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Stakeholder Roles and Perspectives on Sedimentation Management in Small-Scale Irrigation Schemes in Ethiopia

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Abstract: Irrigated agriculture, particularly small-scale irrigation (SSI), is a mainstay for sustainable livelihoods in the developing world. In Ethiopia, SSI sustainability is threatened mainly due to excessive sedimentation. Stakeholders' perceptions of the causes of sedimentation and how they sustain SSI under excessive sedimentation conditions were investigated in two SSI schemes in Ethiopia. A participatory rapid diagnosis and action planning was implemented, consisting of a literature review, participatory rural appraisal, and semi-structured interviews. Results show that farmers slightly differed in perception of excessive sedimentation drivers. Farmers reported design problems as the main cause of excessive sedimentation (64%), followed by poor operation and maintenance (O and M) practices (21%) and external factors (15%). In contrast, 62% of the interviewed engineers indicated erosion and irrigation technologies as the main causes of excessive sedimentation, while few reported poor design (13%). In addition to an intensive desilting campaign, farmers delayed the start of the irrigation season to avoid the intake of highly sedimented water. Local social capital and knowledge appeared to be more important than formal knowledge and blue-print institutions for dealing with sedimentation problems. Well-organized structure and extra time devoted by famers were vital for SSI sustainability. Integration of the farmers' knowledge with that of the engineers could yield more effective ways to deal with sedimentation problems.

Keywords: small-scale irrigation; sedimentation; farmers; water user association (WUA); indigenous knowledge; perception

1. Introduction

Irrigated agriculture is a prime sector to ensure food security, alleviate poverty, and promote economic development in the developing world [1]. Small-scale irrigation (SSI) schemes in particular make a massive contribution to national economies in many developing countries, while also serving as an incubator for collective action [2]. Nonetheless, "traditional" SSI schemes are largely overlooked by states [3]. Governments prefer the development of more "modern" irrigation schemes, considering "farmer-led" irrigation schemes "inefficient", "unproductive" and "traditional" [4–6]. To date in Africa, however, the total area under SSI schemes is much larger than that under medium- and large-scale irrigation [3,7].

In Ethiopia, traditional SSI schemes accounted for 80% of the total irrigated land in 2018/2019 [8]. Ethiopia's largest region, Oromia Regional State (28.66 million ha), had 612 modern irrigation schemes in 2016/2017, compared to 9379 "traditional" and 63,523 pump irrigation schemes, according to data from the Oromia Irrigation Development Authority (OIDA) [9]. However, the contribution of all these schemes to Ethiopia's national economy has been much diminished due to the underperformance of the systems [10,11]. Indeed, most are either non-functional or operate far under their potential [12,13]. For instance, in Oromia Regional State alone, 109 (18%) of the modern schemes and 8,508 (13%) of the pump schemes were reported to be inoperative or semi-functional in 2017 (Figure 1). Several explanations have been given for this underperformance, such as design failure and poor design, excessive sedimentation in the headwork and main canal, scouring damage, poor scheme management, and inferior institutional set-up [2,12,14–16].

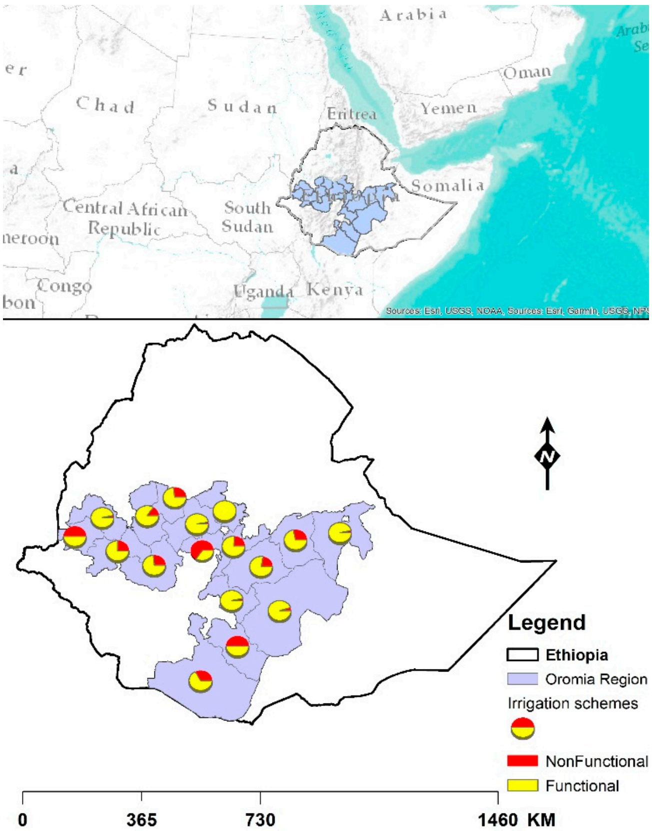


Figure 1. Functional and non-functional irrigation schemes in Oromia Regional State, Ethiopia (source: Oromia Irrigation Development Authority, 2016).

Ethiopia experience the most serious erosion in the world [17–19], one of the most significant adverse environmental problem in developing countries. Excessive sedimentation in irrigation systems gradually blocks the flow of irrigation water, causes water stress and unfair distribution [20], damages infrastructure, and may trigger the complete collapse of irrigation systems. Since irrigation is a major consumer of water [21,22], the loss of water due to damage to infrastructure by excessive sedimentation results in a decline in water availability and increased competition among different water uses and users. The management of sedimentation in irrigation systems requires large and continual maintenance and operation investments [23]. In farmer-managed irrigation schemes, excessive sedimentation places a huge maintenance burden on farmers, in addition to their other farming activities (Figure 2). Irrigation canals with excessive sedimentation are generally collectively dredged, with farmers who are perceived as not doing their share of the work sanctioned. This, however, may generate farmer dissatisfaction and conflicts, possibly undermining collective action and social interaction.

Figure 2. Farmers dredging sediment from a main canal (sediment hotspot section) at Ketar irrigation scheme (August 2017).

Farmers introduced irrigation systems and through decades of experience have developed ways of dealing with excessive sedimentation [6]. Nonetheless, states have tended to overlook this indigenous knowledge. Instead, they have turned their focus to "modernizing" schemes, in the conviction that modernization will deliver improved irrigation performance [4–6]. Yet, without technology appropriation by farmers (i.e., farmers' adoption and adaptation of modern technology to their own setting), modernization of farmer-managed irrigation schemes may actually aggravate the problem of excessive sedimentation. This is because farmers' knowledge about the sedimentation problem may be overlooked and inadequate information and resources/technologies may be available locally for the farmers to undertake operation and maintenance of the system, whereas farmers are the best sources of information and knowledge about their localities [24–27].

Weak institutions for the management of schemes and poor operation and maintenance practices followed by users are also among the major contributors to the problem of excessive sedimentation [2,12,14]. As excessive sedimentation in irrigation schemes is inevitable, strong institutions for scheme operation and maintenance can play a crucial role in reducing the problem. To craft strong institutions for appropriate management of excessive sedimentation, it is essential that local values, norms, and knowledge be considered, as well as the diversity of irrigators, while also ensuring participation of and consultation with all the concerned stakeholders [6,28–30]. This is particularly so in a country like Ethiopia, where social capital is rooted in local groupings organized around religious, burial, and wedding ceremonies, community savings, and loan services. Such local associations serve as platforms for communication and conflict resolution, which are also highly valuable for the sustainable management of irrigation schemes [31]. For instance, farmers value the "traditional or informal" conflict resolution mechanism higher than the "formal" legal system. Often, they discuss issues of scheme management on indigenous social gatherings, such as wedding or burial ceremonies.

