 1a and 1b) whereby land now included in the irrigated command area used to be grazing area. During the upgrading of Ejersa and Boye schemes, responsible government officials made an agreement with LFs regarding measures to facilitate the safe use of irrigation water for livestock. The regional office agreed to construct cattle-troughs in the canal and a bridge to facilitate safe livestock movements in exchange for the LF's consent for the irrigation system construction on their land. The agreed measures implicitly indicate that livestock was expected to drink from the canal. However, at none of the schemes the promised cattle-throughs or watering points were constructed. In response LFs felt cheated and even tried to sabotage the construction of the irrigation scheme, to no avail.

The broken promises and the denial of formal access to the irrigation water led to the absence of ownership feeling among LFs, lack of cooperation for irrigation maintenance and unwillingness to consider measures to reduce the negative effects of livestock roaming. For example, to facilitate livestock drinking, a common practice among livestock farmers is to put local materials in the canal to block the flow and raise the water level. The herders who construct the blockage never remove the material once the cattle have had its fill, thus disturbing irrigation water supply and, inadvertently, creating local hubs for sediments to accumulate.

Livestock owners who have both irrigation and grazing land in the same system act as silent observers. They neither discuss the problem caused by their livestock nor the infrastructure damaged by the livestock. In the Focus Group Discussion in Ejersa and Boye schemes, they stated they were afraid to be taken to task by either irrigators who do not own livestock or

the livestock farmers who do not use the irrigation scheme. Even though they benefit from both resources, grazing land, and irrigation system, they feel trapped in between. Hence, they prefer to remain silent and contribute for canal maintenance as an irrigator and participate in activities of the livestock association.

3.5.3. Irrigators' Interests

Until the schemes were modernized/upgraded by the government, irrigators and livestock farmers in the Boye and Ejersa schemes managed to come to mutually agreed arrangements. The original users in traditional schemes had formed *Abba Melka's* (committee of elders). The latter maintained a user's list based on either the farmer's labour contribution during the development of the original scheme or a monetary joining fee for compensating users' efforts to keep the scheme functional. This contribution formed the basis to acquire a water use right (A. Bolding, Post Uiterweer, & Schippers, 2010).

Once the irrigation infrastructure in Ejersa and Boye 1&2 had been upgraded by the government, the schemes were transferred to the irrigators to use it as a common pool resource and share the burden of operation and maintenance. To become acknowledged as official irrigation scheme, the District Office instituted a new structure of water users' association (WUA or *Korrei*) headed by seven executive committee members. The WUA and the listed members were formally recognized by the district office as the rightful irrigation users. In the Ejersa scheme, soon after completion of the modernization works new members were registered as a water user based on their inclusion in the newly extended command area. In the Boye 1&2 merged scheme, no new members were added due to the limited water supply. By organizing WUAs it was hoped that irrigators would perceive the irrigation schemes as their own and take responsibility to maintain and sustain by regularly removing accumulated sediments and repairing damaged canal banks. In both schemes, the irrigators are deemed as the only water user having the formal right to use the irrigation system and livestock farmers are blamed for regular livestock intrusion in the irrigation system.

In 2018, the Ejersa WUA attempted to communicate with the LFs to reduce the livestock-irrigation interaction with the help of elders from the neighboring villages. However, the LFs without land in the irrigation system could not see the benefit from limiting cattle movement. On the contrary, they claimed the irrigation canal was constructed through their grazing area and blamed the lack of promised cattle throughs to be beyond their remit. Taking their livestock elsewhere to water would involve more work at zero-benefit.

3.5.4. Trespassers

Trespassers are another group of stakeholders (figure 3.2) who do not have a formal water use right. There are two ways in which trespassers can nevertheless make use of the modernized irrigation schemes. One way is through the arrangement made by the WUA in Ejersa; if a farmer has land in different locations in the water course within the same

command area, s/he can choose for which one of his plots s/he can use irrigation each year, but s/he can only irrigate one plot. However, s/he is required to inform the WUA before the irrigation scheduling is made. This is the reason that opens the door for the trespassers to use the irrigation scheme for grazing. Some farmers use this opportunity to steal water even though they are a registered member, and they will be fined when caught. However, the fine is small relative to the benefit.

The second way in which trespassers can make use of irrigation relates to the way livestock farmers acquire the right to grazing land. An informal rule allows the LFs to inherit the user right to a specified section of grazing land and pass this to the next generation. In Ejersa and Boye schemes, the LFs who inherited the right and may not live or irrigate in that specific area can still use the grazing land. They move their livestock to the grazing land and move them back home at night. This is how livestock farmers who irrigate in several or different irrigation schemes and LFs who use rain-fed agriculture maintain access to the grazing land. The LF who has the right can have as much livestock as s/he can afford and graze them with no specific limitation imposed on him/her.

3.5.5. District Office

In the case study area, the District Office pays far more attention to irrigation development than livestock production as testified by recent efforts to upgrade the Ejersa and Boye 1&2 irrigation schemes and recognize the irrigators as their rightful users. The district office maintains regular communication with irrigators. The irrigators and WUA executive committee interact once or twice monthly. During their meeting, they discuss the status of the Scheme, the problems they encountered, and they identify or develop viable solutions, and address any other issues that are raised. The irrigators and the District office interact with each other through the WUA committee. The committee works as a communication platform for the district office, presenting issues and questions raised by the irrigators to the responsible government agencies, though in practice their questions are rarely answered by government agencies.

3.6. Institutional Structures Governing Land and Water Resources

There are three common resources relevant to the livestock-irrigation interaction: the irrigation schemes; the grazing land, and the river and riverbeds. For all three separate collective governance arrangements apply.

The WUA is responsible for operation and maintenance activities of the irrigation schemes in the study area. Their biggest challenge is organizing maintenance, particularly removing deposited sediments from the canal. Different parties' abstract water from the irrigation canal: irrigators, livestock, livestock farmers, and trespassers. Yet the WUA rules and regulations do not apply to all these uses and users. The WUA lacks the power to enforce measures to regulate livestock movement and prevent damage caused by livestock. They

cannot exclude non-irrigators from accessing canal water. Even for the livestock farmers who are also irrigation member, the WUA cannot prevent or punish actions that lead to infrastructure decay.

Similarly, the Livestock Farmer Associations (LFA) manage the grazing lands in Ejersa and Boye SSIs. The LFA aims to manage the grazing land, increase the stock feed growth, and safeguard livestock against any danger (injury and death of livestock being stuck in the canal while drinking). The LFA group the livestock in various paddocks of the grazing area and rotates the livestock herd over different sections. However, livestock is unpredictable and often too restless to stay in the designated areas. The habit of free grazing and the absence of fences results in ineffective grazing management practices. Further, unrestricted access has resulted in overexploitation of the grazing land (Gebremedhin et al., 2004).

The management of livestock grazing in riverbeds does not fall under the LFA nor WUA mandate. The riverbed is not managed by any formal or informal institution, except in the case of Ejersa SSI. Along the Ejersa river, there are 21 traditional and modern small-scale irrigation schemes which make use of its waters, with Ejersa SSI being the fifth scheme counted from the upstream end of the river. These 21 schemes have formed a general committee that has the responsibility of ensuring a fair water distribution of the river water. Even though these committees have the responsibility of managing the river water, their focus has always been on inter-scheme water allocations. They have so far not been capable to control the tress-passers, nor have they expressed an interest in doing so.

The three resources (irrigation system, grazing area and the river) are governed by separate user-based institutions that hardly overlap in terms of institutional membership. None of these institutions engages with irrigation-river-livestock interactions, thus allowing boundary zones where livestock can freely maraud. The burden of damage caused by livestock squarely falls on the irrigators. The position of livestock farmers is similar to that of free-riders: they use a resource (water) without having to sustain it. As (Ostrom, 2010) argued different user groups is a serious deterrent to successful collective governance. In addition, the absence of co-ownership for livestock farmers inhibits collective management.

The problems occur at the physical *and* institutional boundary of the grazing area and irrigation system. Since both the WUA and the LFA lack institutional coverage to sanction or penalize the free-riding behaviors of livestock, the users of both institutions look at the responsible government office to step up on solving the problems (joint FGD December 2019).

3.6.1. The Role of the (Local) Government

The district office is aware of the problem. However, its officials claim they cannot solve the issue of free-riding livestock because there is no assigned body at District level that deals with boundary-crossing problems, even though both the WUAs and LFAs are linked to the district irrigation development office, thus making it indirectly responsible. The district office has so

far absconded its responsibilities, believing that users who are part of the same community are better situated to resolve this issue. Facing staffing and budget constraints, the district officials argue they can only address problems when they acquire a specific budget and institutional mandate (District officer interview December 2019).

Governance of SSIs at District level has been subject to fragmentation, prevalence of top-down approaches and frequent changes in both policy and placement within different Ministries. As a result, there is a lack of coordination and a low level of participation and consultation (M. Yami, 2016). On top of that, reforms have mainly focused on the redesigning of policy documents and restructuring of authorities and not on how to reform the internal organizational/institutional contexts to fit with the plan or vice versa.

Resource users feel part of the institutions governing each resource but dealing with resource access cutting across these various institutions proved difficult. Even with dual members, who had a stake in two resources at the same time, it was challenging to initiate the conversation towards a negotiation. Moreover, the WUA's requests to the district office to help resolve the issues fell on deaf ears (FGD, Waliso, December 2019).

3.7. The Livestock-Irrigation Conundrum – The Missing Link in the Sedimentation Debate

One of the biggest challenges affecting the performance of SSI schemes is linked to canal damage, sedimentation, and the corresponding maintenance burden, caused by different livestock owning farmers. Some of these farmers are members of the affected irrigation scheme itself. What keeps the different actors from coming up with an effective response to the livestock-related challenges?

3.7.1. Top-Down Planning

Informants in the study schemes blame the ineffective response to the livestock-irrigation conundrum on the prevailing top-down approach to irrigation development. The planning and implementation of the SSI projects do not address the concerns of the local community through their active involvement. For instance, issues related to the suitability of the design for cleaning and maintenance, and the trajectory of irrigation canals might cause conflicts within the community. Concretely this may concern the construction of cattle-throughs along with the irrigation canal network or passages where the livestock can safely cross without pushing sediment into the canal. Furthermore, even in livestock dense areas, water demand calculations for scheme design and management does not consider livestock water demand. All these concerns have not been taken up in the design of Boye 1&2 and Ejersa irrigation systems. The infrastructural design was made only from the irrigation perspective, ignoring the interaction with livestock. Even after commissioning the newly rehabilitated (upgraded) irrigation schemes these concerns, while expressed, were not addressed, reflecting a design

culture that ignores the concerns of the actual users and owners of the irrigation schemes once the project's construction has been finalized.

Most of all, the top-down style and sectoral approach of planning and implementation of SSIs by various responsible government agencies hinders addressing inter-sectoral needs and undermines a sense of co-ownership and co-responsibility among users, thus precluding the development of solution pathways that could deal with the negative effects of livestock movement and watering. This finding is confirmed by literature which articulates a lack of pluralistic approaches (Habtu & Yoshinobu, 2006) and lack of integration of users' knowledge and concerns in SSI design (M. Yami, 2016)

3.7.2. Rigid Designs Ignore Users' Needs and Concerns

Even when users explicitly protest certain upgrades, their needs are rebuffed, as transpires from a key informant's description of the planning and construction of the case study schemes:

"The regional Government prepares the plan, provides a framework, and consults the relevant District experts when inputs are needed. Plans are prepared in a top-down manner, and the space given to the District and Kebele officials is that of informants to be consulted. In Ejersa, and Boye 1 and 2 SSIs, the Kebele office was contacted only for informing irrigators about the project. When the irrigators and livestock farmers refused the modernization of their irrigation Schemes (particularly irrigators of Boye-1 scheme and livestock farmers of Ejersa), the Kebele office was contacted again to negotiate between the irrigators, livestock farmers, and regional government office for their plan to proceed. Ultimately, the regional office promised to build additional components, such as cattle throughs, and a bridge, which had not been included in the original design. Yet, at the end of the day, these were not constructed" (Former dembeli-keta kebele Chairperson interview, Waliso, November 2019).

This lack of downward accountability on SSI project planning is compounded by the limited efforts at comprehensive capacity building of project staff, and the tendency to recruit under-equipped construction companies for implementing rigid designs, as transpires from the interview cited below:

"The weak capacity of the study teams and engineers who design and construct the Schemes, which results in poorly designed irrigation infrastructure are challenges of all studied Irrigation Schemes. The challenge becomes prominent because of the frequent restructuring of the irrigation sector, and the confusion on duties and responsibilities of District office staffs, understaffing of the District offices relative to the irrigation Schemes they should monitor, and missing irrigation system documentation. The SSI project documents often state the necessity of capacity building among District staff. Nevertheless, the higher officials do not facilitate the District/Kebele staff to take training on technical and managerial issues of SSI projects. They do not even consider it as their responsibility.

Most times, all the project money was used on project implementation without capacity building. Hence, the staff starts implementation without understanding the plans,”. (Development Agent interview, Waliso, October 2019).

3.7.3. Institutional Limitations

Besides these weaknesses in the design and construction of modernized SSIs, the relationship between the various government agencies, such as the Development Agent, District, and *Kebele* officers, and the WUA is highly political. The pursuit of political agendas using the platform of the WUA reduces farmers' motivation to take part in problem-solving discussions and contribute towards their resolution. The meetings held on the government's political and development agenda often last long, and farmers who participate in the meeting have limited time for raising SSIs problems. As a result, farmers are less interested in the meeting. Most of them do not even show up for the meetings anymore.

Finally, the issuing of standard by-laws for WUAs of modernized SSIs to administer, without user consultation, directly violates several of Ostrom's design principles for successful collective governance of CPRs. The Ejersa WUA chairman claimed that the absence of formal or informal institutions that can be enforced to all stakeholders makes it difficult to control the non-rightful users of the Scheme, and the irrigators (WUA) committee can't take any action against the free riders as they have neither authority over them nor the enforceable rules (WUA chairperson interview, November 2019). This confirms (Baggio et al., 2016) findings that all commons are likely to be non-successful when cognitive principles, accountability of monitors, and gradual sanctions are absent. Including livestock farmers as a separate sub-committee, with specifically drafted by-laws addressing the right to move across canal infrastructure and watering livestock from canals, would go a long way to make sure that cross-cutting livestock and irrigation uses are addressed. The latter would address the boundary problem that is caused by each resource having its own property arrangement and collective monitoring institution, leaving overlapping resource use at the discretion of a non-responsive District office. Successful irrigation-livestock interaction in traditional schemes

The example of Kulit traditional irrigation scheme, albeit at a much smaller scale, provides a refreshing contrast, where irrigators and livestock farmers have drafted mutually agreed resource sharing arrangements that reduce the damage created by livestock (though they have not constructed cattle throughs or bridges to facilitate this). This traditional scheme, which is not recognized by the government, was established by farmers from a modern SSI that was abandoned due to sedimentation and maintenance problems. There are no formal rules that declare who may use Kulit SSI. It is used informally by those users who displayed an interest in continuing irrigation and proved willing to contribute labour to construct the diversion structure and be involved in operation and maintenance of the newly established Kulit scheme. The users have formed a group and are open to registering new members,

especially to reduce the maintenance burden (FGD: Kulit traditional scheme, Ameya, January 2020).

Most irrigators own livestock which they graze near the scheme. They are neighbors and share membership of one or more social groups, like '*Idir*' (burial gathering) '*Mahber*' (religious associations), and '*Équib*' (rotational saving) clubs. As a result, unlike the users of the other schemes, they do not see themselves separately as LF and irrigators. The livestock that grazes around Kulit can use the scheme for drinking (interview: *Kulit* traditional scheme WUA committee, Ameya, January 2020). In this scheme, we can observe that the small number of users and adequate water supply is key in bringing users together in a closely-knit community, avoiding conflicts between irrigators and LFs.

This result may be explained by the fact that, most irrigators and livestock owners are the same people who established and use the same scheme. Having smaller user community with adequate water resources could also be the other key reason in bringing users together in a closely-knit community, avoiding conflicts between irrigators and Livestock-Farmers. Another possible explanation for this is that the rest of the abandoned scheme (Meri-Megari) is under-utilized. It offers a grazing area for their livestock lacking the degree of overstocking and suffering that affects the other schemes. Furthermore, there is no intervention by the government that disturbs their mutually agreed arrangement, thus allowing them to avoid the conflict and negative effects of livestock interaction.

3.8. Conclusion

Irrigation-livestock interactions produce both positive and negative effects. Livestock improves the farmers' livelihood in many ways; however, their interaction with irrigation is a main cause of sedimentation before and especially, during the irrigation season. Livestock in irrigation systems often cause overgrazing, erosion and sedimentation in intakes and canals. Irrigation activities often coincide with higher livestock numbers. At the same time, irrigation systems are often constructed in grazing areas and canals cut through cattle access routes to the river. This potentially leads to conflict.

The top-down style and sectoral approach of planning and implementation of SSIs by various responsible government agencies inhibits addressing inter-sectoral needs and undermines a sense of co-ownership and co-responsibility among users, thus precluding the development of solution pathways that could deal with the negative effects of livestock movement and watering. Furthermore, in making top-down interventions in irrigation systems, livestock-irrigation interactions are insufficiently considered, leading to aggravated conflicts. Issuing of standard by-laws for WUAs of modernized SSIs to administer, without user consultation, directly violates Ostrom's design principles for successful collective governance.