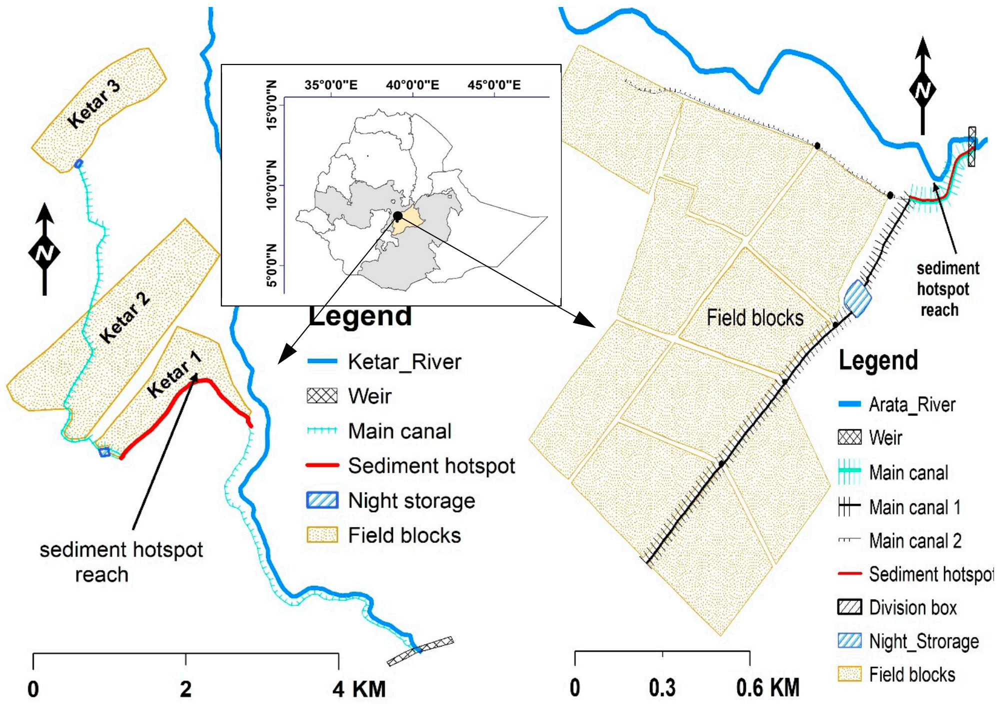
Despite the foremost role of local norms, values, and knowledge, as well as institutions and stakeholders, in managing excessive sedimentation in irrigation schemes, few studies address these aspects directly. Most research rather investigates sediment transport, focusing essentially on understanding sedimentation processes and modelling sediment transport [20,23,32–37]. Improved operation and maintenance of the system and real and coordinated participation of concerned stakeholders are crucial in dealing with excessive sedimentation problems. The current study therefore looks at stakeholder perceptions of the problem of excessive sedimentation and their roles in its management. We applied a collaborative and participatory approach to analyze sedimentation management practices in two irrigation schemes in Ethiopia. The results of the analysis are presented, followed by a discussion of the influence of institutions and scheme modernization.

2. Materials and Methods

2.1. Study Area

2.1.1. Location and Description of the Study Area

Two irrigation schemes in Oromia Regional State in the Great Rift Valley Basin of central Ethiopia, an area seriously affected by land degradation and erosion, were selected: Ketar medium-scale irrigation scheme and the Arata-Chufa small-scale irrigation scheme (Figure 3). The main reason to select these schemes was that farmers manage to keep the irrigation system in good working order despite the excessive sedimentation problems.



(**a**) (**b**)

Figure 3. Location of the study area with the two case-study irrigation schemes: (**a**) the Ketar medium-scale irrigation scheme; (**b**) the Arata-Chufa small-scale irrigation scheme.

In addition, the following criteria were applied in selecting the case study sites: (i) the scheme should be a gravity/diversion type, making use of river runoff; (ii) the scheme of interest should utilize a river as its water source; (iii) the scheme should be managed exclusively by farmers or an irrigation community; (iv) the users should have a relatively long period of experience in water and sediment management; (iv) the scheme should be functional for a relatively long period; (vi) management of the scheme should face relatively severe sedimentation problems; and (vii) a water user association (WUA) should be active in scheme operation and management.

Ketar is medium-scale irrigation scheme, located at 7°49 N and 39°02 E, covering 430 ha, with an average elevation of 2294 m above mean sea level. Having a total main canal length of 12.1 km, the scheme consists of three sections: Ketar 1 (Ketar Genet), covering 110 ha and providing water to 289 households; Ketar 2 (Ketar Golja), covering 200 ha and providing water to 415 households; and Ketar 3 (Hamsa Gasha), covering 120 ha and providing water to 370 households. Each section has its own independent water users' association (WUA). The scheme is affected by sedimentation problems both from the river and overland flow sources.

Arata-Chufa is small-scale irrigation scheme, located at 7°59 N and 39°02 E, covers 100 ha, with an average elevation of 1740 m above mean sea level. This scheme's two main canals have a total length of 1.19 km, and supply water to 10 irrigation blocks. The water users' association of the scheme is one of the well-organized WUAs in the country. The scheme is mainly affected by sediment from the River sources.

2.1.2. Climatic Conditions

Rainfall is bimodal in the study region. There is a long rainy season ("Meher") from June to September, a dry season ("Bega") from October to January and a short rainy season ("Belg") from February to May (Table 1). Maximum and minimum temperatures at the Ketar scheme are 27 °C and 8.5 °C, respectively. The temperature range is wider at the Arata-Chufa scheme, from a maximum of 35 °C to a minimum of 5 °C. In the Ketar area, mean annual rainfall is 800 mm, and it is 620 mm in the Arata-Chufa scheme vicinity (2012–2016 data). The dry and short rainy periods are the main seasons for irrigated agriculture with mainly cash crops planted. The long rainy period provides the main cropping season for cereals, which are widely planted under rainfed conditions. The dry and short rainy periods are the main seasons for irrigated agriculture with mainly cash crops planted. Cereals are also cultivated to a limited extent in the short rainy period under rainfed condition.

Table 1. Mean monthly climatic and cropping data in the study area, from the meteorological stations at Ogolcho (11 km from Arata-Chufa scheme) (2012–2015) and Kulumsa (25 km from Ketar scheme) (2012–2016).

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Season	**Bega**	**Belg (Light Rain)**				**Meher/Kiremt (Rainy)**				**Bega (Dry)**			
Ogolcho Station													
Rainfall (mm)	0	6	49	48	49	55	160	111	99	45	1	0	621
Temperature (°C)	19	21	22	23	23	23	21	22	21	20	20	18	23
Kulumsa Station													
Rainfall (mm)	3	9	47	55	113	77	150	117	150	67	10	3	801
Temperature (°C)	17	18	20	19	19	19	18	16	17	17	17	16	20
Evaporation (mm) (Average monthly from 2012–2015)	196	193	206	176	159	129	104	92	87	185	151	185	206
Crops	=>	<= vegetables =>				<= cereals =>				<= cereals & veg			
IR [1] or RF [2]	=>	<= irrigation & rainfed =>				<= rainfed =>				<= irrigation			

[1] Irrigation; [2] Rainfed.

2.1.3. Irrigated Area and Layout

The Arata-Chufa scheme initially had an irrigated area of 100 ha. Land redistribution activities in 1994/1995 resulted in an average landholding of 0.5 ha (Table 2). At the time of this study (October 2016 to August 2017), the irrigated area had expanded to 120 ha, as irrigation had progressively attracted more users. Likewise, for the Ketar scheme, the initially planned area of 110 ha had expanded to 128 ha, also due to increasing demand. Beneficiary numbers had risen in both the Arata-Chufa and Ketar schemes, respectively, from 324 to 374, and from 280 to more than 680.

Table 2. Irrigated area and numbers of households of the Ketar and Arata-Chufa irrigation schemes ([38]; Arata Chufa and Ketar WUA Office; Personal communication, January 2016).

Ketar	**MC [1] = 2 (1190 m), SC [2] = 8 (3712 m, Division Box = (6), Area Boundary = (10)**		
Subsections	Ketar 1	Ketar 2	Ketar 3
Area	120	200	110
Households (no)	289	415	370

Arata-Chufa	**MC = 2 (1190 m), SC = 8 (3712 m), Division Box = (6), Area Boundary = (10)**										
Field block	1	2	3	4	5	6	7	8	9	10	Total
Area (ha)	10.1	9.9	9.9	10.1	9.9	9.9	10.2	9.6	9.9	9.9	100
Households (no)	36	30	32	36	32	30	35	32	31	30	324

[1] main canal; [2] secondary canal.

2.1.4. Farming System

The study area is characterized by a traditional livestock-based mixed-farming system, with both crop production and animal husbandry. Predominant rainfed crops are food grains and pulses, including wheat, barley, teff, maize, beans, and haricot beans. Teff, onion, potato, cabbage, carrot, and tomato are the main crops grown under irrigation.

2.2. Participatory Rapid Diagnosis and Action Planning Approach

A participatory rapid diagnosis and action planning approach [39] was implemented to identify the causes of excessive sedimentation in irrigation schemes, to analyze the perception of stakeholders on the cause of excessive sedimentation problems and their solutions to perceived causes, and to scrutinize how irrigation systems has sustained under excessive sedimentation conditions by the farmers. This consisted of the following steps:

- A literature review of policy documents, such as the Ethiopia Growth and Transformation Plan, irrigation performance reports, and other written materials from government and non-government sources;
- Semi-structured interviews with selected professionals, WUA members, and farmers to understand their roles in managing excessive sedimentation and their perceptions of the drivers of excessive sedimentation, as well as to understand operation and maintenance practices and farmers' involvement in the schemes;
- A participatory rural appraisal (PRA) of both irrigation schemes, including transect walks, resource map, structured direct observation, cropping calendars, and stakeholder analysis.

One hundred semi-structured interviews were conducted with selected professionals, WUA members, and farmers (Table 3). Interview subjects were selected based on the location of their farmlands and their roles and responsibilities in scheme management. At Ketar 1, three farmers were interviewed, one from the headrace, one from the middle zone, and one from the tailrace. At Ketar 2 and 3, twelve and eleven farmers, respectively, were selected from the secondary block of each. In each field block of the Arata-Chufa small-scale irrigation scheme, two farmers (one from the headrace and one from the tailrace) were selected for interview. Interviews sought to gather the frequencies of maintenance, including sediment cleaning and responsibilities of the various stakeholders, while also investigating how the farmers dealt with the problem of sedimentation. Respondents were asked how they organized dredging, their views on problems related to sedimentation, factors they thought contributed to the problem, and solutions proposed.

The PRA provided insight into the available resources and opportunities and challenges presented by excessive sedimentation. Component structures of the irrigation schemes were catalogued and sediment hotspots were identified. The strategies employed by the farmers to keep the schemes function were analyzed. The types of crops grown and cropping patterns were also documented, alongside the irrigation technologies available and used. Finally, researchers acquainted themselves with operation and maintenance practices.

Table 3. Semi-structured interviews conducted to gain a better understanding of the design, operation, and maintenance of the Ketar and Arata-Chufa irrigation schemes.

Interview Subject Role	Number of Subjects	Topics Addressed
Government		
Department head	2	Role in irrigation scheme, perceived causes of and solutions to excessive sedimentation
Engineer	5	Role in irrigation scheme, perceived causes of and solutions to excessive sedimentation
Researcher	1	Role in irrigation scheme, perceived causes of and solutions to excessive sedimentation
Ketar 1		
WUA official	3	Operation and management of irrigation scheme, perceived causes of and solutions to excessive sedimentation
Gate operator	2	Water distribution and sediment management
Farmer (3 per block)	30	Role, cause of and solution to excessive sedimentation
Ketar 2		
WUA official	1	Operation and management of irrigation scheme, perceived causes of and solutions to excessive sedimentation
Farmer (1 per block)	12	Role, cause of and solution to excessive sedimentation
Ketar 3		
WUA official	1	Operation and management of irrigation scheme, perceived causes of and solutions to excessive sedimentation
Farmer (1 per block)	11	Role, cause of and solution to excessive sedimentation
Arata-Chufa		
WUA official	2	Operation and management of irrigation scheme, perceived causes of and solutions to excessive sedimentation
Block head	10	Water distribution, role and perception of sediment management
Farmer (2 per block)	20	Role, cause of and solutions to excessive sedimentation

3. Results

3.1. Perception of the Drivers for Excessive Sedimentation Problems

3.1.1. Upstream, Midstream, and Downstream Farmers

Many of the farmers interviewed at Ketar—upstream (29%), midstream (31%), and downstream (25%)—identified the earthen canal (main canal without a concrete lining) to be a main cause of excessive sedimentation (Figure 4). The majority of farmers (60% of upstream farmers) and (69% of midstream farmers) considered faulty design to be a major cause of excessive sedimentation. A small proportion (8%) of the midstream farmers attributed the problem to poor operation and maintenance. The majority of downstream farmers (75%) suggested design problems or faulty design as the main cause of excessive sedimentation, and one fourth (25%) pointed to external factors as the main driver. None of the interviewed farmers at the downstream scheme (Ketar 3) attributed the problem of excessive sedimentation to poor operation and maintenance practice.

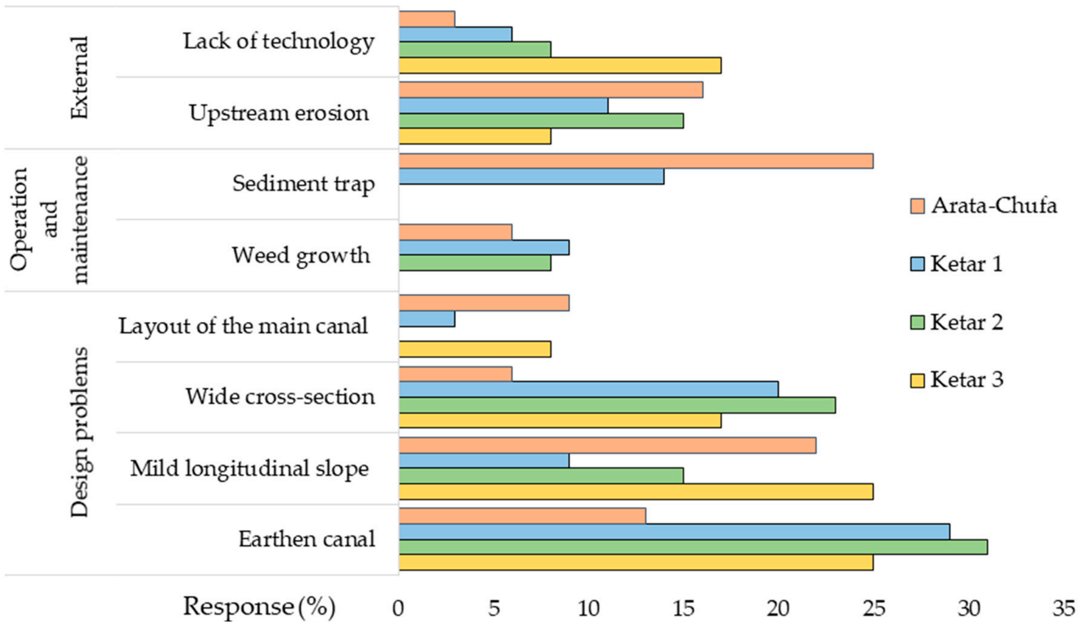


Figure 4. Causes of excessive sedimentation in irrigation schemes, according to upstream (Ketar 1), midstream (Ketar 2), downstream (Ketar 3), and Arata-Chufa farmers.