Frequently proposed solutions to address sedimentation problems caused by livestock do not work because they do not address underlying conflicts between irrigators and livestock

farmers. The irrigation infrastructure design was made only from the irrigation perspective ignoring the inter-dependence of the livestock and irrigation system. It reflects a design culture that ignores the socio-cultural context and concerns of the actual users and denies irrigators to come up with their own technical/design solution to mitigate the negative effect of the interaction.

An appropriate institutional framework to address irrigation-livestock interactions is not in place. The WUA is for irrigators, the LFA is for livestock farmers. They are each organized in their associations. Each resource has its own property arrangement, but these cannot deal with the overlap of resource use at the boundaries. Even when single appropriators are member of two or three institutions, they tend to evade penalization or monitoring of the use their livestock makes or damage it causes. The absence of cross-cutting (in)formal institutions that can police the resource use of all stakeholders makes it difficult to control the non-rightful users in both Boye and Ejersa schemes. The WUA committee is powerless against the free riders from accessing water as it falls outside their jurisdiction. However, in Kilit traditional scheme, all users are collectively co-operating because of their strong ownership feeling for the scheme they established and the smaller numbers of members with adequate water. Their successful, though informal, collective action manages to supersede the artificial institutional boundaries that constrain formalized institutions for collective action. While it seems that both WUA and LFA are properly nested in other governing networks, like the district office, as stipulated by another of Ostrom's design principles, in practice the top-down and compartmentalized way of dealing with resource use precludes effective collective action to control irrigation-livestock interactions. Hence our talk of a missing link.

The persisting problem of sedimentation, irrigator-livestock farmer conflicts in SSI in Ethiopia, has induced the need for strategy development and recommendations for dispute resolution.

3.9. Recommendations

3.9.1. Options to Moderate the Interaction Effect in the Short and the Long Run

Over time, engineers and administrators have cracked their heads over devising sustainable solutions to address the negative effects of livestock-irrigation interactions. The mitigation measures that are going to be introduced in the future should be in consideration of both resources management, irrigation system and grazing land. Our main recommendations focus on two points.

The newly developed projects and rehabilitation of existing schemes could emphasize alternative practical measures for better herd and farming management that consider all potential users of the common resource. This could be done by either creating a platform superseding the WUA and LFA, or by including livestock farmers as a separate sub-committee on the WUA, with specifically drafted by-laws addressing the right to move across canal infrastructure and water animals from canals. Such inclusive arrangements would go a long

way to make sure that cross-cutting livestock and irrigation uses are addressed. The latter would address the boundary problem that is caused by each resource having its own property arrangement and collective monitoring institution, leaving overlapping resource use at the discretion of a non-responsive District office.

During the design of new and upgraded SSI systems, it is important to consider the inter-sectoral needs of both irrigation and grazing systems. The design could include the concerns of the actual users (irrigators and livestock farmers), local knowledge and consider the socio-cultural context of irrigation and consult both irrigators and livestock farmers and account for their interactions.



4

CHAPTER 4.

Key Factors Influencing Farmers' Willingness to Maintain Small-Scale Irrigation Systems in Ethiopia – Going Beyond Ostrom's Design Principles for Successful Collective Action

This chapter is based on:

Dessalegn H.T., Bolding A., Fraiture, C.d., and Ayana, M.

Key factors influencing farmers' willingness to maintain Small-Scale Irrigation systems in Ethiopia – going beyond Ostrom's design principles for successful collective action

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4. Key Factors Influencing Farmers' Willingness to Maintain Small-Scale Irrigation Systems in Ethiopia – Going Beyond Ostrom's Design Principles for Successful Collective Action

Abstract

This paper analyses the sustenance or collapse of collective action of multi-use small-scale irrigation (SSI) systems by studying the willingness to maintain four specimens of sedimented SSI schemes using an analytical framework that applies contextual rather than generic principles in a process-oriented manner. We actively engage with a socio-technical approach that focuses on the interplay between water, technology, and social actors benefitting from and governing SSIs. This study aims to show that the concept of Farmers' Willingness to Maintain (FWM) better explains the sustained operation of SSIs than a singular, snapshot analysis using either Ostrom's (1990) eight institutional design principles or Coward's (1986) hydraulic property relations framework. Data were collected from June to October 2018 and from September 2019 to February 2020. We used in-depth interviews, focus group discussions, and sedimentation data. Even though Ostrom's design principles and Coward's hydraulic property analysis shed light on farmers' willingness to collectively maintain their SSI system, our study has highlighted complementary, contextual factors that help determine the time when SSI schemes are abandoned or sustained. We found four key factors affect FWM either positively (+) or negatively (-). These are (1) dependency on irrigation production (+); (2) Enhanced organizing capability of Water Users Association and shared membership in various local institutions (+); (3) Sophisticated technological design (-) and construction of infrastructural elements that deal with sedimentation (+) and (4) High Sediment load (-). We conclude that further studies should bear out what other contextual factors may affect farmers' willingness to maintain their gravity canal SSIs and when a tipping point may be reached.

Keywords: Farmers' willingness to maintain, Multiple-use, Small Scale Irrigation, Collective action, Institutional design principles, Hydraulic property, sedimentation, Ethiopia

4.1. Introduction

Small-scale irrigation (SSI) plays a big role in local livelihoods and the rural economy in Ethiopia. Yet, several studies show that the performance of particularly small and medium scale irrigation schemes is poor (Dejen, Schultz, & Hayde, 2012; Kassie, 2019), with some of them being abandoned shortly after construction or rehabilitation (S. B. Awulachew & Ayana, 2011). Excessive sedimentation in the headworks and canal network and a lack of funds and labour for operation and maintenance are singled out as key causes (S. B. Awulachew & Ayana, 2011; Kidane & Alemu, 2015).

The government, facing budgetary constraints, adopted various programs to transfer the responsibility for managing and maintaining irrigation infrastructure to farmers organised in Water User Associations (WUA) (Gebul, 2021; Kiprop, Mulungu, Kibet, & Macharia, 2017). To sustainably manage irrigation systems, property rights play an important role, especially when the resources are scarce, users compete over the resources, and conflicts arise over rights (ownership), duties, and responsibilities (Otsuka & Place, 2001). (Coward 1986) hypothesised that in constructing irrigation infrastructure, farmers transform and reinforce their social relationships and establish property relations. These so-called 'hydraulic property' rights are essential for the maintenance of irrigation infrastructure. In contrast, (Ostrom, 1990) explored under which circumstances users of common-pool resources without clearly defined property rights are willing to collaborate for sustainable management. The author defined eight institutional design principles for enduring, self-organized irrigation systems (listed below). Many studies of irrigation schemes use Coward's hydraulic property principle (Coward 1986; Hanemann, 2014; Meinzen-Dick, 2014) or Ostrom's institutional design principles (Baggio et al., 2016; Jelsma, Slingerland, Giller, & Bijman, 2017; Ostrom, 1993) to explain the WUA ability -or inability- to maintain their irrigation system. However, neither Coward's nor Ostrom's framework can fully explain when farmers renounce on an irrigation system that is subjected to heavy sedimentation. When do systems collapse, and why? We believe an analogy can be drawn with the concept of tipping points as used in studying the effect of climate change on socio-ecological systems (Lenton, 2020; Van Ginkel et al., 2020). At some point, the collective action that ensures sustenance of the small irrigation system collapses.

We propose to study this by operationalizing a new concept: Farmers' willingness to maintain the system (FWM). By using such a concept, one can stretch the analysis of the governance of common-pool resources, such as small-scale irrigation systems, beyond a simple checklist of assessing the eight design principles of Ostrom or reconstructing property relations as Coward would have us do. Rather, we propose to analyze sustenance or collapse of collective action not only for irrigation water use as Ostrom and Coward propose, but also for livestock and domestic use as a multiple-use irrigation system that is subject to contextual rather than generic principles. There are different uses of water and different factors, like technology, that inhibit collective action around maintenance. We actively engage with a socio-technical approach that focuses on the interplay between water, technology, and social actors

benefitting from and governing SSIs. Obtaining information on factors influencing farmers' collective willingness to maintain is important to identify the tipping point beyond which the farmers decide to stop maintaining their system at the individual and collective level. This study aims to show that Farmers' Willingness to Maintain (FWM) better explains the sustained operation of SSIs in Ethiopia than a singular, snapshot analysis using either Ostrom's eight design principles or Coward's hydraulic property relations framework.

The innovation in this paper is that we propose an alternative framework that helps understand the abandonment of SSI systems by understanding the process of governance in action. To do so, we examine four case study schemes by using Ostrom's eight design principles to understand to what extent these principles can assess the actual condition of the case study schemes, the farmers' willingness to maintain SSI, and scheme abandonment. Before this assessment, we give a brief description of the study area, our methodological approach, and an outline of both Ostrom's and Coward's theoretical frameworks. After demonstrating the limitations of Ostrom's framework, we identify additional factors that help describe and analyze farmers' willingness to maintain the studied SSIs. Finally, we conclude with an explicit treatment of the key factors that influence the willingness to maintain, which we believe offer new avenues for both policy makers and researchers to explore and prevent the collapse of SSIs due to increased maintenance burdens in both Ethiopia and wider Africa.

4.2. Material and Methods

We selected four SSIs in south-west Shoa zone, central Ethiopia, that vary in size, membership, construction history and sediment loads (see figure 4.1). As a general methodological approach, we used a "follow the water" principle to identify the water users and their networks, and to map all relevant infrastructure and institutions. Participants for a qualitative interview were selected using a purposive and snowball sampling technique to identify the key informants from the head, middle, and tail-end water users. We gathered data during two periods: from June to October 2018 and from September 2019 to February 2020. Open-ended and semi-structured in-depth interviews were conducted with older farmers, the WUA committee members, irrigators, livestock farmers, engineers, and relevant government officials. The number of interviewees was expanded until the collected information reached a certain saturation level, where no new insights could be collected beyond the ones that had already been expressed. Field observations provided first-hand information on the schemes' operation and maintenance practices. We gathered secondary data from the district and a regional office that have had a stake in the respective schemes, and we conducted nine focus group discussions on the topic with 6-8 participants in each session.

We interviewed 75 persons in total, of whom 12 officials (development agents, managerial officials, and engineers). Among the users of the four schemes, we interviewed 18 women and 45 men farmers, spread across the head, middle and tail-end, with some of them acting as WUA committee members. The age of the respondents ranged between 14 and 79 years.

Interviews were translated and transcribed. The qualitative data analysis was conducted after repeatedly reading each transcription line by line. Field notes and observations contributed to triangulate findings and interpreting the results.

4.3. Description of Study Area

In Ethiopia, small-scale irrigation schemes are divided into different categories based on their establishment, management, and nature of the structure. In traditional irrigation schemes, the intake weir is made of an earthen material that needs annual maintenance and is managed by the community. Modern schemes have a permanent diversion weir, and the primary and secondary channels are made of concrete that do not require annual maintenance and are mostly managed by the community. Modernized or upgraded schemes comprise traditional schemes which were improved with more permanent intake structures and concrete (lined) canals after certain years of service, before being handed-over to a formally constituted WUA (Haile & Kasa, 2015).

For this study, we selected four small-scale irrigation schemes in the Southwest Shoa zone in Ethiopia (Figure 4.1). Details on the four schemes are summarized in (Table 4.1). Ejersa SSI scheme is a traditional scheme on the Ejersa river managed by the local community. The WUA (*Aba Bishani*) handles operation and maintenance. It is a heavily sedimented scheme that is located across two kebeles (the lowest administrative unit in the country), Dembeleketa and Bedesa Koricha.

The second scheme, Boye-1 and 2, started as two separate traditional SSI schemes which were merged and upgraded by the government without the irrigators' consent. They share the main canal that bifurcates into two secondary canals. The modernization entailed improvements to the new main intake and the lining of the main canal. This scheme was selected as representative of lightly sedimented schemes. The present scheme comprises two parts: Boye- 1 providing water to 56 households and Boye-2 providing water to 65 households, irrigating a total command area of 56 hectares.²

The third scheme Meri-Megari was constructed in 2000 with Government support as a modern SSI but has been fully abandoned since 2017. The main causes of its abandonment are sedimentation and excessive seepage loss along the canal. Before abandonment, it comprised 200 hectares of command area providing water for 234 households.

² In the result and discussion section we used boye 1, boye 2 and boye 1&2 merged schemes separately and together as needed to show the actual condition of irrigation governance among these users' group.

Lastly, the Kulit traditional small-scale irrigation scheme was initiated and constructed by the same farmers who were previously using the Meri-Megari modern scheme until its abandonment. Kulit traditional diversion was constructed at 5.3 km downstream from the Meri-Megari abandoned scheme. It comprises 17 hectares of command area providing water for 29 households.

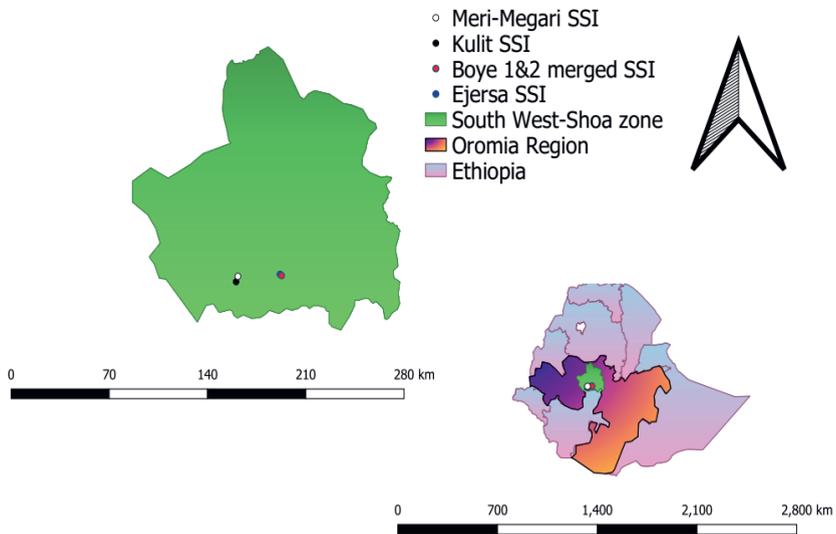


Figure 4.1. Location of the study area with the Four Case-Study Irrigation Schemes. Source: Hanan Tadele, 2021.

Table 4.1. Background information on selected small-scale irrigation

Irrigation Schemes		Boye 1 & 2 merged scheme	Ejersa scheme	Kulit scheme	Meri-Megari
Location	Distance from Addis Ababa (km)	114	110	151	158
	Average elevation (masl)	2120	2123	1834	1902
Type of Scheme		Upgraded	Upgraded	Traditional	Modern
Canal characteristics		partially lined	partially lined	un-lined	Mostly un-lined
Year of construction		1976	1960	2019	2000
Year of rehabilitation		2013	2013	NA	NA
Command Area Hectare (ha)		56	96	17	200
No. of official irrigators		121 beneficiaries	120 beneficiaries	29 beneficiaries	234 beneficiaries
Water Sources		Boye River	Ejersa River	Kulit River	Kulit River
State of the Scheme		Lightly sedimented	Heavily sedimented	Lightly sedimented	Heavily sedimented
Maintenance/labour requirement		3 times a year	8-9 times a year	3 times a year	NA
Status of the schemes		Partially functional	Functional	Functional	Abandoned since 2017

4.4. Results and Discussion

In this section, we first assess the schemes' performance using Ostrom's design principles and Coward's hydraulic property frameworks to test these conceptual frameworks on their empirical validity. Next, we discuss several key factors, comprising willingness to maintain, that better explain the functioning of the four study schemes.

4.4.1. Application of Ostrom's (1990) Design Principles

Design principle 1: clearly defined boundaries of users and resources

On paper, the irrigated area in all four schemes is demarcated by engineers hired by the government based on the trajectory of the canal and water use right given to irrigators. WUAs control and monitor the allocation and distribution of water within that specified boundary. However, the WUAs have neither the power nor regulatory framework to exclude free-riders, like livestock owners without irrigated plots, because of the lack of an effective exclusion rule that can apply to all stakeholders or a mechanism like a fence to stop the free rider, domestic users and livestock. The resource boundaries were not clearly defined nor observed in all studied SSIs.

Design principle 2: proportional equivalence between benefits and costs

In both Ejersa and Boye irrigation schemes, all acknowledged users have a water right to irrigate 0.25 ha. Irrigators pay user fees to cover administration, operation, and simple maintenance costs. However, the labour they contribute to irrigation system cleaning is not equally proportional for all users. The tailenders in these schemes contribute more labour to clean the entire canal than middle and head enders for the same quantity of water or less. The head enders clean only the main canal, and the middle users clean up to the midpoint (location of their farms). Hence, maintenance duties increase with the distance of one's plot from the source. In contrast, the Kulit scheme farmers can irrigate without water limitations. The users are few and the water supply is adequate. The way they contribute labour for maintenance is the same as described for the above schemes. However, their benefits outweigh or are equivalent to their cost in labour contribution.

Design principle 3: collective choice arrangements

All schemes except Kulit have been constructed or rehabilitated by the government but are currently operated and managed by users. The written by-laws were drafted by the government. Farmers in the Ejersa scheme ensured the participation of most users in adapting their rules and by-laws to fit the current situation in 2019. However, government agents still interfere with the exact implementation of those rules while pursuing their political agenda. This reduces the farmers' motivation to participate in problem-solving discussions and negatively affects their contributions towards their resolution. In contrast, in the Kulit scheme, an unregistered traditional scheme, the by-laws were written by the users themselves and they are free to make any change as they see fit. For this scheme, the collective user management is observed.