3.1.2. Ketar and Arata-Chufa Farmers

The farmers interviewed at the two irrigation schemes reported different perceptions of the causes of excessive sedimentation (Figure 4). Foremost driver mentioned by farmers at the Arata-Chufa scheme was an absent and non-functioning sediment trap (25%), while the majority (28%) of the farmers interviewed at the Ketar scheme pointed to the lack of a concrete-lined main canal. This was the fourth most mentioned factor by the farmers at the Arata-Chufa scheme. The minority of respondents at the Ketar scheme (10%) associated the cause of excessive sedimentation with poor operation and maintenance practice. In the Arata-Chufa, a small portion (19%) of the interviewees, unlike Ketar counterparts, reported external factors as a major cause of excessive sedimentation.

3.1.3. Farmers and Engineers

Well over half of the respondent farmers (64%) claimed design problems as a major driver of excessive sedimentation problem, while just a few of the interviewed engineers (13%) agreed that design issues were at fault (Figure 5, Table 4). Nearly two thirds (62%) of the interviewed engineers attributed excessive sedimentation to external factors, particularly erosion of highland areas (37%) and lack of technology and materials (25%). One fourth (25%) of the interviewed engineers claimed poor scheme operation as major driver of excessive sedimentation, while a small portion (21%) of interviewed farmers claimed poor operation and maintenance practice to be a cause of excessive sedimentation problem.

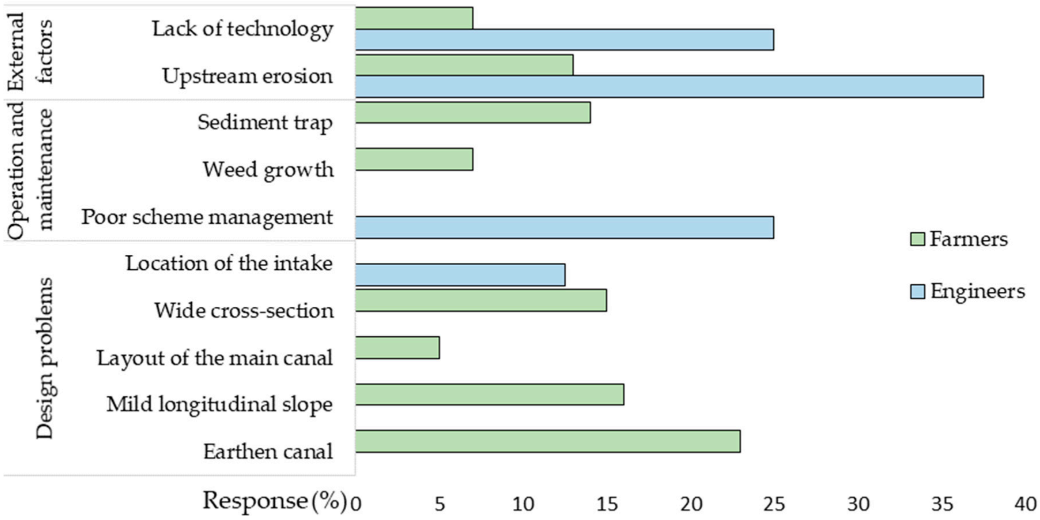


Figure 5. Causes of excessive sedimentation in irrigation schemes, as reported by respondent famers and engineers.

Table 4. Farmers' and engineers' roles and perceptions on excessive sedimentation in the case-study irrigation schemes.

	Farmers/Water User Associations	**Engineers/Government Officials**
Causes of excessive sedimentation	• Design problems: use of earthen canal, a too mild longitudinal slope, an overly wide cross section and poor layout of the main canal • Poor operation and maintenance: weed growth and dysfunctional sediment trap • External factors: upstream erosion and lack of locally available technology and materials	• Design problems: location of the intake • Poor scheme management: poor operation practice of the system by users • External factors: erosion of uphill areas due to land degradation upstream, lack of technology
Solutions proposed	• Lining water conveyance structures with concrete • Acquiring machinery for cleaning the sediment • Frequent and timely maintenance of damaged structures	• Modernization of the scheme: shifting from surface to pressurized systems • Improving operational practices • Improving design practices • Upstream watershed management activities

This study found that the main way farmers dealt with excessive sedimentation was to mobilize and engage huge amounts of labor (among system users) for intensive sediment cleaning campaigns that were completed within just a few days (3–5 days). Dates for canal cleaning were chosen carefully, considering public holidays and the end of the wet season, to avoid having to repeat the job due to overland flows and backflows of sediment removed from the canal. Despite frequent dredging, farmers also used the technique of delaying water abstraction at the beginning of a new irrigation season (in other words, at the end of every wet season), to avoid entrance of huge amount of sediment together with high sediment content water. The process of delaying water abstraction has potentially reduced the sediment load at the beginning of the irrigation season. This process was managed by the WUAs, which had full autonomy to open and close the intake gate. They have also applied their own techniques for frequent removal of weed grown in the canal cross-section as they believed it traps a significant amount of sediment load.

3.2. Days of Labor Invested by Farmers to Manage Excessive Sedimentation

At the Ketar scheme, 3150 and 3086 days of labor were required to dredge 2690 m^3 and 2522 m^3 of sediment from 2433 m (20%) of the main canal (critical sedimentation hotspot) in 2017 and 2018, respectively (Table 5). Each farmer removed an average of 0.85 m^3 and 0.81 m^3 sediment per day in 2016/2017 and 2017/2018, respectively. At the Arata-Chufa scheme, 878 and 709 days of labor were required to clean 1845 m^3 and 163 m^3 volume of sediment from 50% of the main canal (600 m) in 2017 and 2018. Each farmer at the Arata-Chufa scheme removed an average of 0.21 m^3 and 0.23 m^3 per day in 2016/2017 and 2017/2018, respectively. Ketar scheme farmers removed 75% and 72% more cubic meter of sediment in a day than Arata-Chufa scheme farmers in 2017 and 2018, respectively.

Table 5. Sediment volume removed from the main canal of Arata-Chufa and Ketar and days of labor required.

Scheme	Farmers Involved (Number)	Working Hours (Hrs/Day)	Days Input (Day)	Total Input (Day)	Sediment Removed (m^3)	Output (m^3/Day/Farmer)	Canal Reach (m)	Sediment Removed (m^3/Day)
Ketar								
2016/2017	1680	5	3	3150	2690	0.85	2433	1.11
2017/2018	1646	5	3	3086	2522	0.81	2433	1.04
Arata-Chufa								
2016/2017	260	4.5	6	878	185	0.21	600	0.31
2017/2018	252	4.5	5	709	163	0.23	600	0.27

3.3. Time Invested by Farmers in Agriculture and in Cleaning Excessive Sedimentation

Farmers' participation in sediment management varied according to the severity of the sedimentation problem in their particular scheme. The work required to manage excessive sedimentation significantly influenced the labor input to produce a crop (Table 6).

Table 6. Hours invested by farmers in crop production and sediment cleaning activities to produce onion on 0.25 ha, considering a cropping period of four months (data from farmer interviews).

Irrigation Schemes	Number of Hours Invested by Farmers in Crop Production (hrs)	Percentage of Time Invested by Farmers in Sediment Management (%)
Ketar 1(upstream)	585	23
Ketar 2 (midstream)	497	9
Ketar 3 (downstream)	465	3
Arata-Chufa	513	12

Upstream farmers spent 15% more time on crop production and 65% more time on the management of excessive sedimentation than midstream farmers. Compared to downstream farmers, upstream farmers (Ketar 1) spent 20% more time on crop production and 90% more time managing excessive sedimentation. Midstream farmers spent 6% more time on crop production and 68% more time on excessive sedimentation management, compared to downstream farmers. Overall, Ketar farmers spent 12% and 53% more time, respectively, on crop production and excessive sediment management than the Arata-Chufa scheme farmers.

3.4. Role and Structure of Water Users' Associations (WUAs) in Management of Excessive Sedimentation

WUAs collect annual operation and maintenance fees. In the Ketar scheme, farmers paid an annual US$ 8.73 operation and maintenance fee. If they did not participate in sediment cleaning activities, they were fined US$ 4.36, with this amount increased to US$ 6.55 for a second day of nonparticipation. Of that amount, US$ 2.18 went to the local police, who were delegated to take the legal action. At the Arata-Chufa scheme, member farmers paid an annual operation and maintenance fee of US$ 4.36 (1 US dollar = 22.916 birr (June, 2017)) for 0.25 ha of irrigated land, and they were required to participate in maintenance activities. If they did not participate, they were sanctioned with a US$ 1.75 fine. Farmers who were not WUA members paid US$ 13.09 for access to water.

The WUA structure for the Ketar irrigation scheme was originally introduced by "external actors" upon establishment of the scheme (Figure 6). The current organizational set-up has, however, drastically changed; only the functions of WUA head, deputy head, secretary, and cashier existed and the farmers themselves had established the "farmers' collective", which was observed to play an important role in dealing with the problem of excessive sedimentation. This collective implements and manages a major desilting campaign and coordinates minor repair activities. It is made up of subgroups of maximum 20 members. These subgroups are fully autonomous and responsible for imposing sanctions on members who do not participate in sediment cleaning activities.

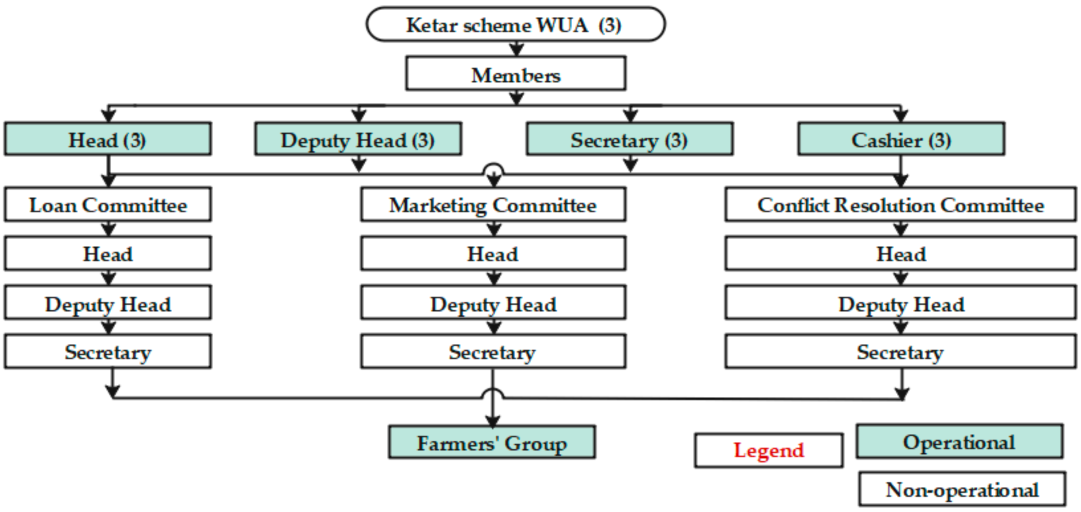


Figure 6. Institutional set-up of the water user association (WUA) of the Ketar irrigation scheme (from the interview results).

The institutional set-up of the Arata-Chufa WUA was also established by "external actors" in 1985/1986, at the time the scheme was handed over to the beneficiaries (Figure 7). The WUA head, deputy head, secretary, and cashier were observed to still be active and engaged in scheme operation and maintenance. The "field block", though not part of the original structure, had been set up by farmers to monitor the operation and maintenance of each block. As such, the field block heads were the main bodies responsible for monitoring sediment cleaning activities in secondary and tertiary systems and managing water distribution to each field block.

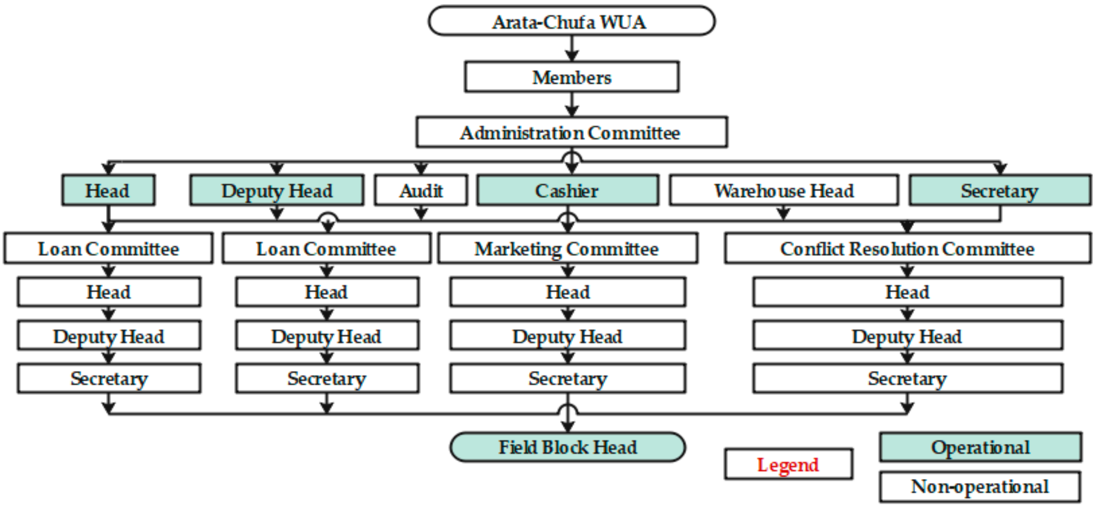


Figure 7. Institutional set-up of the water user association (WUA) of the Arata-Chufa irrigation scheme (from the interview results).

3.5. Scheme Modernization and Management of Excessive Sedimentation

The annual operation and maintenance fees paid by the farmers were not sufficient for required maintenance or repair cost. Farmers reported undertaking only minor maintenance activities by their own, saying that lack of resources and technology limited their ability to do so (Table 7). Due to lack of technology appropriation, farmers depend on "external actors" for major maintenance activities that curtailed their autonomy in keeping excessive sedimentation under control. The dependence of the farmers on external actors for maintenance and repair particularly concern the farmers for two issues. One, they could not afford the maintenance cost of the scheme requested by local contractor. Two, as they file scheme maintenance requests to the lowest Government office, this often took longer to respond to the timely needed repair request of the farmers.

Table 7. Scheme component structures and ability of farmers to maintain them autonomously at the Arata-Chufa and Ketar irrigation schemes.

Scheme Component Structures	Maintained by Farmers
Headwork/intake/weir	no
Lined canal	no
Earthen/unlined canal	yes
Division boxes	no
Gates	no
Night storage ponds	no
Sediment cleaning—canal systems	yes
Sediment cleaning—night storage ponds	no
Chute	no
Drop	no
Turnouts/offtakes	no

3.6. Opportunity Cost of Scheme Operation and Maintenance

The farmers at the Ketar scheme paid US$ 8.37 annually for operation and maintenance (O and M), whereas Arata-Chufa farmers paid US$ 4.36. O and M fee was based what normally the users have agreed and afford to pay. The opportunity cost incurred by the farmers for their labor to dredge sediment just of 50% and 20% of the main canal length, respectively, for the Arata-Chufa and Ketar scheme were US$ 3457 and US$ 13,594, respectively. This means that if the farmers should be paid from annual O and M fees to cover for cleaning of excessive sedimentation from the canal and did not contribute labor, the WUAs would encounter a budget deficit of 145% and 45% for the Arata-Chufa and Ketar scheme, respectively (Table 8).

Table 8. Average annual maintenance opportunity cost incurred by water user association (WUA) members and actual cost to clean sediment from the main canal systems.