Design principle 4: monitoring

The users or those accountable to users should monitor the scheme's physical condition and users' behaviors and observe/administer penalties on rule-breaking behaviors. In three of the schemes, it is done by the farmers and WUA and occasionally by woreda officers. Many users

in modernized SSIs feel that government plays a key role in enforcing WUA rules (also since these rules/by-laws have been imposed by the government). In such instances monitoring and enforcement is no longer done by users themselves, while the government does not have the manpower and budget to undertake the task. Kulit SSI provides a contrast in the sense that the government does not recognize the scheme and its locally drafted by-laws, and hence user-based monitoring and enforcement works well, as observed in DP 4 by Ostrom.

Design principle 5: Graduated sanctions

In all irrigation schemes graduated sanctions are described in the written by-laws with the level of sanction varying per scheme. However, its implementation is poor.

Design principle 6: conflict resolution

All irrigation schemes have included conflict resolution mechanisms in their by-laws. Most users are part of a common social institution where they get together, interact, and discuss their problems. The latter institutional rules are more effective in resolving conflicts than the rules written in the by-laws. However, in Boye SSI conflicts are not easily resolved despite the written conflict resolution mechanism in their by-law because the quarrelling user groups live in different villages with different informal institutions and are unwilling to share the irrigation system. The government officials simply imposed their decision to merge the two systems. As a result, their conflicts remain unresolved. The conflict resolution mechanism is not rapid and accessible at low cost particularly in Boye 1 and 2 merged schemes.

Design principle 7: minimal recognition of rights to organize

In both Ejersa and Boye upgraded SSI and Meri-Megari modern scheme, issuing standard by-laws for WUAs to administer, without user consultation, directly violates this design principle. However, in Kulit traditional scheme, farmers have full right to make a rule or make a change as they see fit, and this is not challenged by external government authorities since the scheme is not recognized and acknowledged by the government.

Design principle 8: Nested enterprises

Nested enterprises exist for all schemes partially. In Boye merged SSI, the user groups are divided into two user groups, each with their own committees responsible for the management of the canal in their area. However, the overall management is poor and there are no nested enterprises with outside agencies, thus hampering the management of the scheme. In contrast, in Ejersa scheme, the secondary and tertiary canals are each managed by different groups of farmers under the WUA. The nested enterprises structure in Ejersa scheme helped to keep a tab on each farmer's participation. However, the nested enterprises are only available for the irrigators, not for other users like livestock holders, organized in Livestock Farmers Associations. As a result, the nested enterprise principle applies only partially. In Kulit tradition small scale irrigation scheme, the secondary and tertiary canals are each managed by different groups of farmers under the WUA as well. In this scheme, most of

the irrigators are the livestock farmers, hence, we didn't see the difference in the water use interest as we observed in other schemes. The nested enterprises are available for the irrigators and livestock farmers. In Meri-Megari scheme. The secondary and tertiary canals are each managed by different groups of farmers under the WUA. However, the management is poor. The nested enterprise is partially available only for irrigators not for livestock holders and with outside agencies.

Table 4.2 Summary of Ostrom's Design Principles applied to the Study Areas

S/N	Principles	Meri-Megari	Ejersa	Boye 1 and 2	Kulit
1	Clear boundary of users and resources	Not clear	Not clear	Not clear	Not clear
2	Proportional equivalence between cost and benefit	Imbalance	Moderate	Imbalance	Good
3	Collective choice arrangements ³	Poor	Moderate	Poor	Good
4	Monitoring	Poor	Poor	Poor	Good
5	Graduated sanctions	Poor	Moderate	Poor	Moderate
6	Conflict resolution	Good	Good	Poor	Good
7	Organizational legitimacy	No recognition	No recognition	No recognition	Good ⁴
8	Nested enterprises	Poor	Moderate	Poor	Good

4.4.2. Evaluation of Ostrom's Principles

Part of Ostrom's design principles apply to all the case study schemes. Yet, while the Ejersa scheme performs relatively better in terms of collective action, it lacks applicability of certain principles. If we look at the Boye scheme and Meri Megari schemes, the assessment result based on Ostrom DPs (Table 4.2) is almost the same except for the nested enterprises. However, the Boye scheme is functioning and Meri-Megari has collapsed. Despite the broad applicability of the design principles and the ability to account for and explain the successes and failures of collective action in the study areas, the DPs could not fully account for all the factors that influence sustenance or collapse of SSI in Ethiopian context.

³ Collective choice arrangements being formulated and implemented by the users themselves.

⁴ The rights of appropriators to devise their own institutions are not challenged by external authorities since the scheme is not recognized by the government.

Ostrom's DPs have been used instrumentally by various studies (Baggio et al., 2016; Gari, Newton, Icelly, & Delgado-Serrano, 2017) analyzing user governance of CPRs like SSIs. This is problematic for various reasons: Firstly, Ostrom's principles were never meant to be used instrumentally to assess sustainability of self-governance. Rather, such use leads to snapshot analysis without addressing key factors explaining continuity or collapse of self-governance in the face of adversity. For the latter, one needs an analytical framework that pays tribute to factors that analyze and explain the process of collective governance of SSIs. Secondly, Ostrom uses a rational choice approach which ascribes successful governance of CPRs in terms of incentives for individual actors. It does not analyze the influence of contextual factors (e.g., amount of sedimentation and corresponding maintenance burden), nor does it engage with outside interference with the process of collective governance that engages with use of multiple resources (i.e., water and grazing land).

4.4.3. Coward's Hydraulic Property Rights and Existing Institutional Arrangements

Constructing irrigation infrastructure constitutes a property creation process in a specific location through investments in labour and materials. Through such local investments, property relations are established that spell out governance arrangements for its operation and maintenance (Coward, 1986). In farmer-led irrigation systems, like Kulit SSI, local investors are obliged to maintain their scheme in proportion to the use they make of the water conveyed. In case of outside investment, for instance, by State actors to modernize existing SSIs, there is a high risk of 'property extinction', whereby users no longer experience the obligation to maintain the newly created hydraulic property objects (like a concrete intake and lined canals). To prevent this from happening Coward (1986) recommends a process of indirect investment and recognition of existing institutions, whereby existing property relations are acknowledged, and users invest in their scheme's modernization through funds and expertise that is indirectly availed to them by the outside investor. This requires a bottom-up, participatory 'improvement' approach.

During the construction of Meri-Megari SSI and the modernization and merger of Boye 1 and 2 and Ejersa SSI, the government intervention negatively affected the existing hydraulic property relations of the users. The users' participation in organizing the design and construction activities of these schemes was not more than participating in paid labour works. Using top-down approaches and poor attention given to local knowledge in planning and implementation of the SSI projects resulted in a situation of (partial) property extinction, resulting in poor collective maintenance by the local communities. This result is consistent with the findings of others (Yami, 2016) and reduces the willingness to maintain the scheme on the part of the users.

In contrast, in Kulit traditional scheme, the farmers directly invested labour and money to construct the irrigation scheme and drafted collective arrangements for its operation and maintenance. They have a WUA that organizes the operation and maintenance and reconstruction of the river intake structure every year. Constructing irrigation infrastructure

constituted a participatory property creation process in Kulit scheme and the WUA has crafted clear governance arrangements based on property rights.

In conclusion, government involvement negatively affected the property relations of the users in three of the case studies schemes and such is expressed in the weak or failing collective maintenance performance in those schemes.

4.4.4. Evaluation of Coward's Principle Applied to the Case Studies

Coward's hydraulic property relations analysis does pay attention to the influence of outside actors on the execution of, for instance, maintenance tasks. With hydraulic property extinction through technical interventions (as in the case of rehabilitation and infrastructural improvement by State actors), his theory can explain why collective governance collapses. This provides promising insights for analyzing collapse and abandonment of SSIs in Ethiopia because of excessive sedimentation *after* so-called upgrading/modernization. However, Coward's analytical framework is limited as well, because of its singular focus on property relations, ignoring other potential factors that might explain sustained or collapsed collective maintenance of SSIs.

If we analyse and compare Boye 1 and 2 and Meri-Megari schemes based on Coward hydraulic property relations, we can observe that both schemes witnessed intervention and investment by the Government. However, Coward's hydraulic property theory cannot explain why Meri-Megari scheme has collapsed and Boye scheme has remained operational.

In conclusion, Ostrom DPs and Coward's property theory cannot fully explain when an SSI scheme is about to fail, or when a tipping point is reached when farmers decide to quit cooperating for the process of collective maintenance. Hence, we propose an alternative framework that complements Ostrom's DP and Coward's hydraulic property analysis. This framework highlights the internal and external factors that influence farmers' willingness to maintain SSI at the individual level, as well as at the collective level.

4.5. Towards a New Framework: Farmers' Willingness to Maintain

We propose a framework that comprises a list of attributes that are of key importance understanding when the farmers' willingness to maintain the SSI would become too low, leading to scheme abandonment. Such an understanding needs to go beyond Ostrom's design principles and Coward's hydraulic property relations. Based on extensive interviews with respondents from the four study schemes, our framework highlights the following key factors that affect FWM (Table 4.3); design and construction failure, dependency on irrigation production, trust and organizing capability of WUA's, magnitude of maintenance requirement and farmers capability to maintain the system, hydraulic property relations, social relations, outside interference including Government intervention, urbanization, and ethnic heterogeneity. We raised an open question on which factors would affect willingness to maintain SSI and then clustered and counted the frequency of certain factors being

mentioned by respondents and calculated its percentage. Below we discuss the four significant factors that affect all four schemes which are listed in the first four row of the table.

Table (4.3) factors that influence FWM SSI as per the percentage of the respondents' answer. We discuss the first four factors that have a high percentage of being mentioned for all the schemes. (Source; interviews conducted in 2018 and 2019).

Factors affecting FWM	Boye		Ejersa		Meri-Megari		Kulit	
	No. of Respo ndent	% Of Respo ndent	No. of Respo ndent	% Of Respo ndent	No. of Respon dent	% Of Respo ndent	No. of Respon dent	% Of Respo ndent
Dependency on irrigation production	17	59	24	80	6	35	8	73
Design and construction failure (sophisticated design)	18	62	26	87	15	88	6	55
Trust and organizing capability of WUA	20	69	22	73	13	76	7	64
Magnitude of maintenance requirement and Farmers' capability to maintain the system	21	72	20	67	15	88	4	36
Hydraulic property relations	19	66	9	30	7	41	0	0
Social relationship ⁶	10	34	11	37	4	24	6	55
Outside interference including government intervention	17	59	19	63	4	24	0	0

⁵ The total number of interviewees per scheme including the government officials who gave interviews for all the schemes and counted as 4 interviewees when the vote is categorized per scheme. Hence the sum total of interviewee is great than the actual respondent.

⁶ The presence of high social capital, developed through family lineages and neighbourhood, was an important asset in establishing social institutions. These social institutions are called *Mahber* (religious associations), *Équib* (rotational saving) *Idir* (burial gathering create an environment for the farmers to get along with each other and inspires members to collaborate to foster good friendship or neighbourhoods. The social institutions have a positive influence on farmers' willingness to maintain SSI.

Urbanization ⁷	7	24	0	0	0	0	0	0
Ethnic heterogeneity ⁸	3	10	0	0	0	0	0	0

4.5.1. Dependence On Irrigated Production

The Irrigators' willingness to participate in SSI maintenance highly depends on the level of their dependence on irrigation for earning a livelihood. For instance, Boye 1 is functioning because these users' group highly depends on the irrigation water and their irrigated production. The irrigators have access to small plots, without access to alternative sources of income that can adequately support their family. Their rainfed crop and livestock production is low, while most irrigators maintain large families. The Boye irrigators display a keen entrepreneurial spirit by growing cash crops out of season and collectively marketing their produce by selling directly to the wholesaler (both increasing their returns). The profitability of their irrigated production activities makes Boye 1 farmers willing to invest labour in scheme maintenance, despite existing problems with design and construction of their SSI and enforced cooperation. This finding is consistent with (Okoth & Mbugua, 2018) argument that the people's choice to engage in communal projects is dictated by the benefits that are likely to be obtained through their active participation.

In contrast, Boye 2 scheme users were not using the irrigation scheme during the data collection time (February 2019). The irrigation season had started by the end of September, yet the users didn't clean the canals until February (after the first irrigation season). One of the main reasons for Boye 2 users' reluctance to perform maintenance is that they are not dependent on irrigated production for their livelihood. They have access to large agricultural plots, which they use to produce crops during summer (rain-fed) that provide them with sufficient food and income for almost a year. They have more livestock as an alternative source of income than Boye 1 users. This shows that most Boye 2 users are less dependent on irrigated production than the Boye 1 users. The Boye 2 command area has recently been incorporated in the urban zone of a nearby city, offering many irrigators the opportunity to sell part of their land as residential area for high prices. Thus, urbanisation is a major factor negatively influencing the Boye 2 irrigators' willingness to maintain their scheme. This finding is confirmed by Takayama et al. (2018) who argued that the number of non-farmers or part-time farmers increased with urbanisation, inducing significant heterogeneity among the members of a rural community in Japan. Hence, involving all households in irrigation

⁷ Urbanization has a negative influence on farmers' willingness for instance in Boye 2 scheme. This scheme is close to the city and farmers are selling their land for the residence. Even though it is not sustainable income, it seems to affect their willingness to maintain and use irrigation.

⁸ In Boye 1 and 2 schemes, the differences in ethnicity (equivalent number of irrigators from each Ethnic group) made consensus-building and norm-enforcement difficult. The diversity is the result of new settlers moving to the region. They came from diverse sociocultural backgrounds and share access to a common irrigation system as they were forced to merge without considering the cultural differences, norms and existing institutions. Hence, they have a difficult time self-organizing to govern the scheme.

management became more difficult. Urbanization increased the value of the agricultural land ironically decreasing dependency on irrigated production for generating a livelihood.

The Meri Megari scheme suffered from a heavy sediment load that the farmers could not cope with, leading to its abandonment in 2017. In Meri-Megari scheme, many of the respondents (65%) claimed that their dependence on irrigation was low, which in turn did not help promote their willingness to maintain the scheme, since a design failure made the maintenance burden insuperable (see next section). However, despite the sediment loads in the river and the associated heavy maintenance burden, some users who needed irrigation started a traditional irrigation scheme called Kulit on the same river. This proves they were willing enough to invest the labour for sediment cleaning and irrigation system maintenance, including re-construction of the diversion structure every year. In this scheme, 73% of the respondents claimed they are prepared to commit a huge annual labour investment, because they depend on the income derived from irrigated production, and they do not have an alternative source of income to support their families.

Finally, Ejersa scheme is functioning well despite the heavy sedimentation and design problem of the scheme. Most respondents (80%) showed that they are investing a significant amount of labour for scheme maintenance, because of their dependence on irrigated production for their livelihood. Since Ejersa is the fifth of the 21 schemes that have been constructed along the same river, the scheme suffers from frequent water scarcity. This scarcity of water re-enforces their commitment to clean their canals, so that they lose no more water because of silted canals.

In conclusion it can be observed that the extent to which farmers depend on irrigated production for their livelihood is recognised as one of the key factors for success in collective irrigation management, despite the other challenges, unless they are unable to maintain it as seen in the Meri-Megari case or when urbanisation inflates land prices so much that switching land use from irrigation to housing becomes financially much more attractive.

4.5.2. Design and Construction Failure

Poorly designed systems that inhibit the farmers' maintenance by increasing the burden or financial and organizational demand on the farmers can form root causes for poor operation and maintenance of SSI as supported by findings from Ethiopia and Philippines (Bueno, 2021; Fayisa Ertiro, 2017; Gebul, 2021; M. Yami, 2016). Design faults have been experienced in three of the studied schemes, with Kulit traditional scheme forming the exception.

Particularly in Meri Megari scheme, a major design problem affected the ability of farmers to fulfil maintenance requirements. It ultimately affected their willingness to maintain the scheme, leading to its abandonment. The problematic aspect of the scheme is an inverted syphon which re-crosses the river at a short distance from the intake. It is unclear why such a complicated intake structure was included in the design (alternative means and sites for

constructing a run of the river intake without inverted syphon are available). The inverted syphon is difficult to enter to remove accumulated sediment. Most of the respondents (88%) claimed that their inability to clean the sediment from the inverted syphon is the main reason affecting their willingness to continue maintaining the scheme.

Similarly, in Ejersa and Boye schemes, we observed that the irrigation design for the modernization of those schemes did not include important components like cattle-throughs (preventing sedimentation) that the users insisted on during the design process. The absence of farmer consultations at an early stage of the planning, design and construction of irrigation schemes resulted in Boye 2 SSI not benefiting from an additional water source (spring water) located in the middle of the canal. This spring used to contribute water for the downstream users, especially during periods of scarcity. However, during the upgrading, this source was blocked by the lining of the canal. Hence, the tailenders (Boye 2 users) received less water than they used to, negatively affecting their willingness to contribute labour for maintenance. Since a lack of funds affected the upgrading of both schemes, choices had to be made which parts would be lined. Rather than listening to the users, engineers failed lining of sections where seepage losses and sedimentation accumulation were highest. Instead, those canal sections visible from the road (by visiting officials) were given priority for lining. As a result, 87% of Ejersa and 63% of Boye respondents indicated that the scheme improvement failed to ease their maintenance burden, which in turn negatively affected their willingness to maintain the scheme. These findings are in line with other studies which point at design faults as one of the major challenges of irrigation development and management in Ethiopia (S. B. Awulachew & Ayana, 2011; Dejen et al., 2012; Yohannes et al., 2017).

In Kulit SSI the irrigation scheme was built with local materials, based on the skill of the irrigators themselves. The irrigators themselves designed their scheme and decided on the alignment of the structures. They collectively reconstruct their intake every year in September after the peak flood flow in the river has decreased. The decisions on each issue are made based on communal agreement. Their autonomy in designing, constructing, and maintaining their scheme within the limits of their capabilities and skills results in a high willingness to maintain their scheme. This result is consistent with (Habtu & Yoshinobu, 2006) argument that the traditional irrigation schemes are collectively maintained and operated by the irrigators as they are locally and collectively constructed based on the local knowledge and available resources.

4.5.3. Trust and Organizational Skill of WUA (Working Proactively, Accommodative to other Suggestions and Capable of Running an Organization)

Organizations alone will not influence resource management unless they are active. The extent of collective action and the respondents' answers enables us to differentiate between organizations that have strong and weak leaders as a committee. The interviewed farmers had varied opinions regarding the influence of WUA capability on the collective action,

ranking the extent from moderate to great (Okoth & Mbugua, 2018). In our case study schemes, the farmers' participation in the scheme's management was attributed to the WUA leadership potential that ensured fair and equal treatment of the farmers in the scheme, effective coordination of farmers for collective scheme management despite the difficulty/limitations caused by the by-laws which were written by the government.

The WUA needs to facilitate collective action because maintenance activities require coordination (Morales & Mongcopa, 2008), for example, in calling working days, determining the labour and cash contributions of each person, and monitoring and sanctioning those who do not participate. 73%, 69% and 64% of the respondents in Ejersa, Boye 1 and Kulit schemes respectively claimed WUA capacity has a strong influence on their willingness to maintain. As these committees earned the irrigators' trust over the time, the users had good expectations that these leaders would bring good irrigation management. Hence, the irrigators comply with their maintenance orders willingly. As (Miao, Heijman, Zhu, & Lu, 2015) argued at places where a higher level of social trust exists, communities will also be more willing to act collectively for public goods. Particularly regular maintenance is more likely when there is a strong organisation that makes these issues routine. In the above-mentioned schemes, we observed a high level of collective action relative to the Boye 2 and Meri-Megari schemes. The WUA of Ejersa, a scheme suffering heavy sediment loads, calls for maintenance eight to nine times a year and the farmers comply. The WUA committees of Ejersa and Kulit schemes use existing social institutions to get the maintenance done. These social institutions are called *Mahber* (religious association), *'Équib'* (rotational saving club) and *'Idir'* (burial society). These institutions are common practice in Ethiopia and people join any of the groups willingly and members meet regularly on various social events and are expected to support each other in a good times and bad (Flemmen & Zenebe, 2016). By making use of such voluntary organisations, the effectiveness of collective action for irrigation maintenance is increased.

In contrast, the assessment of Boye 2 and Meri-Megari schemes provides evidence that a combination of poor trust and failing organizational capability of the WUA has a negative influence on the FWM their own schemes. Even though the WUA of both SSIs has the right strategies in place, enforcement of the rules has been challenging. In the Boye 1 & 2 merged scheme, the government's involvement in the scheme's rehabilitation that ignored the existing arrangements negatively affected the capability, acceptance, and trust of the WUA committee.

The forced nature of the merger already created tension between the users, which the new committee could not overcome. From this analysis, we can conclude that the organisational capability of the WUA committee has a positive influence on farmers' willingness to maintain the SSI. The external interventions that undermine existing hydraulic property relations can cause a fatal loss of trust of users in their WUA committee, undermining users' willingness to maintain their scheme.

4.5.4. Magnitude of Maintenance Requirement and Farmers' Capability to Maintain the System

Farmers' capability to perform maintenance is one of the main factors that influences farmers' willingness to maintain their schemes. Operation and maintenance of the case study schemes are clearly stated as WUAs tasks in the written by-laws and the regional manual (proclamation no 204/2017 issued by Oromia Regional State and national proclamation 841/14), but it is not clearly stated what level of maintenance is expected to be accomplished by users. Therefore, there is no clear task division to participate in SSI maintenance activities between WUAs and government agencies. The government did not provide a budget for maintenance in any of the schemes, thus rendering it unable to prevent (partial) collapse of Boye and Meri-Megari SSIs. Because of the low financial and technical capacity of the associations, it often proves difficult for the users to accomplish this responsibility, particularly when the maintenance burden becomes heavy as in Meri-Megari. There, irrigators could not cope with canal cleaning because of high sediment inflow and unfavorable design (as explained above) for cleaning. Even though they contributed both money and labour for maintenance, the farmers were unable to collectively clean the sediment and keep the system functional. The maintenance requirement was beyond their capacity and there was no maintenance budget from the government. As a result, the farmers were forced to abandon the scheme.

In Kulit traditional SSI, the sedimentation load is considerable, requiring three to four collective efforts to clean the canals in a year. The canal cleaning for the first irrigation season of each year takes up to a month of labour for each member. The farmers collectively perform the maintenance as they consider the scheme belongs to them and it is their responsibility to keep it up. In Kulit SSI, having a labor-intensive traditional diversion structure improved their maintenance capability. The deposited sediment is washed away by the seasonal flood during the rainy season. Thus, sediment deposition in the main canal during the rainy season is avoided. On the other hand, the diversion structure needs to be rebuilt every year. Studies on traditional irrigation show that in many cases traditional systems perform better than government intervened systems (Meinzen-Dick, 2014).

Ejersa is one of the SSI systems that is being challenged by suffocating sedimentation loads. The maintenance requires intensive labour inputs to keep the SSI in working condition. The canal cleaning in this scheme is scheduled every month (from September/October to May). They organize collective maintenance activities eight to nine times a year depending on the sediment accumulation in the canal. Despite the sediment load, the WUA's strong capability of organizing the operation and maintenance activity (as explained above) keeps the scheme in good working condition.

In contrast in Boye scheme, though in theory the farmers' organization can cater for the maintenance duties, Boye 2 users are unwilling to contribute to collective maintenance as

they are less dependent on irrigation for their livelihoods. Moreover, technical improvements foisted on the users by the government did not lessen the maintenance burden. The situation in Boye1&2 merged SSI might ultimately lead to scheme abandonment when the maintenance burden is beyond farmers' capability.

Table 4.4. The overview of factors besides Ostrom's DPs influencing FWM

Key factors affecting FWM	Meri-Megari scheme	Boye 1 and 2 scheme	Ejersa scheme	Kulit scheme
Dependency on irrigation scheme	Less influence	Moderate	Strong influence	Strong influence
Design and construction failure	Strong influence	Strong influence	Strong influence	No influence
Heavy maintenance load and their inability to maintain	Strong influence	Moderate	Moderate influence	Less influence
Responsible/organizing capability of WUA	Strong influence	Strong influence	Strong influence	Strong influence

4.6. Conclusion

Poor participation of smallholder farmers in irrigation infrastructure maintenance has been a challenge in many developing countries, leading to underperformance and abandonment of irrigation schemes. This paper analysed the sustenance or collapse of collective action subject to contextual rather than generic principles by studying the willingness to maintain in a process-oriented manner. We use Ostrom's (1992) design principles for robust common pool resources (CPRs) institutions and Coward's hydraulic property relations framework to assess whether they fully explain the collapse or sustenance of four SSIs in Ethiopia.

Ostrom's (1992) design principles for sustainable collective action in irrigated settings are of a generic nature, irrespective of contextual characteristics, such as cultural differences and technology demands. This choice for universally applicable principles reflects Ostrom's reliance on a rational choice theory perspective, where the (collective) behaviour of rational actors is predicted through neo-institutional game theory. In her perspective cultural differences, dependency on irrigated production for livelihoods and differences in O&M requirements posed by the used technology do not feature.

Coward's (1986) hydraulic property approach attempts to link technology (hydraulic property objects) and governance arrangements, thus paying tribute to the hydraulic context of farmer-led irrigation systems. Yet Coward's singular focus on property relations for explaining

success or failure of collective action in SSIs, ignores other relevant aspects of the context (e.g. technology demands, social relations, and sediment loads) that provide a better understanding of success or failure in collective maintenance efforts by farmers.

In our own pragmatic perspective, context matters. We actively engage with a socio-technical approach that focuses on the interplay between water, technology and social actors benefitting from and governing SSIs. Seeking to deepen our understanding of farmers' willingness to collectively maintain their SSI system, the four case study SSIs bear out four key sets of factors.

First, socially irrigated production may play a different role in the livelihood portfolios of smallholder farmers. Various studies on SSI systems in African contexts have shown that irrigated production is often only one of many livelihood pursuits engaged with by smallholder farmers: rain-fed production, off farm employment, and livestock rearing, in various degrees, make up the rest of the livelihood portfolio (J. Bolding, 2004). Our study established that when the dependence on irrigated production is greater, the willingness to maintain the SSI system is equally greater. In addition, urban encroachment, through a process of increased value of farmland, may offer a way out of farming altogether, leading to a decreased willingness to maintain the SSI system.

Second, the very users of SSIs may vary in the use they make of the resources offered by the irrigation scheme (water for irrigation, water for livestock, grazing land along the scheme's margins) making them less homogenous or uniform in their interest in maintaining the SSI system. Equally, one may observe that user groups vary in socio-economic status and cultural or ethnic background, providing variation (and not uniformity) in the cultural and social norms informing leadership styles, trust and organisational capacity to perform collective action to maintain their scheme. Our study bears out that shared membership in various local institutions increases willingness to engage in collective maintenance activities. While previous studies have debated how socio-economic differentiation and asymmetries in access to water amongst users affects sustainable collective governance of SSIs (Komakech, Van Der Zaag, & Van Koppen, 2012; Ostrom & Gardner, 1993), our study shows how differences in ethnic, cultural and social homogeneity can undermine trust and organisational performance of users' committees.

Third, different irrigation technologies pose different maintenance demands, which in turn ask for different degrees of organisational capacity on the governing bodies of SSIs. Whilst our study shares a bias for gravity canal irrigation systems with the studies that informed the conception of Ostrom and Coward's theories on collective action, one can imagine that pump driven SSI systems or SSIs using drip or sprinkler technologies pose different demands on the organisational and financial capacity of user committees (see also (Kloezen & Mollinga, 1992). This affects the willingness of farmers to maintain their scheme. In general, one could pose that the more sophisticated the irrigation technology, the greater the organisational (skills, know-how) and financial demands for collective maintenance. The case of Kulit SSI shows that

as long as users can locally mobilise the technical know-how, materials and labour required, traditional technologies like unlined canals and temporary intake structures do not negatively affect the capacity and willingness to maintain their scheme. Our case study SSIs show that equally important in this respect is the technical design and construction of infrastructural elements that diminish the sedimentation loads caused by roaming livestock and heavily silted river water. The inverted syphon at the intake of Meri-Megari SSI system proved to pose an insuperable maintenance burden on the users, who proved incapable of removing the clogging sediment load inside the syphon.

Fourth, the sediment loads contained in the irrigation water at the source proved to influence the collective willingness to maintain their scheme. Whilst farmers often prove capable of considerable maintenance burdens in terms of labour days per annum, there is a breaking point when their willingness to maintain dissolves in the face of the heavy burden posed.

While Ostrom's design principles and Coward's hydraulic property analysis shed light on farmers' willingness to collectively maintain their SSI system, our study has highlighted complementary, contextual factors that help determine when SSI schemes are abandoned or sustained. Further studies should bear out what other contextual factors may affect farmers' willingness to maintain their gravity canal SSIs and when a tipping point may be reached.

The image features a large, bold, black number '5' centered on a white background. The background is composed of several geometric shapes: a light gray triangle in the top-left corner, a dark gray triangle in the bottom-left corner, and a small gray trapezoidal shape on the left side of the number. The overall composition is minimalist and modern.

5

CHAPTER 5.

Suffocated by Sediment? Charting a New Way to Deal with Sedimentation in Small-Scale Irrigation in Ethiopia through Inclusive Self-Governance

This chapter is based on:

Dessalegn H.T., Bolding A., Fraiture, C.d., and Ayana, M.

Suffocated by Sediment? Charting a new way to deal with sedimentation in Small-scale irrigation in Ethiopia through inclusive self-governance

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5. Suffocated by Sediment? Charting a New Way to Deal with Sedimentation in Small-Scale Irrigation in Ethiopia through Inclusive Self-Governance

Summary

Our study on the conundrum of sedimentation in small scale irrigation (SSI) in Ethiopia shows that irrigation development policy lacks a comprehensive strategy for sediment management and self-governance. Lacking policy that promotes effective sediment management and inclusive self-governance leads to low performance, underperformance, or abandonment of many SSIs in Ethiopia due to excessive maintenance burdens. This policy brief highlights the need for inclusive self-governance by different user groups to develop effective sediment management measures. Key policy recommendations include (1) acknowledging the significance of before and in-season sedimentation caused by livestock-irrigation interactions and making sure the sediment mitigation measures address this cause as well; (2) addressing issues of confused ownership and maintenance responsibilities; (3) improving levels of participation in land and water governance; (4) devolving rulemaking capacity to users; (5) establishing inclusive users' institutions that incorporate and address needs of multiple users, not just irrigators; and (6) bridging the interaction of both government and users' needs through a common platform.

5.1. Introduction

In Ethiopia, the government and its development partners show a growing interest in developing small-scale irrigation (SSI) projects. However, many newly established SSI schemes are underperforming. Some of them have ceased functioning, due to excessive sedimentation and inadequate management caused by weak irrigation governance. Livestock-irrigation interactions are a prime cause of sedimentation before and during the irrigation season (Dessalegn et al., 2021). Suffocating levels of sedimentation present an enormous challenge, drawing heavily on the maintenance budget and available labour. Facilitating collective maintenance to clean the sediment from the irrigation system requires effective irrigation system governance. Yet many of the livestock owners causing the in-season sedimentation are no members of existing Water User Associations.

5.2. Problem Statement

Past policies regarding SSI management and governance have proven ineffective for two main reasons. All previous policies were directed at minimizing sedimentation through either measure aiming at upstream catchment conservation or technical measures to deal with suspended sediments entering the scheme from the main intake. Both sets of measures overlook the problem of in-season sedimentation caused by livestock-irrigation interactions. Second, none of the past policies achieved effective forms of user governance and participation, precipitating SSI scheme collapse and abandonment. Based on the key findings of three research papers, we propose recommendations that would fill this policy gap.

In this policy brief, we aim to (1) review past policies identifying the key reasons behind their ineffectiveness to remedy sedimentation in SSIs; (2) summarize key challenges regarding the conundrum of sedimentation in small scale irrigation systems in Ethiopia based on four case study schemes and (3) provide policy recommendations to reduce sedimentation and improve the governance and sustainability of irrigation systems in Ethiopia.

5.3. Policy Review on SSI in Ethiopia

SSI development and water management strategies in Ethiopia are not appropriate since water utilization is inefficient (S. B. Awulachew et al., 2005). Uncertainties and ambiguities in planning and lack of stakeholder participation are challenges that preclude achievement of better irrigation practice. (Eshete, Sinshaw, & Legese, 2020) argue that the policy crafted for SSI includes adequate strategies like designing the irrigation infrastructure by considering the physical condition of the irrigation field, hydraulic characteristics, irrigation engineering, and management capacity of the users, among others. However, these considerations are not fulfilled on the ground during the planning and construction phase of such schemes. Across many levels of the government, there is no standardized approach for mapping and monitoring existing irrigation performance; a lack of project ownership on the part of users; lack of institutional memory; lack of inter-departmental coordination of Government offices and lower-level administrative organs; and legal entities do not play any meaningful role in

water control and conflict resolution (S. Awulachew, Erkossa, & Namara, 2010; Belete, Kebede, Biru, & Natea, 2011; Gebul, 2021). To draft effective remedies, we will address three major challenges for SSI sustainability, which we derived from our study of four SSIs (Table 5.1) that vary in degree of sedimentation (light, medium, heavy plus one abandoned scheme).

Table 5.1. Characteristics of the study schemes (all located in Woliso, central Ethiopia)

S. No	SSI Scheme	Type of scheme	Command area Hectare (ha)	No. of users	State of the scheme
1	Boye 1 & 2 merged scheme	Upgraded	56	121	Light sedimented
2	Ejersa scheme	Upgraded	96	120	Heavily sedimented
3	Kulit scheme	Traditional	17	29	Medium sedimented
4	Meri-Megari	Modern	200	234	Abandoned

5.4. The Key Sustainability Challenges Affecting the Four Study Schemes Can Be Listed as Follows:

5.4.1. Ignoring the Potential Causes of Sedimentation

Ignoring in-season sedimentation caused by livestock-irrigation interactions as manifested through infrastructural damage, over-grazing, and in-scheme sedimentation. In-season sedimentation caused by livestock-irrigation interaction is one of the key factors that is negatively affecting the case study irrigation schemes' maintenance and sustainability (Dessalegn et al., 2021). Livestock causes sedimentation challenges through infrastructure damage during livestock watering and over-grazing of both riverine and in-scheme vegetation that precipitates sheet erosion. Remedies to control such in-season causes of sedimentation often fall short because existing rules and regulations only apply to irrigators, ignoring other potential users like livestock. Since livestock owners are not acknowledged SSI users or members of the WUA, their use of the scheme is difficult to monitor or police.

Existing users' institutions do not cater for the needs of multiple users besides irrigators. The irrigation systems lack certain components like cattle-throughs or watering points for the livestock to drink safely which could reduce the negative impact of livestock causing damaged irrigation infrastructure and sedimentation (O' Sullivan et al., 2019).

Recommendation: Inclusive, Multiple Use

To increase the effectiveness of sediment management measures, all potential causes of sedimentation need to be considered. The regional office could pay more attention to the in-season sedimentation caused by livestock-irrigation interaction, by developing a strategy that recognises the livestock owners as one of the rightful users. Also, the membership of existing users' institutions could incorporate and address the needs of multiple users (not just irrigators).