Water User Association (WUA)	Members (Farmers)	Operation and Maintenance Fee (US$/Year)	Total Operation and Maintenance Fees Paid (US$/Year)	Average Time Spent on Desilting (Days/Year)	Labor Cost Per Day (US$)	Estimated Maintenance Opportunity Cost (US$)
Arata-Chufa	324	4.36	1413	793	4.36	3457
Ketar	1074	8.73	9376	3118	4.36	13,594

4. Discussion

A few key differences were found in the perceptions of the farmers on the sedimentation problems. The difference in views reflects the farmers' awareness of the problems they were facing. For instance, the foremost mentioned driver by the farmers interviewed at the Ketar scheme was the lack of a concrete-lined main canal, while the majority of respondents at the Arata-Chufa scheme pointed to an absent and non-functioning sediment trap. This difference in views can be attributed to the fact that the main canal of the Arata-Chufa scheme was already lined with concrete at the most critical sediment hotspot, whereas it was still earthen at the Ketar scheme. The cross-section (width and depth) of the main canal was the other most reported cause of excessive sedimentation problem by the farmers at the Ketar scheme. The farmers mainly concerned with the cross-section of the main canal at the critical sedimentation sections. This is because the cross-section determines the quantity of sediment cleaned by the farmers. They remove the deposited sediment from the canal bed and weeds from the side banks of the canal at the same time. In doing so, they further dig the bed of the canal and trim the side banks of the canal. This combined activity results in a damaged canal cross-section: deeper, wider, and a changed longitudinal slope of the canal. The maximum width and depth of canal at the sediment hot spot were recorded as 3.2 m and 0.85 m. Though this was not too wide, it was difficult for the farmers to remove the sediment from such cross-section by manual labor only.

The other reasons mentioned by the farmers as the causes excessive sedimentation that related to their acute awareness of their specific scheme were; absence and non-functional sediment trap, source of erosion, and longitudinal slope of the main canal. The Ketar upstream and Arata-Chufa farmers emphasized the importance of having a working sediment trap. Ketar 1 and Arata-Chufa schemes were initially equipped with sediment trap and undersluice gate that serve to flush sediment back into the river, which was non-functional during interview period. The farmers indicated that with timely repair and improved operation of the sediment trap and undersluice gate, the problem of excessive sedimentation could be substantially reduced. This is because they had previous experience with the function of fully operational structures. With regard to sources of erosion, farmers at the Arata-Chufa scheme reported erosion outside the scheme as a major factor aggravating sedimentation problems. Here they referred to farmers who used pumps to irrigate in a buffer zone of the river just upstream of the intake for causing much of sedimentation problems in their scheme. Ketar farmers, however, attributed excessive sedimentation to erosion of agricultural lands within the scheme. Contrary to other farmers, farmers at the Ketar 3 mainly identified gentle longitudinal slope as a cause of excessive sedimentation problems. This is due to the fact that most reaches of the main canal from Ketar 2 to Ketar 3 was laid in chute structure, which is not suitable condition either for the sediment to settle or for the growth of weed. None of the downstream farmers though mentioned weed growth in the canal as a major cause of sedimentation problem

It is not surprising that engineers had somewhat different perceptions of excessive sedimentation than farmers. While farmers saw structural, technical, and external factors as the main drivers of excessive sedimentation, engineers attributed excessive sedimentation mainly to poor scheme operation and maintenance, as well as erosion of upstream areas. One design problem that engineers did note was the location of the intake, though the design issues cited by farmers related to the layout of the main canal (slope, cross-section, lining materials). With respect to technology, the engineers emphasized the potential of moving away from surface irrigation towards pressurized irrigation technologies (sprinklers and drip) as an option to address excessive sedimentation, while farmers demanded technologies for removing the sediment from the canal and night storage ponds and conveying irrigation water. In sum, most of the drivers of excessive sedimentation reported by farmers (too mild longitudinal slope, wide and shallow canals, absence of and dysfunctional sediment trap) were indeed consequences of poor design and operation and maintenance of the schemes. In this regard, the findings of the current study confirm evidence from previous work [2,12,14]. For instance, the longitudinal slope of the main canal at the sediment hotspot was calculated as 2.3‰ for the Arata-Chufa scheme and 1.4‰ for the Ketar scheme. This can be regarded as a very gentle slope, confirming farmers' claims. This sediment hotspot reach of the canal with very gentle slope reduces flow velocity and allows the sediment to settle. Designing for an optimum permissible velocity that neither allows sediment to deposit nor scours the canal bed could improve sediment transport in the canals.

At the Ketar scheme, the main sediment hotspot section was found at the upstream scheme (Ketar 1) 5 kilometers from the intake (Figure 3). This section covers 2433 m (20% of the main canal). The main canal is collectively cleaned mostly once, but sometimes twice a year depending on sediment inflow load. The secondary and tertiary canals, which are adjacent to the field plots, were cleaned by the farmers individually. The work load of sediment management differed between the upstream, midstream and downstream farmers due to the difference in sediment inflow load (Table 6). The majority of the sediment settled at the upstream (Ketar 1) scheme. Thus, upstream farmers spent more time on sediment management compared to midstream and downstream farmers. Furthermore, downstream farmers were least affected by the sedimentation problem, and contributed the fewest hours of labor to cleaning sediment as they irrigate with water stored at night storage pond. This reveals that the management of excessive sedimentation brings other issues to the fore regarding interactions between upstream, midstream and downstream farmers. Previous studies [2,40,41] argue that upstream farmers may have a comparative advantage over midstream and downstream farmers in terms of water availability; that is, more water may be available to upstream users, with less flowing to the middle and downstream zones. We point out, however, that this is not always the case. The current case study suggests that middle-stream and downstream farmers had similar water allocations to upstream farmers, but invested less time in management of excessive sedimentation.

The role of the WUAs in relation to sediment management tasks were to set the annual sediment cleaning and maintenance dates, monitor sediment cleaning activities, and communicate with the local government bureau to file requests for scheme maintenance and repairs that the farmers could not perform on their own. WUAs also play the role of enforcing the sanction that was set out in the WUA by-laws. However, it was found that these rules were hardly applied. For instance, in the Arata-Chufa scheme, the fines farmers paid depended on crop yields and market values in a particular year. If productivity was high, the sanction to be paid by offending farmers was increased; otherwise, it would be reduced. By-laws stipulating that farmers would not get water if they did not participate in maintenance were also softened, in particular, for women and elderly farmers or at least excused from participation in the heavy work of desilting. At the Ketar scheme, farmers followed their own rules for sediment cleaning. The farmers' group (formed by the farmers themselves) decided collectively what type and magnitude of sanctions to impose on those who did not participate. It was observed that there was relatively good communication and consensus within the groups, which made it easy for farmers to empathize with the situation of those who had not participated in cleaning activities. If the reason for not participating was deemed acceptable, the farmer was excused; if not, an appropriate sanction either in kind or in cash was imposed and the farmer generally paid it. Thus, local norms, values, and social capital seem to have played a substantial role in keeping these schemes functional for more than 30 years. Functions introduced by the "external actors", such as audit, loan, marketing, conflict resolution, and warehouse, were inactive. Instead farmers themselves formed positions like "farmers' group" "field block head". Farmers consider roles that still exists such as head, deputy head and secretary as "traditional role".

The majority of farmers were willing to pay the annual operation and maintenance fee, to contribute labor to clean the sediment, and to pay sanctions if required. Moreover, they considered the annual operation and maintenance fee to be fair. There were, however, various scheme components that the farmers could not maintain and repair on their own, mainly due to the modernization of the schemes. While farmers could do minor repairs of earthen canal works and dredge sediment from the main canal, they could not remove sediment from the night storage ponds. In 2016/2017, Ketar scheme farmers paid a local contactor US$ 13,090 to use heavy machinery to excavate the sediment from the night storage pond. At the time of the field work, Arata-Chufa scheme farmers were facing a shortage of water because they lacked the machinery and funds to pay for sediment to be cleaned from the night storage pond, which supplied 60 ha, or 60%, of the total irrigated area. This reflects the problem of a lack of technology appropriation, which studies have shown leaves users dependent on external technology and developers [5,6]. Farmers were willing to invest, and of course they annually contributed a huge amount of labor to manage excessive sedimentation, but the operation and maintenance fees paid were insufficient to cover major maintenance and repair costs.