Involving different user groups from the very start of the irrigation scheme design would help to include the users' concerns, such as types of infrastructure that ease sediment removal, special needs like cattle-troughs to facilitate the multiple-use of the irrigation systems and limit the damage caused by livestock-irrigation interaction. Limiting the interactions will reduce canal bed vulnerability to erosion and sedimentation. The government could consider using the existing institutions to smooth the transition rather than ignoring the issue. To develop a comprehensive strategy for improved sediment management, irrigation system governance, and its sustainability, each of the challenges will be discussed with a recommendation on how they could be addressed by the different government offices.

5.4.2. Lacking Effective User Participation and Governance to Address Sedimentation in SSI

Due to existing top-down, siloed governance structures, which inhibit the emergence of inclusive and effective forms of governance and policing among irrigation users, livestock owners, and responsible government agencies. Moreover, lack of user participation and ownership in formulating/devising effective solutions to remedy the sedimentation challenge, particularly in so-called upgraded or modernized projects which rely on formalized Water User Associations.

In our case study schemes in Ejersa and Boye, the top-down governance structure established after upgrading the traditional irrigation system without the involvement of the stakeholders ruined the existing institutions responsible for collective maintenance. During the so-called modernization of Boye 1 and 2 SSIs, the regional government officials merged the two schemes into one by constructing one concrete weir intake and lined canal despite explicit resistance by the users of both schemes. The upgrading process ignored existing differences in culture, ethnicity, institutions, and articulated special needs during the merger. This created lasting disagreement between the two groups of users on co-governing the scheme.

The government's modernization of Ejersa SSI ignored the users' special needs and suggested solutions for the existing challenges (irrigation design that eases sediment removal for instance canal lining where sediment deposition is higher rather than less susceptible area since the budget is limited to line entire canals). Moreover, our analysis indicated that the stakeholder's participation in finding an effective solution for their case-specific challenge (sedimentation) has been undermined as they were not given the chance to indicate the

challenging spot for sediment cleaning and the sediment cleaning approach that the farmers used before the upgrading indicates that their local knowledge is undermined. Both In Ejersa and Boye the bylaws guiding user governance through a new Water Users Association had been drafted by the regional office in accordance with a nationally endorsed template without consulting the various user groups. The regional office used one-way communication to inform the users about the rules they should follow (bylaws), while the decision regarding the design and construction of the system were all made by the regional office. The drafted bylaws apply uniformly for all small-scale irrigation schemes in the region despite their differences in culture, challenges (sedimentation), special needs (water point) and different users (only irrigators, or both irrigators and livestock). This uniform imposition of bylaws without the active participation of the stakeholders hinders their effectiveness as has been shown convincingly by the work of Ostrom (1990, 1992). Moreover, the coordination between the irrigators and livestock farmers for the collective sediment cleaning doesn't exist.

Recommendations

To foster the emergence of a successful, inclusive form of self-governance by users, the following key factors need to be addressed.

➤ Increasing the level of participation in land and water governance

The stakeholders' level of participation in governing the grazing land around the irrigation system and the irrigation infrastructure needs to be improved. The regional office should involve the stakeholders from an early stage of the irrigation design by following a hybrid mix of top-down and bottom-up approaches (the broader objectives are set at the regional level, but the special needs, context-specific concerns, challenges, and solutions set by users). The existing and desired level of participation for better self-governance is summarized in (Table 5.2) below.

➤ Devolving rule-making capacity to the users

The regional office could decentralize the rule-making approach to the users. The rules that the schemes prioritize could be different responding to local needs. For instance, for Boye merged scheme, it would be helpful to jointly draft rules that promote co-governing the system dovetailing the interests of the two different users' group (Boye 1 and Boye 2 users) who presently do not maintain the system collectively. On the other hand, for the Ejersa scheme, the main challenge is sedimentation due to livestock-irrigation interaction. This scheme could benefit from a rule that promotes collaboration between the irrigators and livestock farmers for effective scheme maintenance and management. Hence, the regional government needs to give the mandate to the users to formulate their own rules that help to govern the system effectively.

➤ Streamlining Interaction of Both Government Departments and Different Users

The coordination between the irrigators and livestock farmers for effective scheme management needs to be bridged by creating a common platform to communicate, interact and collectively take part in the maintenance. Moreover, the government system also needs to improve their inter-departmental communication, as well as their interaction with both irrigators and livestock farmers by communication through the common platform.

5.5. Conclusion

The existing sediment mitigation measures in SSI irrigation have not been effective since these didn't address all potential causes like in-season sedimentation due to livestock-irrigation interaction and the lack of an effective, inclusive form of user governance and participation.

To promote the emergence of a successful self-governance by users and effective sediment management measures, key policy recommendations involve (1) the regional government could consider researching the impact of livestock-irrigation interaction to learn the extent of the sedimentation problem caused by it and include it in the sediment management measures; (2) regional bureaus could take the lead in developing new guidelines for irrigation modernization/upgrade that includes the need to do a rapid appraisal of design needs by the users, and a participatory WUA bye-law formulation workshop; (3) The regional office could develop a strategy that recognises the livestock owners as one of the rightful users eligible for membership of existing users' institutions and create a platform for all users to coordinate the irrigation management; (4) at Woreda level, the various departments responsible for livestock grazing and irrigation could establish a working committee to coordinate actions related to livestock-irrigation interactions.

Table 5.2 Summary of the existing and desired level of stakeholders' participation for self-governance and better collective action.

Existing level of participation	Desired level of participation/alternative for better governance
✓ Top-down irrigation development approach (inform)	✓ A hybrid (mix) of bottom-up and top-down (consult and involve the users from early stage)
✓ Regional office formulates standard WUA bylaws	✓ Rule-making capacity needs to be devolved to users
✓ Irrigators are the only acknowledged users of SSI	✓ All potential users (irrigators, livestock, domestic users) need acknowledgement and their interaction needs to be bridged through a common platform or user sub-committees at WUA level

-
- | | | | |
|---|---|---|---|
| ✓ | The user institution addresses the needs of irrigators only | ✓ | Institution needs to incorporate and address needs of multiple users, not just irrigators |
|---|---|---|---|
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CHAPTER 6.

Synthesis and Reflection

6. Synthesis and Reflection: Coping with Sedimentation in Small Scale Irrigation in Ethiopia

6.1. Introduction

In Ethiopia, the government and development partners show a growing interest in developing small-scale irrigation (SSI) projects. However, the performance of many of the new SSI schemes is far below expectations. Sedimentation and inadequate management render many SSI schemes non-functional within a short time after their modernization or new construction. Sedimentation forms the main challenge affecting their sustainability since it draws heavily on the maintenance budget and labour needs before and during the irrigation season (Dessalegn et al., 2021). Moreover, the collective maintenance to clean the sediment from the irrigation system requires a form of good irrigation system governance. So far, sediment management mitigation measures have proven ineffective for two main reasons: Firstly, all previous policies were directed at minimizing sedimentation either through measures aiming at upstream catchment conservation or technical measures to deal with suspended sediments entering the scheme from the main intake. Both sets of measures overlook the problem of in-season sedimentation caused by livestock-irrigation interactions. Secondly, none of the past policies achieved effective forms of user governance and participation, capable of coping with the huge maintenance burden posed by sedimentation.

The study seeks to generate approaches and insights to better understand the causes of the ineffectiveness of the sediment management mitigation measures and the dynamics of the collective action underpinning those measures. First, it identifies the causes and extent of sedimentation in four small-scale irrigation schemes. It argues that livestock-irrigation interaction is the main cause of sedimentation during the irrigation season. Digging deeper it seeks to disentangle the livestock-irrigation conundrum, exploring the various causes for sedimentation and the challenges of coming up with effective solutions. An alternative framework is presented that helps to understand the sustenance/abandonment of SSI systems beyond Ostrom's institutional design principles for sustainable collective action and Coward's hydraulic property theory. The framework analyses the process of governance in action by addressing contextually established factors that influence farmers' willingness to maintain small-scale irrigation systems. Finally, the thesis presents a policy brief, that contains policy recommendations to enhance SSI sustainability in Ethiopia and beyond.

Each chapter of this thesis addresses one of the four main research questions.

- What are the major causes of sedimentation during the irrigation season? (Chapter 2)
- Which factors inhibit the emergence of effective and sustainable collective action? (Chapter 3)
- When do SSIs collapse, and what factors play a decisive role in that? (Chapter 4)

- What are the policy recommendations that could enhance SSI sustainability? (Chapter 5)

The remainder of this chapter is organized as follows: Section 6.2 briefly answers the four research questions by way of a conclusion. Section 6.3 sketches this study's contribution to a conceptual understanding of the conundrum of sedimentation and scheme abandonment in Ethiopia. Section 6.4 presents a reflection on the main finding and used research approach in this study, outlining possible biases while assessing the representativeness of its findings. Section 6.5. reviews the proposed study objectives that could not be attained. Section 6.6 outlines the recommendations for future research. Finally, section 6.7 presents the overall conclusion.

6.2. Step-by-Step Conclusion

Q1. What are the major causes of sedimentation during the irrigation season?

In Ethiopia, the sediment management strategy established in irrigation schemes is largely ineffective. The discourse around the sedimentation of SSI schemes is based on erroneous assumptions regarding its causes. The focus of the dominant discourse is on upstream catchment protection, neglecting both protection against soil erosion through overland flow along the margins of the canal network and sedimentation caused by livestock movement for drinking from the canals and through disturbances caused by livestock grazing and trespassing. It is unsurprising that the remedies that have been tried in the past have proven ineffective so far. Considering the ineffectiveness of the proposed sediment management solutions and the vital role of the mitigation measures, a deeper understanding of the extent and causes of the sedimentation is warranted. Therefore, four small-scale irrigation schemes in different settings suffering from variable rates of sedimentation were studied to assess the causes and extent of the sedimentation before and during the irrigation season.

It was found that overland flow in agricultural areas, particularly on land that is susceptible to soil erosion due to livestock trampling during the rainy season contributes to sediment accumulation in the SSI canal network. As confirmed by (Dereje & Yusuf, 2015; Haregeweyn et al., 2017; Kassie, 2019; Wolancho, 2012), soil erosion in the upstream catchment area is an important sediment source whereby sediment-laden water from the upper catchment enters the canal system through the intake structure at the beginning of the irrigation season. However, livestock-irrigation interaction was identified as the main cause of sedimentation *during* the irrigation season.

The extent of sedimentation in the canals during the pre-irrigation season in relation to canal capacity was 100% in lined and unlined canals in Meri-Megari (abandoned) scheme at the time of data collection (2018). The story of Meri-Megari SSI is one of a gradually contracting irrigation command area during its first five years of operation: sedimentation caused a reduction in irrigation potential from 200 hectares to 40 hectares. Excessive sedimentation at

both the intake and main canal network ultimately led to its abandonment. In Ejersa SSI, a heavily sedimented scheme, the accumulated sediment was 68% in its lined, and 84% in its unlined canals. In contrast, the lightly sedimented schemes in Boye 1 & 2 merged SSI suffered from 38% in its lined and 46% of its unlined canals.

Even though both upstream erosion and overland flow both contribute to sedimentation, it is difficult to single out their contribution without detailed research. However, considering the fact that the irrigation scheme was closed for a certain period during the rainy season, it is safe to assume that overland flow along the margins of the canal network had a significant contribution to the sedimentation.

Measurements in the Ejersa main canal demonstrated that the sediment inflow rate per cubic meter increases from the intake to the furthest point, whereby sediment concentration spikes were found at places where there was a disturbance caused by livestock interactions. Moreover, the inconsistencies in peaks demonstrate that disturbances caused by livestock explain the values at any point along the canal during the irrigation season, rather than sediments originating from upstream catchment erosion. This finding highlights the importance of an often-overlooked third cause for sedimentation: livestock. Livestock–irrigation interactions contribute to sedimentation and canal bank damage during the irrigation season. It also affects the water supply since livestock is a considerable water consumer.

Q2. What factors inhibit the emergence of effective and sustainable collective action?

Irrigation-livestock interactions produce effects that are experienced as both positive and negative. Livestock provides many benefits for improving the livelihoods of farmers. But at the same time, their interaction with irrigation is a main cause of sedimentation before and, especially, during the irrigation season in all studied schemes. Overgrazing, erosion, and eventually sedimentation is frequently caused by livestock movements in irrigation systems, clogging the main intake and canal network. Irrigated production frequently increases prevalent livestock densities, with livestock being a favorite investment option for surplus generated by irrigated production. Simultaneously, irrigation systems are frequently built in former grazing areas, and canals cut through cattle access routes to lush riverbeds. This causes a conflict between irrigators and livestock owners, though it should be noted that these land user groups are not mutually exclusive.

The study digs deeper into this conundrum seeking to disentangle the complex interactions between irrigators, livestock farmers, and local government by looking into the extent of sedimentation caused by livestock; various forms of collective action controlling livestock movements inside the irrigation perimeter, along its margins, and on grazing land; and distinguishing various owner groups of livestock and their motives for interaction with the scheme. These interactions explain why technical approaches are ineffective, but also why effective collective action is not a straightforward matter. This is the missing link in the

ongoing SSI sedimentation debate in Ethiopia that may well be of relevance in other irrigated contexts as well. The presence of different stakeholders, who have partly overlapped interests and who are dependent on functional irrigation systems aggravates the situation.

Top-down planning and implementation in SSIs by various responsible government agencies inhibits addressing inter-sectoral needs and undermines a sense of co-ownership and co-responsibility among users, preventing the development of solution pathways that could deal with the negative effects of livestock production, movement, and watering. Furthermore, when top-down interventions in irrigation systems are implemented, livestock-irrigation interactions are not adequately considered, resulting in aggravated conflicts.

Frequently proposed solutions to address sedimentation problems caused by livestock do not work because they do not address underlying conflicts between irrigators and livestock farmers. The irrigation infrastructure design was often made only from the irrigation perspective ignoring the inter-dependence of livestock and irrigated production. It reflects a design culture that ignores the socio-cultural context and concerns of the actual users, both livestock farmers and irrigators, thus being unable to come up with technical/design solutions that mitigate the negative effect of the interaction. There is no appropriate institutional framework in place to address irrigation-livestock interactions. The WUA applies to irrigators, while the LFA applies to livestock farmers. They each have their own institutional realm (association). Each resource has its own property arrangement, but these cannot handle resource overlap at the boundaries. The lack of cross-cutting (in)formal institutions capable of policing all stakeholders' resource use makes it difficult to control non-rightful users in both the Boye and Ejersa schemes.

The WUA committee has no authority to prevent free riders (livestock owners who are not members of the irrigation scheme) from accessing water. It is outside the WUA committee's jurisdiction because it concerns water use by non-members. However, in the Kulit traditional scheme, all users are collectively cooperating because they have a strong ownership feeling for the scheme they established, there are small members, and they have access to adequate amounts of water. Their successful, though informal, collective action overcomes the artificial institutional boundaries that limit formalized institutions for collective action. While it appears that both the WUA and the LFA are properly nested in other governing networks, such as the district office, as stipulated by another of Ostrom's design principles, the top-down and compartmentalized approach to resource use precludes effective collective action to control irrigation-livestock interactions in practice. Hence the talk of a missing link.

The persisting problem of sedimentation, and associated irrigator-livestock farmer conflicts in SSI in Ethiopia, have induced the need for strategy development and recommendations for dispute resolution.

Q3. When do SSIs collapse, and what factors play a decisive role in that?

In many developing nations, insufficient smallholder farmer engagement in irrigation infrastructure maintenance has been a problem that has resulted in irrigation system underperformance and abandonment. By examining the willingness to sustain in a process-oriented approach, the study analyses the sustenance or collapse of collective action. It focuses on contextual rather than general principles. The study evaluated whether the four samples' SSIs in Ethiopia were properly explained by Ostrom's (1992) design principles for robust common pool resources (CPRs) institutions and Coward's hydraulic property relations framework.

The design principles proposed by Ostrom (1992) for sustainable collaborative behaviors in irrigated environments are of a generic nature, independent of local factors like cultural diversity and technological requirements. This preference for universally applicable rules reflects Ostrom's dependence on a rational choice theory viewpoint, in which neo-institutional game theory is used to forecast the (collective) behaviors of rational agents. According to her, cultural differences, varying degrees of dependency on irrigated production for a livelihood, and variations in O&M requirements caused by the technology being used do not come into play.

In order to honour the hydraulic context of farmer-led irrigation systems, Coward's (1986) hydraulic property approach makes an effort to connect technology (hydraulic property objects) and governance arrangements. Coward, however, ignores other relevant contextual factors (such as technical requirements, social relations, and sediment loads) that could help us better understand the success or failure of collective maintenance efforts by farmers. Coward focuses solely on property relations to explain the success or failure of collective action in SSIs. This study concludes that Ostrom's institutional design principles and Coward's property theory cannot fully explain when an SSI scheme is about to fail or when a tipping point is reached for the farmers to decide quitting the process of collective maintenance through a systematic application and evaluation of both Ostrom's and Coward's framework for the four case study schemes.

A socio-technical method is actively used in this study to examine the interactions between water, technology, and the social actors who utilize and manage SSIs. The four case study SSIs illustrate *four* key sets of factors (framework) that act as a complementary and aid in understanding when a tipping point is reached in farmers' willingness to collectively maintain their SSI system. This is done in an effort to further the understanding of farmers' willingness to collectively maintain their SSI system. The key factors are illustrated below.

Dependency on irrigation production: - Irrigated agriculture may, first and foremost, play a different function in smallholder farmers' portfolios of sources of income socially. Numerous research on SSI systems in African contexts have demonstrated that smallholder farmers often engage in a variety of livelihood activities in addition to irrigated agriculture, including

rain-fed agriculture, off-farm jobs, and livestock rearing to various degrees (Diemer 1990, Bolding 2004). The research showed that the willingness to sustain the SSI system increases together with the degree of irrigated production dependence. Furthermore, the value of farmland may rise due to urbanization, providing a way out of farming entirely and reducing the willingness to maintain the SSI system.

Leadership and organizational capacity: - The farmers who utilize SSIs may use the resources provided by the irrigation scheme differently than one another (water for irrigation, water for livestock, grazing land along the scheme's boundaries), which makes them less consistent or homogeneous in their interest in maintaining the SSI system. Additionally, it is possible to note that user groups differ in terms of economic status as well as in terms of cultural or ethnic background, resulting in variation (and not uniformity) in the cultural and social norms that influence leadership styles, organizational capacity for collective action, and trust. Moreover, the different irrigation technologies have distinct maintenance requirements, which in turn ask for different degrees of organizational capacity on governing bodies of SSIs. This in turn influences the farmers' willingness to maintain their scheme.

Sophisticated irrigation design and construction: - The study SSIs demonstrates that farmers' willingness to maintain their SSI is significantly influenced by the technical design and implementation of infrastructure elements that diminish the sedimentation loads caused by roaming livestock and heavily silted river water. The inverted siphon at the intake of Meri-Megari SSI system proved to pose an insuperable maintenance burden on the users, who proved incapable of removing the clogging sediment load inside the siphon. One could argue that the organizational (skills, know-how), financial, and maintenance demands increase with the sophistication of irrigation technology. The example of Kulit SSI demonstrates that traditional technologies like unlined canals and temporary intake structures do not adversely influence users' capacity and willingness to maintain their scheme as long as they can locally mobilize the technical know-how, materials, and labour required.

Sediment load and maintenance Burdon: - The sediment loads contained in the irrigation water at the source proved to influence the collective willingness to maintain their scheme. There is a breaking point when farmers' willingness to maintain dissolves in the face of the high strain offered, even though they frequently demonstrate their capacity for considerable maintenance burdens in terms of labor days per year.

Even though Coward's hydraulic property analysis and Ostrom's design principles provide insight into farmers' willingness to collectively maintain their SSI system, the study has highlighted complementary contextual aspects that influence when SSI schemes are abandoned or sustained. A tipping point may be reached, and further research should confirm whether other contextual elements may influence farmers' willingness to maintain their gravity canal SSIs.

Q 4 What are the policy recommendations that could enhance SSI sustainability?

The study review past policies to address sedimentation in SSIs and why they have been unsuccessful. Based on the four case study schemes, the study summarizes the main challenges found in the study concerning the problem of sedimentation in small-scale irrigation systems in Ethiopia. It provides policy suggestions to improve the governance and sustainability of Ethiopia's irrigation systems and decrease sedimentation.

The existing sediment mitigation measures in SSI irrigation have not been effective since these didn't address all potential causes for sedimentation, like in-season sedimentation due to livestock-irrigation interaction and the lack of an effective, inclusive form of user governance and participation. The suggestions are listed below.

1. The regional government could do further research to discover the extent of sedimentation caused by livestock-irrigation interaction
2. The regional bureaus could conduct an assessment on user's design demand and formulate WUA by-laws with users' participation specially during the upgrade.
3. The regional Bureaus craft a policy that acknowledge the livestock owner as one of legitimate users of SSI.
4. Create a platform for all stakeholder to coordinate irrigation management

6.3. Scientific and Societal Relevance of this Study

6.3.1. Scientific Contribution

The present study attempts to address multiple gaps and in doing so makes important contributions. One of the biggest challenges affecting the performance of SSI schemes is linked to canal damage, sedimentation, and the corresponding maintenance burden. Sedimentation problems due to livestock-irrigation interactions were first noted as a big problem in 1965 in Rhodesia (Roder, 1965). However, this cause has been overlooked for decades. The study reconfirms that sedimentation in small-scale irrigation is a big issue and livestock movement has a big role in destabilizing the canal bank, increasing the land susceptibility to erosion, and contributing to the sedimentation because livestock density is higher in irrigation settings.

Second, this study contributes to the conceptual debate concerning the causes of sedimentation. Most studies identify erosion in the upper and middle river catchment as the main contributor to sedimentation. High sediment loads travel through the intake structure of the irrigation system and build up in the canal network, causing excessive sedimentation (Dereje and Yusuf, 2015; Wolancho, 2012; Kassie, 2019; Haregeweyn et al., 2017). Other studies (Gurmu et al., 2019) have shown that the reasons of sedimentation vary depending on how different stakeholders perceive them. Most engineers attribute sedimentation to design issues, whereas others attribute it to erosion in the upstream river basin and a lack of

suitable technology and material. The study contributes to acknowledging the other sources and filling the knowledge gap that livestock-irrigation interaction is the main cause of sedimentation during the irrigation seasons. The lack of acknowledging this source of sediment is one of the possible reasons why commonly proposed mitigation measures are ineffective.

Moreover, it also contributes to the understanding of the challenges of effective collective action to maintain SSIs, particularly in multi-use irrigation systems. This study integrates insights from two theoretical approaches, *viz.* Ostrom's (1990) design principles for long-enduring, self-organized irrigation systems, and Coward's (1986) hydraulic property framework, to assess scheme performance, sustenance, or collapse by testing these conceptual frameworks on their empirical validity and identifying additional factors that play a decisive role in farmers' willingness to maintain their SSI. In doing so, it expands previous studies (theories) that have been developed based on a general perspective. The study explores factors that help explain the sustenance or collapse of multi-use SSI systems by studying the farmers' willingness to maintain their SSI, using an empirically based analytical framework that applies contextual rather than generic principles in a process-oriented manner. This analytical framework yields lessons to the factors that analyse and explain the process of collective governance of SSIs and opens the door for further research to identify when the tipping point may be reached and what other contextual factors may influence farmers' willingness.

6.3.2. Societal Contribution - Lessons Learned

Presenting the experience of successfully maintained irrigation like the Ejersa SSI scheme can give a good indication of how to organize successful collective action that can sustainably maintain the irrigation system. The lesson learned from this scheme is that trusted and proactive WUA committee members constitute one of the key factors influencing the collective maintenance of irrigation systems. Their experience in coordinating the actions of fellow irrigators by building trust and using various social institutions to coordinate the sediment cleaning responsibility shows us what can be done by committed leaders.

Moreover, the Kulit traditional SSI can be a good example to learn how to manage the livestock-irrigation interaction and coordinate irrigation maintenance by avoiding the difference between livestock owners and irrigators and working on their responsibility of sediment cleaning for better collective action. How these farmers collaborated to clean the sedimentation as well as the way they created the system for an effective collective action could be a good insight for other farmers to manage the irrigation systems effectively. This finding contradicts dominant beliefs in the Regional Bureaus that traditional irrigation ventures using temporary intake structures are bound to fail. Rather the opposite has been found true – once such schemes become subject to modernizing efforts through the merging and making permanent of intake structures (as was done in Boye 1 & 2 SSI) the collective

activities to clean canals, which existed before, are somehow destroyed. This calls for a more sensitive, bottom-up approach when initiating and implementing modernization and improvement efforts.

This thesis also contributes to the lesson of understanding the design and construction factor that inhibits the farmers from maintaining the irrigation system. Proper small-scale irrigation design that includes the necessary components like cattle throughs, sediment traps or infrastructure can ease the collective burden of sediment maintenance. On the other hand, the lesson from the Boye scheme indicated that an upgraded irrigation scheme without due consideration of culture, norms, and existing institutions before the design and construction could lead to worsening the situation rather than improving the water supply and sustainability of the irrigation system.

Furthermore, the higher institutions in Ethiopia that provide bachelor's or master's degree training in agricultural science need to train the students that addressing the socio-technical aspects of small-scale irrigation is equally important as the engineering aspects of the irrigation systems. The institutes should pay more attention in their curriculums to how societal aspects impact the sustainability of the irrigation system and include practical lessons on how one could sustain or help farmers to sustain their irrigation system.

6.4. Reflection on the Major Finding and Research Approach

6.4.1. Reflection on the Major Results

The results of this thesis are relevant to other small-scale irrigation systems in Ethiopia as well as sub-Saharan African countries. The knowledge of the causes and the extent of sedimentation in irrigation schemes confirms that sedimentation is a big challenge that requires a massive amount of labor and money for scheme maintenance that hinders irrigation sustainability in most parts of Ethiopia and sub-Saharan Africa. As a result, the extent of the problem aligns with the findings of (de Sousa et al., 2019; Awulachew and Ayana, 2011; Aynekulu Ermias et al., 2009; Bhatti et al., 2021; Depeweg and Méndez, 2002; Gurmu et al., 2019; Adongo et al., 2020). By indicating that livestock-irrigation interaction is the main cause of sedimentation during the irrigation season, the findings in my opinion confirm that the sedimentation problem is due to livestock-irrigation interaction which was first noted in 1965 in Rhodesia (Roder, 1965).

The negative impact of livestock-irrigation interaction, as a result, is consistent with research findings (Parker and Williams, 2012; Vidon et al., 2008; Madden et al., 2019; O'Sullivan et al., 2019; O'Callaghan et al., 2019; Roder, 1965; Ebling et al., 2020). I agree that the livestock interaction with water courses is a separate erosion and sediment source. However, most of the previous research (Gurmu et al., 2019; Dereje and Yusuf, 2015; Wolancho, 2012; Kassie, 2019; Haregeweyn et al., 2017; Wilson, 2007; Descheemaeker et al., 2010) has focused on determining the sources of sedimentation in the catchment during the rainy season, ignoring

the in-season sedimentation. I believe this is one of the reasons why sediment management measures are not effective. I argue, identifying all year-round possible causes of sedimentation is one of the major steps in developing effective sediment mitigation measures.

I believe the lessons learned from the livestock-irrigation interaction conundrum; would appeal in many small-scale irrigation schemes in African countries. It could provide a solution for the irrigation governance problems; by shedding a light on what needs to be addressed to create an effective collective action for a multi-user irrigation system.

Irrigation governance is the major challenge to irrigation sustainability in Africa (Solomon et al., 2014; Mutambara and Munodawafa, 2014; Moris, 2019). collective action is the key to sustaining the irrigation schemes, and I think creating it requires bringing the stakeholders together to enhance cohesiveness, responsibility, and accountability in their service to the small-scale irrigation scheme. Creating a sense of ownership and responsibility by creating a common user group or including all users in a sub-user group of the main user group and providing a common platform for all the users to communicate can be a key factor in achieving sustainable collective action.

The analytical framework developed in the study includes a list of key contextual factors for determining whether farmers' willingness to sustain the SSI would become too low, resulting in scheme abandonment. It in my opinion can provide insight into the components that analyse and explain the collective governance of SSIs, and it also provides a starting point for future studies to determine when the tipping point may be reached and what additional contextual factors may affect farmers' willingness to maintain the irrigation scheme.

6.4.2. Reflections on the Methodology

The methodology applied in this research was chosen to understand the causes of sedimentation and farmers' willingness to collectively maintain their small-scale irrigation scheme. This study selected four small-scale irrigation schemes in two districts that have different characteristics like different sediment loads (light and heavy), representing either traditional, modern, or upgraded small-scale irrigation schemes to learn how these schemes compare with one another and empirically establish the factors that affect their sustainability under different contexts. Understanding the sedimentation and collective action process for sustaining the irrigation systems requires a variety of methods, including sediment concentration measurements and getting to know the place, the infrastructures, and the users by following the water, both on my own and through informants. By making use of multiple methods, the interlinked aspects of how people are attached to a place and to their environment, and information on the schemes' operation and maintenance practices and the interaction with livestock and livestock farmers were uncovered.

I have also discussed preliminary analyses with key informants in an iterative process to verify and validate my interpretations of the results. In another effort to check my own interpretations and analyses. This study has relied wholly on multiple qualitative methods. This methodology provides in-depth information about the study areas. By using semi-structured, open-ended interviews rather than surveys or questionnaires, I have been able to collect more in-depth empirical material. The questions asked, in interviews and surveys, could have been similar, but the interview situation provides direct contact with the interviewees and allows for opportunities to elaborate and follow up questions. Gaining access to information, either through interviews or focus group discussions did not represent major challenges during the fieldwork. One of the main challenges I had during fieldwork was a lack of access roads during the summer (rainy season) to the irrigation schemes, especially for Kulit traditional scheme and the Meri-Megari modern scheme. Hence, I was unable to measure the accumulated sediment before the irrigation season in Kulit traditional scheme. For the rest of the scheme, even though the road was a challenge, I managed to collect sufficient empirical material with the cooperation of the WUA leadership, and most farmers. Except for a few people who were either not able to or not interested in meeting me, I was well-received in both districts.

To avoid the risk of bias, and potential shortcomings of the methods applied, the selection of interviewees was initially based on informants' geographic location with respect to the irrigation scheme (head, middle and tail end users), females, elders, livestock holders, and government officials. Attempts were made to include a larger group of informants, but not everyone that was approached was interested in participating in the research project. A few did not find the time or did not want to talk to me, but this is a common issue when undertaking interviews. The final sample of interviewees was considered acceptable because the collected information reached a level where no new insights were added beyond the ones that had already been expressed. I gathered secondary data from the district and a regional office that have had a stake in the respective schemes.

This Ph.D. project is presented as a collection of articles on various themes from the case study schemes, and they cover different aspects of the research material. Presenting a PhD study in a monograph would have allowed more scope to both include, and elaborate upon, the empirical material collected during this project. The rationale behind presenting the PhD results as a collection of published academic articles is to make my research easily and quickly available.

6.5. Proposed Study Objectives that could not be Attained

Identifying an optimum operation arrangement to reduce sediment deposition in the canals and assessing its implication on the sustainability of the scheme was originally proposed as a key element of this study. This could have allowed investigation of the possibility of instituting

a different operational plan for water distribution to reduce sediment deposition in both a lightly and heavily sedimented SSI scheme. However, a lack of measuring equipment and suitable conditions for measuring sediment deposition in different parts of the canal network precluded the execution of this part of the study.

Qualitative and quantitative data collection was proposed to take place during at least two irrigation seasons. However, I was unable to pursue this objective for two main reasons: one, due to the Covid-19 outbreak and the travel restrictions imposed by Wageningen University, I was unable to do the second-round fieldwork for the second irrigation season which was supposed to take place in the 2020/2021 season. Second, due to the deteriorating safety and security situation in the study area (local instability and lawlessness) caused by the civil war between TPLF and the Ethiopian military, further fieldwork was not feasible⁹.

6.5.1. Positionality and Possible Biases of the Study

I am a graduate of hydraulic and water resources engineering with a bachelor of science from Arba Minch university and a Master's in water science and technology from India agricultural research institute. Both my B.Sc. and Master's courses were exclusively focused on the engineering aspects of the water resources project. Hence, I had a frame of mind that thinks, I am an engineer who can design the engineering infrastructures for water resources, and never considered the sociotechnical influence of the sustainability of the systems. I carried this awareness until I started the PhD. Hence, lack of awareness and practical experience on the social-technical aspect of the water resources system might have challenged me to objectively describe the relationship as it existed (reality). Since reality is impossible to describe (Holmes, 2020). Furthermore, women are rare in the Ethiopian irrigation sector, which is dominated by men, particularly in formal institutions. My being a woman, may have produced a contradictory effect on the interviews I held and the respondents I interviewed. Some male respondents may not have taken my queries on irrigation engineering aspects very seriously, feeling disinclined to share technically relevant information or information that relates to the male-dominated domain in irrigated farming and engineering. On the other hand, women respondents may be inclined to share more sensitive and crucial information on their livelihoods and practices with a woman than with a male researcher.

Moreover, the security situation in Ethiopia required me (as a researcher who doesn't speak their language and woman) to hire an assistant and translator who was well respected and feared in the area for his military acumen. This was important to allow the possibility to enable the doing of fieldwork in uncertain and unsafe times. However, it may have produced certain biases – Respondents might have felt intimidated and not disclosed all relevant aspects of their irrigated livelihoods. Moreover, it made the researcher difficult to approach, informally. The latter normally allows a researcher to receive more insights into what makes

⁹ My field work assistant and translator were murdered for reasons not yet known to date. May he rest in peace.

an irrigation system or household tick, giving an edge akin to 'reading between the lines'. It also constrained the researcher's room for maneuver – all field visits had to be planned, and often involved forms of motorized transport (As some of the schemes are located in remote areas). This constraint resulted in a considerable reduction in the possibility to build relations of trust with respondents, for which casual meetings are often paramount. It also made an overly formal setting to research interactions almost inevitable, which creates the undesired effect of eliciting socially desirable answers on the part of some respondents.

The Covid-19 outbreak and its subsequent restrictions during the pandemic have resulted in a number of constraints and possible biases. The second fieldwork period which was key in deepening the qualitative aspects of my study had to be postponed several times because of travel restrictions. When it ultimately took place, I had to keep it short and very targeted on aspects I considered essential for the validation of key aspects of my research. Thus, a more thorough follow-up on initial research insights could not be undertaken. Once, in the Netherlands, other constraints during the writing phase had to be overcome. Intermittent closures of child-care facilities seriously reduced the possibility for concentrated periods of analysis and writing since part of my time had to be spent on taking care of my two children. Hence a number of supporting training events had to be foregone. It also made the writing phase less efficient than could have been without Covid-19.