The labor output in the Ketar scheme was higher than the Arata-Chufa scheme (Table 5). This difference could be attributed to the work processes implemented to manage the desilting activities at the different schemes. The Ketar scheme had a better system, which was more effective in utilization of the labor days invested by the farmers. Farmers were divided into groups numbering a maximum of 20 each. The desilting operation was then divided among the groups, with every 20 farmers responsible for about 100 m of the canal. At the Arata-Chufa scheme, sediment cleaning was carried out collectively in a process in which only a few farmers could be actively engaged in dredging at a time, while the remaining farmers stood aside and waited for their turn. It is very difficult to compare the labor output at the two schemes to experiences elsewhere in the country, as very little data exists on the quantity of sediment desilted by farmers from canals and numbers of labor days devoted to the task. However, we estimated the opportunity cost of those labor days as US$3457 and US$13,594 for the Arata-Chufa and Ketar schemes, respectively. Comparing these estimates to the total regional operation and maintenance budget for 2017/2018 ($1.2 million), we found that 0.28% and 1.11% of the regional budget would be spent to remove sediment from 50% and 20% of the main canals of the Arata-Chufa scheme and Ketar scheme, respectively. The region had 612 modern, 9379 traditional, and 63,523 pump irrigation schemes in that year (OIDA, 2017).

5. Conclusions

Excessive sedimentation is indeed one of the major causes of underperformance of small-scale irrigation schemes in Ethiopia. In this study, the stakeholders' roles and perspectives on sedimentation management in two small-scale irrigation schemes, Ketar (430 ha) and Arata-Chufa (120 ha), were analyzed using a collaborative and participatory approach. In these farmer-led irrigation schemes, farmers use their local knowledge and informal institutions to mobilize and engage huge amounts of labor for intensive sediment cleaning campaigns. In the Ketar Scheme, the farmers (1680 in 2016/2017 and 1646 in 2017/2018, respectively) spent on average 3 days per year on this campaign and the farmers in Arata-Chufa (260 in 2016/2017 and 252 in 2017/2018, respectively) on average 5.5 days per year. The upstream farmers spent between 12% (Arata-Chufa) and 23% (Ketar 1) of the total time invested in crop production on sedimentation management, compared to only 3 to 9% of the midstream and downstream farmers. On top of this input in labor, farmers pay annual operation and maintenance fees, US$ 8.37 in Ketar and US$ 4.36 in Arata-Chufa. In these farmer-led irrigation systems, the farmers mainly devoted extra hour of drudgery for desilting excessive sedimentation from the canal, but they have also used their knowledge, such as delaying the abstraction of irrigation water at the start of new irrigation season (end of wet season) to avoid entrance of excessive sedimentation to their scheme together with diluted irrigation water. They have also applied own technique of frequent removal of weed grown in the canal cross-section as they believed it traps a significant amount of sediment load.

Farmers' understanding of the drivers of excessive sedimentation reflected their close personal knowledge of the irrigation system and the sedimentation problems they faced. Farmers and engineers have different perceptions of the causes of sedimentation. The drivers of excessive sedimentation were indeed the consequences of poor or faulty design, poor operation, and maintenance practices and external factors like erosion due to degradation of the land and low-technology level of water conveyance systems. Farmers reported design problems as the main cause of excessive sedimentation (64%), followed by poor operation and maintenance (O and M) practices (21%), and external factors (15%). Contrary, the engineers indicated erosion and irrigation-technologies as the main causes of excessive sedimentation (62%) and only 13% on design problems. Though low-technology level contributed to the excessive sedimentation problem, lack of adaptation and adoption of the technology by the farmers have aggravated the problem

The existing role and structure of the Water Users Associations are significantly simplified compared to the institutional set-up introduced by external actors, as most of the planned management layers and committees were not operational. Local social capital appeared to be more important than by-laws in enforcing O and M practices. It can be concluded that the cost of sediment management for the farmers is very high and requires new socio-technical solutions that capitalize on the existing local social capital, norms, values, and indigenous knowledge. The integration of the farmers' knowledge with that of the engineers could yield more effective ways to deal with sedimentation problems. To implement a sustainable intervention to rehabilitate excessive sedimentation problems in farmer-led irrigation systems, it should follow a proper technology appropriation by the farmers.

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References

1. De Fraiture, C.; Molden, D.; Wichelns, D. Investing in Water for Food, Ecosystems, and Livelihoods: An Overview of the Comprehensive Assessment of Water Management in Agriculture. (Special Issue: Comprehensive Assessment of Water Management in Agriculture.). *Agric. Water Manag.* **2010**, *97*, 495–501. [CrossRef]
2. Amede, T. Technical and Institutional Attributes Constraining the Performance of Small-scale Irrigation in Ethiopia. *Water Res. Rural Dev.* **2015**, *6*, 78–91. [CrossRef]
3. De Fraiture, C.; Giordano, M. Small Private Irrigation: A thriving but Overlooked Sector. *Agric. Water Manag.* **2014**, *131*, 167–174. [CrossRef]
4. Beekman, W.; Veldwisch, G.J.; Bolding, A. Identifying the Potential for Irrigation Development in Mozambique: Capitalizing on the Drivers Behind Farmer-led Irrigation Expansion. *Phys. Chem. Earth Parts A B C* **2014**, *76–78*, 54–63. [CrossRef]
5. De Bont, C.; Komakech, H.C.; Veldwisch, G.J. Neither Modern nor Traditional: Farmer-led Irrigation Development in Kilimanjaro Region, Tanzania. *World Dev.* **2019**, *116*, 15–27. [CrossRef]