6.6. Future Research

This section discusses two main limitations of the chosen research emphasis and approaches, which warrant further research. First, one of the limitations relates to the livestock-irrigation interaction, which this thesis argues is one of the main causes of sedimentation during the irrigation season, as proven by the four-case study small-scale irrigation schemes. However, sediment concentration measurements took place only in one scheme for one irrigation season due to the lack of instruments that could be used during the same irrigation season and the above-mentioned challenges. Considering this, it is recommended to undertake further research to evaluate the extent of sedimentation in a variety of small-scale irrigations for more than one irrigation season to validate whether livestock-irrigation interaction is the main and significant sediment cause *during* the irrigation season.

The second limitation relates to the challenges of collective action, particularly for multiple-use irrigation systems. The proposed analytical framework pays tribute to factors that analyze and explain the process of farmers' willingness to undertake collective governance of SSIs and their sustainability. While Ostrom's design principles and Coward's hydraulic property analysis shed light on farmers' willingness to collectively maintain their SSI system, The study has emphasized supplementary, contextual elements that influence whether SSI programs are maintained or abandoned. There is a varied range of elements that affect collective action in various circumstances. Therefore, further studies should bear out what other contextual

factors are embedded in a specific socio-technical context that may affect farmers' willingness to maintain their gravity canal SSIs and when a tipping point may be reached.

6.7. Overall Conclusion

The research on sedimentation and farmers willingness to maintain their own small-scale irrigation system has provided more insights about the conundrum of livestock-irrigation interaction and the reason why collective action is not straight forward. The findings suggest that a policy gap exists that influences the sustainability of irrigation systems. The research shows that the policy support sustaining small-scale irrigation systems is weak and lacks clear strategies to facilitate smooth user-based operation and maintenance of the irrigation systems. Strategies for development and dissemination of technologies or modernization of the systems also face an implementation challenge due to the weak capacity of the agricultural extension system 'on the ground' and the improper use of the outreach programs for political purposes. Therefore, policy actors at national and regional levels should aim to address the policy gaps by designing clear strategies for the key challenges. Similarly, development partners could strengthen their support to policy processes. For irrigation policy and governance to be successful, various actors must be able to work together for sustaining the irrigation systems and to ensure equity in and sustainability of water use. These actors include water users, Government offices, engineers, developing partners, and researchers. As an engineer and researcher, I am firmly committed to contribute to this goal.

The image features a large, bold, black number '7' centered on a white background. The background is composed of several geometric shapes: a light gray triangle in the top-left corner, a dark gray triangle in the bottom-left corner, and a small gray trapezoidal shape positioned to the left of the number. The number '7' is rendered in a clean, sans-serif font with a slight slant to the right.

7

CHAPTER 7.

References

7. References

- Abera, A., Verhoest, N. E., Tilahun, S. A., Alamirew, T., Adgo, E., Moges, M. M., & Nyssen, J. (2019). Performance of small-scale irrigation schemes in Lake Tana Basin of Ethiopia: technical and socio-political attributes. *Physical Geography*, 40(3), 227-251.
- Agide, Z., Hailelassie, A., Sally, H., Erkossa, T., Schmitter, P. S., Langan, S. J., & Hoekstra, D. (2016). *Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia: Diversity and lessons across schemes, typologies and reaches*: International Livestock Research Institute.
- Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision.
- AUC (2014). Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods Doc. Assembly/AU/2 (Xxiii).
- Awulachew, S., Erkossa, T., & Namara, R. (2010). Irrigation potential in Ethiopia—constraints and opportunities for enhancing the system, International Water Management Institute. *Colombo, Sri Lanka*.
- Awulachew, S. B., & Ayana, M. (2011). Performance of Irrigation: An Assessment at Different Scales in Ethiopia. *Experimental Agriculture*, 47(S1), 57-69. doi:10.1017/s0014479710000955
- Awulachew, S. B., Merrey, D., Kamara, A., Van Koppen, B., Penning de Vries, F., & Boelee, E. (2005). *Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia* (Vol. 98): IWMI.
- Baggio, J. A., Barnett, A. J., Perez-Ibarra, I., Brady, U., Ratajczyk, E., Rollins, N., . . . Janssen, M. A. (2016). Explaining success and failure in the commons: The configural nature of Ostrom's institutional design principles. *International Journal of the Commons*, 10(2), 417-439. doi:10.18352/ijc.634
- Bartram, J., Ballance, R., World Health, O., & United Nations Environment, P. (1996). *Water Quality Monitoring : A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programs*; Jamie, B., Richard, B., Eds. London, UK: E & FN Spon.
- Beegle, K., Christiaensen, L., Dabalen, A., & Gaddis, I. (2016). *Poverty in a rising Africa*: World Bank Publications.
- Bekele, Y., Tadesse, N., & Konka, B. (2012). Preliminary study on the impact of water quality and irrigation practices on soil salinity and crop production, Gergera Watershed, Atsbi-Wonberta, Tigray, Northern Ethiopia. *Momona Ethiopian Journal of Science*, 4(1), 29-46.
- Belaud, G., & Paquier, A. (2001). Sediment diversion through irrigation outlets. *Journal of irrigation and drainage engineering*, 127(1), 35-38.
- Belete, Y., Kebede, H., Biru, E., & Natea, S. (2011). Small-Scale Irrigation Capacity Building Strategy for Ethiopia. *Ministry of Agriculture, Addis Ababa*.

- Bernard, H. R., & Bernard, H. R. (2013). *Social Research Methods: Qualitative and Quantitative Approaches*: Sage, University of Florida, USA.
- Beyene, F. (2009). Exploring incentives for rangeland enclosures among pastoral and agropastoral households in eastern Ethiopia. *Global Environmental Change*, 19(4), 494-502. doi:10.1016/j.gloenvcha.2009.07.002
- Bjornlund, V., Bjornlund, H., & Van Rooyen, A. F. (2020). Why agricultural production in sub-Saharan Africa remains low compared to the rest of the world—a historical perspective. *International Journal of Water Resources Development*, 36(sup1), S20-S53.
- Bolding, A., Post Uiterweer, N., & Schippers, J. (2010). The fluid nature of hydraulic property: a case study of Mukudu, Maira and Penha Longa irrigation furrows in the upper revue river, Manica District. *What role of law in promoting and protecting the productive uses of water by smallholder farmers in Mozambique*, 105-136.
- Bolding, J. (2004). *In hot water. A study on sociotechnical intervention models and practices of water use in smallholder agriculture, Nyanyadzi catchment, Zimbabwe*: Ponsen & Looijen.
- Brits, J., Van Rooyen, M., & Van Rooyen, N. (2002). Ecological Impact of Large Herbivores on The Woody Vegetation at Selected Watering Points on The Eastern Basaltic Soils in The Kruger National Park. *African Journal of Ecology*, 40(1), 53-60.
- Bueno, D. C. (2021). The National Irrigation System in the Philippines: Analysis of issues, impact on agricultural performance and opportunities in Region III. *IMRaD Journal*.
- Chun, N. (2014). The challenge of collective action for irrigation management in India. *Asian Economic Papers*, 13(2), 88-111.
- Collins, A. L., Walling, D. E., McMellin, G. K., Zhang, Y., Gray, J., McGonigle, D., & Cherrington, R. (2010). A preliminary investigation of the efficacy of riparian fencing schemes for reducing contributions from eroding channel banks to the siltation of salmonid spawning gravels across the south west UK. *Journal of Environmental Management*, 91(6), 1341-1349.
- Coward, W. (1986). "State and Locality in Asian Irrigation Development: The Property factor."
- Davis, B., Di Giuseppe, S., & Zezza, A. (2017). Are African households (not) leaving agriculture? Patterns of households' income sources in rural Sub-Saharan Africa. *Food policy*, 67, 153-174.
- De Fraiture, C., & Giordano, M. (2014). Small private irrigation: A thriving but overlooked sector. *Agricultural Water Management*, 131, 167-174.
- Dejen, Z. A., Schultz, B., & Hayde, L. (2012). Comparative irrigation performance assessment in community-managed schemes in Ethiopia. *African Journal of Agricultural Research*, 7(35), 4956-4970.
- Dereje, B., & Yusuf, K. (2015). Determining Sediment Load of Awash River Entering into Metehara Sugarcane Irrigation Scheme in Ethiopia. *Journal of Environment and Earth Science*, 5(13), 110-117.

- Descheemaeker, K., Amede, T., & Hailelassie, A. (2010). Improving water productivity in mixed crop-livestock farming systems of sub-Saharan Africa. *Agricultural Water Management*, 97(5), 579-586. doi:10.1016/j.agwat.2009.11.012
- Descheemaeker, K., Amede, T., & Hailelassie, A. (2010). Improving water productivity in mixed crop-livestock farming systems of sub-Saharan Africa. *Agricultural Water Management*, 97(5), 579-586. doi:10.1016/j.agwat.2009.11.012
- Design-Documents. (2013). *Ejersa Small Scale Diversion Irrigation Project*. Retrieved from
- Dessalegn, H. T., Bolding, A., Fraiture, C. d., & Ayana, M. (2021). Livestock and Small-Scale Irrigation Scheme Interactions as a Key Source for Sedimentation during the Irrigation Season: Four Case Studies from South-West Shoa, Ethiopia. *Sustainability*, 13(10), 5745.
- Eshete, D. G., Sinshaw, B. G., & Legese, K. G. (2020). Critical review on improving irrigation water use efficiency: Advances, challenges, and opportunities in the Ethiopia context. *Water-Energy Nexus*, 3, 143-154.
- Fan, S., & Rue, C. (2020). The role of smallholder farms in a changing world *The role of smallholder farms in food and nutrition security* (pp. 13-28): Springer, Cham.
- FAO (2012). *The state of food insecurity in the world*. Retrieved from Rome: <http://www.fao.org/3/a-i3027e>.
- FAO. (2015). *The state of food insecurity in the world (SOFI) 2015*. Retrieved from Rome: <http://www.fao.org/publications/card/en/c/c2cda20d-ebeb-4467-8a94-038087fe0f6e/>
- FAO. (2016). *The state of food and agriculture*. Rome: FAO. Retrieved from <http://www.fao.org/3/a-i6030e>.
- Fayisa Ertiro, S. P., Negash Wagesho (2017). Evaluation of Failures and Design Practices of River Diversion Structures for Irrigation: A Revisit of Two SSI Schemes in Ethiopia. *International Journal of Earth Sciences and Engineering International Journal of Earth Sciences and Engineering*, 10(03), 495-505. doi:10.21276/ijee.2017.10.0305
- Flemmen, A. B., & Zenebe, M. (2016). Religious Mahbär in Ethiopia: Ritual Elements, Dynamics, and Challenges. *Journal of religion in Africa*, 46(1), 3-31.
- Gari, S. R., Newton, A., Icely, J. D., & Delgado-Serrano, M. M. (2017). An analysis of the global applicability of Ostrom's design principles to diagnose the functionality of common-pool resource institutions. *Sustainability (Switzerland)*, 9(7). doi:10.3390/su9071287
- Gebre-Kiros, F. (1980). Agricultural land fragmentation: a problem of land distribution observed in some Ethiopian peasant associations. *Ethiopian Journal of Development Research*, 4(2), 1-12.
- Gebremedhin, B., Pender, J., & Tesfay, G. (2004). Collective action for grazing land management in crop-livestock mixed systems in the highlands of northern Ethiopia. *Agricultural Systems*, 82(3), 273-290.
- Gebreyohannes, G., & Hailemariam, G. (2011). *Challenges, opportunities and available good practices related to zero grazing in Tigray and Hararghe, Ethiopia*. Retrieved from

- Gebul, M. A. (2021). Trend, Status, and Challenges of Irrigation Development in Ethiopia—A Review. *Sustainability*, 13(10), 5646.
- Gelagay, H. S., & Minale, A. S. (2016). Soil Loss Estimation Using GIS and Remote Sensing Techniques: A Case of Koga Watershed, Northwestern Ethiopia. *International Soil and Water Conservation Research*, 4(2), 126-136.
- Glaser, B. G., & Strauss, A. L. (2017). *Discovery of Grounded Theory: Strategies for Qualitative Research*: Routledge, New Brunswick, USA.
- Gurmu, Z. A., Ritzema, H., de Fraiture, C., & Ayana, M. (2019). Stakeholder Roles and Perspectives on Sedimentation Management in Small-Scale Irrigation Schemes in Ethiopia. *Sustainability*, 11(21), 6121.
- Habtu, S., & Yoshinobu, K. (2006). Traditional irrigation management in Betmera-Hiwane, Ethiopia: The main peculiarities for the persistence of irrigation practices. *Journal of Mountain Science*, 3(2), 139-146.
- Hagos, F., Makombe, G., Namara, R. E., & Awulachew, S. B. (2009). Importance of Irrigated Agriculture to the Ethiopian Economy: Capturing the Direct Net Benefits of Irrigation. *IWMI Research Reports Series*(128).
- Haile, G. G., & Kasa, A. (2015). Irrigation in Ethiopia: A review. *Academia Journal of Agricultural Research*, 3(10), 264-269.
- Hanemann, M. (2014). Property rights and sustainable irrigation-A developed world perspective. *Agricultural Water Management*, 145, 5-22. doi:10.1016/j.agwat.2014.07.001
- Hanjra, M. A., & Gichuki, F. (2008). Investments in Agricultural Water Management for Poverty Reduction in Africa: Case sStudies of Limpopo, Nile, and Volta river basins. *Natural Resources Forum*, 32(3), 185-202. doi:10.1111/j.1477-8947.2008.00191.x
- Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D. T., Fenta, A. A., . . . Adgo, E. (2017). Comprehensive Assessment of Soil Erosion Risk for Better Land Use Planning in River Basins: Case Study of the Upper Blue Nile River. *Science of the Total Environment*, 574, 95-108.
- Holmes, A. G. D. (2020). Researcher Positionality--A Consideration of Its Influence and Place in Qualitative Research--A New Researcher Guide. *Shanlax International Journal of Education*, 8(4), 1-10.
- Jelsma, I., Slingerland, M., Giller, K. E., & Bijman, J. (2017). Collective action in a smallholder oil palm production system in Indonesia: The key to sustainable and inclusive smallholder palm oil? *Journal of Rural Studies*, 54, 198-210. doi:10.1016/j.jrurstud.2017.06.005
- Kassie, A. E. (2019). Challenges and Opportunities of Irrigation Practices in Ethiopia: A Review. *Journal of Engineering Research and Reports*, 1-12.
- Kidane, D., & Alemu, B. (2015). The Effect of Upstream Land Use Practices on Soil Erosion and Sedimentation in the Upper Blue Nile Basin, Ethiopia. *Research Journal of Agriculture and Environmental Management*, 4(2), 55-68.

- Kiprop, J., Mulungu, K., Kibet, N., & Macharia, A. (2017). Determinants of smallholder farmers' willingness to pay for irrigation water in Kerio Valley basin, Kenya. *Journal of Sustainable Development*, 10(2), 135-142.
- Kloezen, W., & Mollinga, P. P. (1992). Opening closed gates: recognizing the social nature of irrigation artefacts *Irrigators and engineers* (pp. 53-64): Thesis Publ.
- Kloos, H. (1991). Peasant irrigation development and food production in Ethiopia. *Geographical Journal*, 295-306.
- Komakech, H. C., Van Der Zaag, P., & Van Koppen, B. (2012). The dynamics between water asymmetry, inequality and heterogeneity sustaining canal institutions in the makanya catchment, Tanzania. *Water Policy*, 14(5), 800-820. doi:10.2166/wp.2012.196
- Lambisso Wamiso, R. (2008). Assessment of Design Practices and Performance of Small-scale Irrigation Structures in South Region, M Sc Thesis *International Water Management Institute (IWMI)*, 47-57. doi:10.20372/nadre:1554185374.2
- Lenton, T. M. (2020). Tipping positive change. *Philosophical Transactions of the Royal Society B*, 375(1794), 20190123.
- Line, D., Harman, W., Jennings, G., Thompson, E., & Osmond, D. (2000). Nonpoint-source pollutant load reductions associated with livestock exclusion. *Journal of Environmental Quality*, 29(6), 1882-1890.
- Madden, D., Harrison, S., Finn, J. A., & Huallacháin, D. Ó. (2019). The Impact of Cattle Drinking Points on Aquatic Macroinvertebrates in Streams in South-East Ireland. *Irish Journal of Agricultural and Food Research*, 58(1), 13-20. doi:10.2478/ijafr-2019-00021
- Makarigakis, A. K., & Jimenez-Cisneros, B. E. (2019). UNESCO's contribution to face global water challenges. *Water*, 11(2), 388.
- Makombe, G., Namara, R., Hagos, F., Awulachew, S. B., Ayana, M., & Bossio, D. (2011). *A Comparative Analysis of the Technical Efficiency Of Rain-Fed and Smallholder Irrigation in Ethiopia* (Vol. 143): IWMI, Colombo, Sri Lanka.
- McMichael, A. J., Powles, J. W., Butler, C. D., & Uauy, R. (2007). Food, livestock production, energy, climate change, and health. *The lancet*, 370(9594), 1253-1263. doi:10.1016/S0140-6736(07)61256-2
- Meinzen-Dick, R. (2014). Property rights and sustainable irrigation: A developing country perspective. *Agricultural Water Management*, 145, 23-31. doi:10.1016/j.agwat.2014.03.017
- Meul, M., Van Passel, S., Fremaut, D., & Haesaert, G. (2012). Higher sustainability performance of intensive grazing versus zero-grazing dairy systems. *Agronomy for Sustainable Development*, 32(3), 629-638.
- Miao, S., Heijman, W., Zhu, X., & Lu, Q. (2015). Social capital influences farmer participation in collective irrigation management in Shaanxi Province, China. *China Agricultural Economic Review*.
- Morales, A., & Mongcopa, C. (2008). Best Practices in Irrigation and Drainage Learning from Successful Projects: A Case study from 2006 Annual Evaluation Review: Asian Development Bank, Manila, Philippines.

- Munir, S. (2011). *Role of Sediment Transport in Operation and Maintenance of Supply and Demand Based Irrigation Canals: Application to Machai Maira Branch Canals: UNESCO-IHE PhD Thesis*. Boca Raton, FL, USA: CRC Press.
- O' Sullivan, M., Ó hUallacháin, D., Antunes, P. O., Jennings, E., & Kelly-Quinn, M. (2019). The Impacts of Cattle Access Points on Deposited Sediment Levels in Headwater Streams in Ireland. *River research and applications*, 35(2), 146-158.
- O' Sullivan, M., Huallacháin, D. Ó., Antunes, P. O., Jennings, E., & Kelly-Quinn, M. (2019). The Impacts of Cattle Access to Headwater Streams on Hyporheic Zones. *Biology and Environment*, 119B(1), 13-27. doi:10.3318/bioe.2019.02
- O'Callaghan, P., Kelly-Quinn, M., Jennings, E., Antunes, P., O'Sullivan, M., Fenton, O., & Huallachain, D. O. (2019). The Environmental Impact of Cattle Access to Watercourses: A review. *Journal of Environmental Quality*, 48(2), 340-351. doi:10.2134/jeq2018.04.0167
- Okoth, A. B., & Mbugua, J. (2018). Factors influencing small scale farmers' participation in management of Gem Rae irrigation scheme in Nyando Sub-County, Kisumu County, Kenya. *International Academic Journal of Information Sciences and Project Management*, 3(2), 394-417.
- Ostrom, E. (1990). *Governing the Commons: The Evolution Of Institutions For Collective Action*: Cambridge University Press.
- Ostrom, E. (1992). Institutions and common-pool resources. *Journal of Theoretical Politics*, 4(3), 243-245. doi:10.1177/0951692892004003001
- Ostrom, E. (1993). Design principles in long-enduring irrigation institutions. *Water Resources Research*, 29(7), 1907-1912. doi:10.1029/92WR02991
- Ostrom, E. (2010). Analyzing collective action. *Agricultural economics*, 41, 155-166.
- Ostrom, E., & Gardner, R. (1993). Coping with asymmetries in the commons: self-governing irrigation systems can work. *Journal of economic perspectives*, 7(4), 93-112.
- Otsuka, K., & Place, F. M. (2001). *Land tenure and natural resource management: A comparative study of agrarian communities in Asia and Africa*: Intl Food Policy Res Inst.
- Peden, D., Freeman, A., Astatke, A., Notenbaert, A., Ayalneh, W., Baltenweck, I., . . . Faki, H. (2006). *Investment options for integrated water-livestock-crop production in sub-Saharan Africa*. Retrieved from
- Pekor, A., Miller, J. R., Flyman, M. V., Kasiki, S., Kesch, M. K., Miller, S. M., . . . Lindsey, P. A. (2019). Fencing Africa's protected areas: Costs, benefits, and management issues. *Biological Conservation*, 229, 67-75. doi:10.1016/j.biocon.2008.09.022
- Ringler, C., Mekonnen, D. K., Xie, H., & Uzunamure, A. M. (2020). Irrigation to transform agriculture and food systems in Africa South of the Sahara. *2020 Annual trends and outlook report: Sustaining Africa's agrifood system transformation: The role of public policies*, 57-70.
- Roder, W. (1965). *Sabi Valley irrigation projects*. Chicago Illinois.
- RVO/NWP. (2015). Ethiopia, Positioning Survey for the Dutch water sector.

- Shaimaa A. Theol, C. d. e. F., F.X. Suryadi. Understanding cohesive sediments behaviour in irrigation canals using delft 3d model simulation; in preceding of the 2nd world irrigation Forum, 6-8 Nov. Chaing Mai, Thailand (2016).
- Sileshi, Z., Tegegne, A., & Tsadik, G. T. (2003). Water Resources for Livestock in Ethiopia: Implications for Research and Development. *Integrated water and land management research and capacity building priorities for Ethiopia, Vol. 66*, 66-77.
- Takayama, T., Matsuda, H., & Nakatani, T. (2018). The determinants of collective action in irrigation management systems: Evidence from rural communities in Japan. *Agricultural Water Management*, 206, 113-123. doi:<https://doi.org/10.1016/j.agwat.2018.04.031>
- Tamene, L., Park, S., Dikau, R., & Vlek, P. (2006). Analysis of Factors Determining Sediment Yield Variability in The Highlands of Northern Ethiopia. *Geomorphology*, 76(1-2), 76-91.
- Theol, S. A., C. de Fraiture, & Surya, F. X. (2016). *Understanding Cohesive Sediments Behaviour in Irrigation Canals Using Delft 3d Model Simulation*. Paper presented at the 2nd World Irrigation Forum, 6-8 Nov., Chaing Mai, Thailand.
- Tolera, T. (2017). The Problems, Opportunities and Implications of Small-Scale Irrigation for Livelihood Improvement in Ethiopia-A Review. *Civil and Environmental Research* 9, 27-34.
- Tushaar shah, R. N., Abhishek Rajan. (2020). *Accelerating Irrigation Expansion in Sub-Saharan Africa*. Retrieved from
- UNICEF. (2021). The state of food security and nutrition in the world 2021.
- Van Ginkel, K. C., Botzen, W. W., Haasnoot, M., Bachner, G., Steininger, K. W., Hinkel, J., . . . De Murieta, E. S. (2020). Climate change induced socio-economic tipping points: review and stakeholder consultation for policy relevant research. *Environmental Research Letters*, 15(2), 023001.
- Widgren, M., & Sutton, J. E. (2004). *Islands of intensive agriculture in Eastern Africa: Past & present*.
- Wilson, R. T. (2007). Perceptions, Practices, Principles and Policies in Provision of Livestock Water in Africa. *Agricultural Water Management*, 90(1), 1-12. doi:10.1016/j.agwat.2007.03.003
- Wolancho, K. W. (2012). Watershed Management: An Option to Sustain Dam and Reservoir Function in Ethiopia. *Journal of Environmental Science and Technology*, 5(5), 262-273.
- World Bank. (2008). World development report 2008: agriculture for development.
- Yami, M. (2013). Sustaining participation in irrigation systems of Ethiopia: what have we learned about water user associations? *Water Policy*, 15(6), 961-984.
- Yami, M. (2016). Irrigation projects in Ethiopia: What can be done to enhance effectiveness under 'challenging contexts'? *International Journal of Sustainable Development and World Ecology*, 23(2), 132-142. doi:10.1080/13504509.2015.1057628

- Yohannes, D. F., Ritsema, C., Solomon, H., Froebrich, J., & Van Dam, J. (2017). Irrigation water management: Farmers' practices, perceptions and adaptations at Gumselassa irrigation scheme, North Ethiopia. *Agricultural Water Management*, *191*, 16-28.
- You, L., Ringler, C., Wood-Sichra, U., Robertson, R., Wood, S., Zhu, T., . . . Sun, Y. (2011). What is the irrigation potential for Africa? A combined biophysical and socioeconomic approach. *Food Policy*, *36*(6), 770-782.
- Zelege, A. D., Bart, S., & Laszlo, H. (2012). Comparative irrigation performance assessment in community-managed schemes in Ethiopia. *African Journal of Agricultural Research*, *7*(35), 4956-4970.



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APPENDICES

Summary

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Acknowledgements

List of Publications

SENSE Education Certificate

Summary

Small-scale irrigation development is considered a key strategy for developing countries to maintain food security and eradicate poverty. However, its expansion in sub-Saharan Africa has experienced an endless loop, with new systems being constructed while a majority of the existing systems underperform, with some being partially or fully abandoned. Excessive sedimentation and inadequate maintenance are the major causes of underperformance and abandonment. It has proven impossible to mobilize sufficient funds and labour to perform proper and timely maintenance. The existing mitigation strategies for sediment management in small-scale irrigation have not been successful for two reasons. First, all prior policies were focused on reducing sedimentation either through measures aimed at upstream catchment conservation or technical measures to deal with suspended sediments entering the system from the main intake. Both sets of measures overlook the problem of in-season sedimentation caused by livestock-irrigation interactions. Second, none of the past policies achieved effective forms of user governance and participation, precipitating SSI scheme collapse and abandonment.

To fill these gaps, this study considered four small-scale irrigation schemes in Ethiopia, which differ in sediment-loads (light to heavily sedimented) and functionality (traditional and modern, fully functional and abandoned). Both a qualitative and quantitative approach was used to analyse four specific research questions. First, the study determines that livestock-irrigation interaction is the primary factor causing sedimentation *during* the irrigation season. Second, the study disentangles the livestock-irrigation conundrum and explores the challenges of coming up with effective solutions, such as collective action for canal cleaning. Thirdly, the study presents a framework to understand sustenance or abandonment of SSI systems that goes beyond Coward's hydraulic property theory and Ostrom's institutional design principles for sustainable collective action. It addresses contextually established factors that affect farmers' willingness to maintain small-scale irrigation systems, thus engaging with the governance process in action. Finally, a policy brief is presented offering suggestions for improving SSI sustainability in Ethiopia and elsewhere. The study concludes that policy support for small-scale irrigation systems is weak, lacking clear strategies to ensure the irrigation systems' efficient user-based operation and maintenance. Strategies for the development and dissemination of effective technologies through the modernization of systems also encounter severe implementation problems. The thesis ends by charting a way for all stakeholders (regional office, development partners, users, researchers, engineers) to create a clear and effective strategy that addresses the key challenges affecting the SSI sector.

ማጠቃለያ

አነስተኛ የመስኖ ልማት የምግብ ዋስትናን ለማስጠበቅ እና ድህነትን ለማጥፋት ቁልፍ መላ ተደርጎ ይወሰዳል። ነገር ግን ከሰሃራ በታች ባሉ የአፍሪካ አገሮች በጣም ብዙ እንቅፋቶች አጋጥመውታል። ማለትም ነባር መስኖዎች በከፊል ወይም ሙሉ ለሙሉ አገልግሎት የማይሰጡ ቢሆንም እንኳን፣ በትኩረት እየተሰራ ያለው የአዳዲስ የመስኖ ግንባታዎች በመሆናቸው የቀደምቶቹን መስኖዎች ችግሮች የሚደግሙ ናቸው። መስኖዎች በአግባቡ አገልግሎት እንዳይሰጡ እና ወጤታማነታቸው እንዲቀንስ ብሎም አገልግሎታቸው እንዲቋረጥ ካደረጉ ምክንያቶች መካከል፣ በግድብ እና በመስኖ በዮች ወስጥ ከመጠን ያለፈ ደለል መሙላት፣ በቂ ያልሆነ የደለል ጠረጋ እንዲሁም ተገቢ እና ወቅታዊ ጥገና ማካሰን ዋና ዋናዎቹ ናቸው። ተገቢውን እና ወቅታዊ ጥገናን ለማከናወን የገንዘብና የሰው ሀይል እጥረት እንዳለ የጥናቱ ግኝት ያመለክታል። በአነስተኛ መስኖ መሰረተ ልማት ላይ ያለውን የደለል ክምችት የመቀነስ እርምጃዎች በሁለት ምክንያቶች ውጤታማ ሊሆኑ አልቻሉም። በመጀመሪያ ደረጃ፣ ሁለቱም ቀደምት የፖሊሲ ስብስቦች በላይኛው ተፈሰስ ላይ የሚፈጠረውን የአፈር መሸርሸር እና ጥበቃ ላይ ያተኮሩ ወይም ደግሞ ቴክኒካል መላዎችን በመጠቀም ከወንዞች ወደ መስኖ ግድቦች የሚገቡትን ተንሳፋፊ ደለሎች የመቀነስ አላማ ላይ ያተኮሩ እርምጃዎች መሆናቸው ነው። በዚህም ምክንያት የደለል መቀነሻ እርምጃው ችግሩን ሙሉ ለሙሉ የማይሳይና በእንስሳት-መስኖ መስተጋብር ምክንያት የሚፈጠረውን ደለል ችላ ያለ ነው። በተጨማሪም ፖሊሲዎቹ ተጠቃሚውን ያላካተቱ መሆናቸው ሌላ ችግር ነው። ይህ ጥናት በኢትዮጵያ ውስጥ የሚገኙ አራት አነስተኛ የመስኖ መሰረተ ልማቶችን ተመልክቷል። ጥናቱ አራት የምርምር ጥያቄዎችን አቅርቦ የመለስ ሲሆን መረጃዎቹን ለመሰብሰብና ለመተንተን አይነታዊ (qualitative) እና መጠናዊ (quantitative) ዘዴዎችን ተጠቅሟል። የትንተናው አደረጃጀትም በደለል-ክምችት (ቀላል እና ከባድ)፣ በአይነት (ባህላዊ እና ዘመናዊ) እንዲሁም በአገልግሎት አሰጣጥ (ሙሉ በሙሉ ወይም በከፊል አገልግሎት ያቋረጠ) መስኖ ግድቦችን አጥቷል። የጥናቱ ውጤት የሚያሳየውም በመጀመሪያ ደረጃ በመስኖ ወቅት ደለል እንዲፈጠር ቀዳሚው ምክንያት የአንስሳትና የመስኖ መስተጋብር መሆኑን አረጋግጧል ። ጥናቱ በሁለተኛ ደረጃ የመስኖና የ እንስሳቶችን መስተጋብር በጥልቀት በመመልከት ቀደምት የደለል መቀነሻ መላዎች ያላቸውን ክፍተት በመረዳት ውጤታማ የመፍትሄ ሀሳቦችን ጠቁሟል። በሰብተኛ ደረጃ፣ ጥናቱ የአነስተኛ መስኖ ግድብ ዘላቂነትን ወይም አለመጠቀምን ለመረዳት ኮዋርድ ሀይድራሊክ ፕሮፕርቲ (Coward Hydraulic Property) ንድፈ ሃሳብ እና ከአስተርም ዲዛይን ፕሪንሰፕልስ (Ostorom Design Principles) ባሻገር ዘለቄታዊ የጋራ ተግባርን ለመረዳት የሚያስችል ንድፈ መዋቅር አቅርቧል። አርሶ-አደሮቹ አነስተኛ የመስኖ ግድቦችን ለመጠበቅ እና ለመጠገን ያላቸውን ፍላጎት የሚቀንሱ በወውድ ላይ የተመሰረቱ ምክንያቶችን (Contextually established factors) ዳሷል። በመጨረሻም በኢትዮጵያ እና በሌሎች ሀገራት የአነስተኛ መስኖ ግድብ ዘላቂነትን ለማሻሻል ሀሳቦችን የሚሰጥ አጭር የፖሊሲ መግለጫ አቅርቧል። የጥናቱ ማጠቃለያ የሚያሳየው የአነስተኛ መስኖ ግድብ አስተዳደሮችን ደካማነት፣ የመስኖ ተጠቃሚውን መሰረት ያላደረጉ እና ጥገናዎችን ለማከናወን ግልጽና ምቹ አሰራር የለሌላቸው መሆኑን ነው። በተጨማሪም የመስኖ ግድቦችን ለማዘመን የሚያስችሉ ቴክኖሎጂዎችን የመተግበር ችግሮችም እንዳሉ ተዳሷል። በመጨረሻም በሁሉም ባለድርሻ አካላት ፣ ማለትም፣ የክልሉ መስተዳድር፣ የልማት አጋሮች፣ ተጠቃሚዎች፣ ተመራማሪዎች እና መሐንዲሶች ፣ የአነስተኛ መስኖ ዘርፍን ድርሻ የሚመለከቱ ቁልፍ ተግዳሮቶችን ለመቅረፍ የሚያስችላቸው ግልጽ እና ውጤታማ ስትራቴጂ ለመፍጠር የሚያስችል መንገድ አቅርቧል።

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Short Biography

Mrs. Hanan Tadele is a highly motivated and enthusiastic individual with over 10 years of experience in academia and research. She holds a bachelor's degree in hydraulic and water resources engineering from Arba Minch University and a master's degree in water science and technology from the Indian Agricultural Research Institute. She worked as a lecturer and researcher at Arba Minch University before pursuing a PhD at Wageningen University, Netherlands, where she studied sedimentation, livestock, and farmers' willingness to maintain small-scale irrigation schemes in Ethiopia. Her research and professional interests are in sustainable water resource management through the integration of water, technology, and society.

List of Publication

Dessalegn H.T., Bolding A., Fraiture, C.d., and Ayana, M. (2021). Livestock and Small-Scale Irrigation Scheme Interactions; As a Key Source for Sedimentation during the Irrigation Season: four case studies from South-West Shoa, Ethiopia. *Sustainability*, 2021, 13,5745. Doi:10.3390/su13105745

Dessalegn H.T., Bolding A., Fraiture, C.d., and Ayana, M. (2022). Livestock-Irrigation Interaction and Its Influence on the Sustainability of Small-Scale Irrigation Schemes in Ethiopia *Irrigation and drainage journal* (under review)

Dessalegn H.T., Bolding A., Fraiture, C.d., and Ayana, M. (2022). Key factors influencing farmers' willingness to maintain Small-Scale Irrigation systems in Ethiopia – going beyond Ostrom's design principles for successful collective action *Water SA journal* (Under review)

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Conference

Factors affecting farmers willingness to maintain small scale irrigations schemes in Ethiopia; beyond Ostrom Design principles. Delft international conference on Sociohydrology, 6-8 September 2021, Delft, The Netherlands.



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Oral Presentations

- o *Factors affecting farmers willingness to maintain small scale irrigations schemes in Ethiopia; beyond Ostrom Design principles.* Delft international conference on Sociohydrology, 6-8 September 2021, Delft, The Netherlands

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