6. Veldwisch, G.J.; Venot, J.P.; Woodhouse, P.; Komakech, H.C.; Brockington, D. Re-introducing Politics in African Farmer-Led Irrigation Development: Introduction to a Special Issue. *Water Altern.* **2019**, *12*, 1–12.
7. Beekman, W.; Veldwisch, G. Supporting Farmer-Led Irrigation in Mozambique: Reflections on Field-Testing a New Design Approach. *Sustainability* **2016**, *8*, 580. [CrossRef]
8. Ministry of Water Irrigation and Electricity, Ethiopia. *Paper Presented on Ethiopian Water Week by Irrigation Advisory Consultant*; Ministry of Water Irrigation and Electricity: Addis Ababa, Ethiopia, 2019.
9. Tamirat. *Scheme Administration Head*; Oromia Irrigation Development Authority: Addis Ababa, Ethiopia, 2016.
10. Haile, G.G.; Kasa, A.K. Irrigation in Ethiopia: A Review. *Acad. J. Agric. Sci.* **2015**, *10*, 264–269.
11. Lankford, B. Irrigation Improvement Projects in Tanzania; Scale Impacts and Policy Implications. *Water Policy* **2004**, *6*, 89–102. [CrossRef]
12. Awulachew, S.; Ayana, M. Performance of Irrigation: An Assessment at Different Scales in Ethiopia. *Exp. Agric.* **2011**, *47*, 57–69. [CrossRef]
13. Dejen, Z.A.; Schultz, B.; Hayde, L. Comparative Irrigation Performance Assessment in Community-managed Schemes in Ethiopia. *Afr. J. Agric. Res.* **2012**, *75*, 4956–4970.
14. Abate, A.; Gallet, L.; Tina, R.L. Design Challenges in SSI Systems and O and M: Experiences from Ethiopia, Tanzania and Madagascar. In: Agricultural Water Management: A Critical Factor in Reduction of Poverty and Hunger. In Proceedings of the Second Regional Workshop on AWM in Eastern and Southern Africa, Maputo, Mozambique, 18–22 September 2006.
15. Aberra, Y. Problems of the Solution: Intervention into Small-Scale Irrigation for Drought Proofing in the Mekele Plateau of Northern Ethiopia. *Geogr. J.* **2004**, *170*, 226–237. [CrossRef]
16. Yohannes, D.F.; Ritsema, C.J.; Eyasu, Y.; Solomon, H.; van Dam, J.C.; Froebrich, J.; Ritzema, H.P.; Meressa, A. A Participatory and Practical Irrigation Scheduling in Semiarid Areas: The Case of Gumselassa Irrigation Scheme in Northern Ethiopia. *Agric. Water Manag.* **2019**, *218*, 102–114. [CrossRef]
17. Erkossa, T.; Wudneh, A.; Desalegn, B.; Taye, G. Linking Soil Erosion to On-site Financial Cost: Lessons from Watersheds in the Blue Nile Basin. *Solid Earth* **2015**, *6*, 765–774. [CrossRef]
18. Gelagay, H.S.; Minale, A.S. Soil Loss Estimation Using GIS and Remote Sensing Techniques: A Case of Koga Watershed, Northwestern Ethiopia. *Int. Soil Water Conserv. Res.* **2016**, *4*, 126–136. [CrossRef]
19. Haregeweyn, N.; Tsunekawa, A.; Poesen, J.; Tsubo, M.; Meshesha, D.T.; Fenta, A.A.; Nyssen, J.; Adgo, E. Comprehensive Assessment of Soil Erosion Risk for Better Land Use Planning in River Basins: Case Study of the Upper Blue Nile River. *Sci. Total Environ.* **2017**, *574*, 95–108. [CrossRef] [PubMed]
20. Theol, S.A.; Jagers, B.; Suryadi, F.X.; de Fraiture, C. The use of Delft3D for Irrigation Systems Simulations. *Irrig. Drain.* **2019**, *68*, 318–331. [CrossRef]
21. He, L.; Wang, S.; Peng, C.; Tan, Q. Optimization of Water Consumption Distribution Based on Crop Suitability in the Middle Reaches of Heihe River. *Sustainability* **2018**, *10*, 2119. [CrossRef]
22. Li, G.; Zhou, D.; Shi, M. How Do Farmers Respond to Water Resources Management Policy in the Heihe River Basin of China? *Sustainability* **2019**, *11*, 2096. [CrossRef]
23. Depeweg, H.; Méndez, V.N. Sediment Transport Applications in Irrigation Canals. *Irrig. Drain.* **2002**, *51*, 167–179. [CrossRef]
24. Ritzema, H.; Anh, L.Q.; Kim, B.T. Collaborative Research to Improve Water Management in Two Polders in the Red River Delta in Vietnam. In *Knowledge in Action*; Paassen, A.V., van den Berg, J., Steingröver, E., Werkman, R., Pedroli, B., Eds.; Wageningen Academic Publishers: Wageningen, The Netherlands, 2011; pp. 57–84.
25. Oliver, D.M.; Fish, R.D.; Winter, M.; Hodgson, C.J.; Heathwaite, A.L.; Chadwick, D.R. Valuing Local Knowledge as a Source of Expert Data: Farmer Engagement and the Design of Decision Support Systems. *Environ. Model. Softw.* **2012**, *36*, 76–85. [CrossRef]
26. Nigussie, Z.; Tsunekawa, A.; Haregeweyn, N.; Adgo, E.; Nohmi, M.; Tsubo, M.; Aklog, D.; Meshesha, D.T.; Abele, S. Farmers' Perception about Soil Erosion in Ethiopia. *Land Degrad. Dev.* **2017**, *28*, 401–411. [CrossRef]
27. Kolagani, N.; Ramu, P.; Varghese, K. Participatory Model Calibration for Improving Resource Management Systems: Case Study of Rainwater Harvesting in an Indian Village. *JAWRA J. Am. Water Resour. Assoc.* **2015**, *51*, 1708–1721. [CrossRef]
28. Dessie, Y.; Wurzinger, M.; Hauser, M. The Role of Social Learning for Soil Conservation: The Case of Amba Zuria Land Management, Ethiopia. *Int. J. Sustain. Dev. World Ecol.* **2011**, *19*, 258–267. [CrossRef]

29. Fraser, E.D.G.; Dougill, A.J.; Mabee, W.E.; Reed, M.; McAlpine, P. Bottom up and top Down: Analysis of Participatory Processes for Sustainability Indicator Identification as a Pathway to Community Empowerment and Sustainable Environmental Management. *J. Environ. Manag.* **2006**, *78*, 114–127. [CrossRef]
30. Yami, M. Sustaining Participation in Irrigation Systems of Ethiopia: What have We Learned about Water User Associations? *Water Policy* **2013**, *15*, 961. [CrossRef]
31. Yami, M. Irrigation Projects in Ethiopia: What can be Done to Enhance Effectiveness under 'Challenging Contexts'? *Int. J. Sustain. Dev. World Ecol.* **2016**, *23*, 132–142. [CrossRef]
32. Depeweg, H.; Mendez, N. A New Approach of Sediment Transport in the Design and Operation of Irrigation Canals (Unesco-Ihe Lecture Note Series). In *Proceedings and Monographs in Engineering, Water and Earth Sciences*; Taylor and Francis/Balkema: Leiden, The Netherlands, 2007; p. 240.
33. Depeweg, H.; Paudel, K.P.; Schultz, B. Evaluation of the Procedure to Design Irrigation Canals with Sediment-Laden Water by the Rational Method. *Irrig. Drain.* **2016**, *65*, 589–600. [CrossRef]
34. Osman, I.S.E. Impact of Improved Operation and Maintenance on Cohesive Sediment Trandport in Gezira Scheme Sudan. Ph.D. Thesis, UNESCO-IHE Institute for Water Education, Leiden, The Netherlands, 2015; p. 202.
35. Timilsina, P. One-Dimensional Convection Diffusion Model for Non-Equilibrium Sediment Transport in Irrigation Canals. Master's Thesis, UNESCO-IHE Institute for Water Education, Delft, The Netherlands, 2005.
36. Paudel, K.P. Role of Sediment in the Design and Managemnet of Irrigation Canals; Sunsari Morgan Irrigation Scheme, Nepal. Ph.D. Thesis, UNESCO-IHE-Institute for Water Education, Leinden, The Netherlands, 2010; p. 299.
37. Munir, S. Role of Sediment Transport in Operation and Maintenance of Supply and Demand Based Irrigation Canals: Application to Machai Maira Branch Canals. Ph.D. Thesis, UNESCO-IHE Institute for Water Education, Leiden, The Netherlands, 2011.
38. Japan International Cooperation Agency; Oromia Irrigation Development Authority; The Federal Democracti Reuplic of Ethiopia. *The Study on Capacity Building Programs for Community-Based Irrigation Development in Central Oromia Region of Ethiopia*; NIPPON KOEI CO., LTD.: Tokyo, Japan, 2004; p. 91.
39. Lempériere, P.; van der Schans Martin, L.; Bavanirajan, V.J.G. *Research for Development Using Participatory Rapid Diagnosis and Action Planning for Irrigated Agricultural Systems: A Manual for Development Researchers and Practitioners: Updated Edition*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy; International Water Management Institute (IWMI): Colombo, Sri Lanka, 2014.
40. Bijani, M.; Hayati, D. Farmers' Perceptions Toward Agricultural Water Conflict: The Case of Doroodzan Dam Irrigation Network, Iran. *J. Agric. Sci. Technol.* **2015**, *17*, 561–575.
41. Ravnborg, H.M.; Bustamante, R.; Cissé, A.; Cold-Ravnkilde, S.M.; Cossio, V.; Djiré, M.; Funder, M.; Gómez, L.I.; Le, P.; Nyambe, I.; et al. Challenges of Local Water Governance: The Extent, Nature and Intensity of Local Water-related Conflict and Cooperation. *Water Policy* **2012**, *14*, 336–357. [CrossRef]