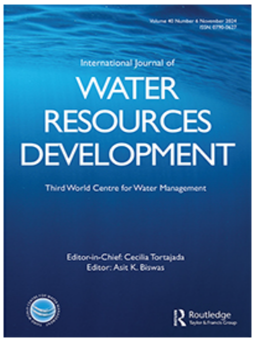

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Adapting smallholder irrigation systems to extreme events: a case of the Transforming Irrigation in Southern Africa (TISA) project in Zimbabwe

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ABSTRACT

Smallholder irrigation schemes are vulnerable to increased climate variability and change, particularly increased water stress. This paper explores whether the introduction of Agricultural Innovation Platforms and soil monitoring tools in smallholder irrigation schemes can improve the adaptive capacity of farmers and schemes in the Insiza District. Drawing on household survey and qualitative data, collected through the Transforming Irrigation in Southern Africa project, we analyse a comprehensive set of measures across four domains: field, household, community and markets. We find that social capacity and increased climate adaptation can be built with modest cost through combined social and technological interventions.

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SUSTAINABLE DEVELOPMENT GOAL
SDG 13: Climate action

Introduction

Climate change is already stalling progress towards food security in Africa. Like other countries in Africa, Zimbabwe is at significant risk from climate change due to its variable climate, widespread poverty and limited capacity to cope with increased variability (Chagutah, 2010). The Intergovernmental Panel on Climate Change [IPCC], 2007) indicates that the impacts of climate variability are not evenly distributed, most severely affecting the poorest. Additionally, in the case of Zimbabwe, the political and economic instability of the past has exacerbated the situation, rendering many smallholder farmers increasingly vulnerable to climate variability and change.

Agriculture is the backbone of Zimbabwe's economy as Zimbabweans remain largely rural people who derive their livelihood from agriculture and other related rural economic activities (Food and Agriculture Organization [FAO], 2020; World Bank, 2020). Although agriculture contributes only 11–14% of gross domestic product (GDP), the sector provides employment for some 70% of the population, and about 45% of the country's exports are of

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agricultural origin (Runganga & Mhaka, 2021). Climate change impacts both the demand for and availability of water for agriculture, affecting the proportion of people suffering from insecure access to water. Smallholder farmers are among the most vulnerable to the impact of climate variability. Given the huge role of the agricultural sector in the Zimbabwe economy, the millions of smallholder farmers whose livelihoods depend on it, and the growing challenges of hunger, food insecurity and malnutrition, adaptation of agriculture in Zimbabwe is critical to building resilience. This heavy dependence on agriculture, and lack of financial resources for mitigation and adaptation, might influence the severity of climate change impacts. Low-cost climate change adaptation strategies, especially in the agricultural sector, are therefore a principal development challenge in Zimbabwe.

The challenges related to unpredictable rainfall patterns have seen the Government of Zimbabwe, with support from development agencies, invest in new irrigation development and measures to maximize the use of existing water and irrigation facilities (Mwadzingeni et al., 2022a). Development of irrigation infrastructure allows continuous crop production and can facilitate increased smallholder productivity, especially where farmers supplement rainfed agriculture. Irrigation development enables expansion of agricultural activities by turning dry areas into highly productive lands. Significant investment is being made in irrigation in Zimbabwe to overcome the unreliability of dryland farming. While there are many important irrigation systems, including dambos and other farmer-led systems (Faulkner & Lambert, 1991; Mabeza & Mawere, 2012; Nyamadzawo et al., 2014), the government's plans to almost double the area of smallholder irrigation schemes (SISs) by 2025 (Government of Zimbabwe [GoZ], 2020) makes them of considerable interest in terms of their functionality and outcomes. There is increasing recognition that the resilience of this sector must also be enhanced as part of the investment in development, and to build capacity to withstand reduced water supply, more frequent floods and droughts, and overall greater climatic variability (Mutambara et al., 2017; Muzari et al., 2013; Nkomozepi & Chung, 2012). Water stress will be further exacerbated by urbanization, and expanding populations and industrial development (Mutambara et al., 2017). The importance of improved resilience is evident for schemes such as Mkoba, where the scheme's dam was only sufficient to irrigate 20% of the irrigable area in 2015 (Bjornlund et al., 2017).

Irrigation development is also a challenge in Zimbabwe because of the high cost of irrigation infrastructure development and the limited suitable hydrogeological conditions (Bjornlund et al., 2020; Mwadzingeni et al., 2022a). Water management in smallholder irrigation systems in Zimbabwe has been associated with inefficient and inflexible scheduling, making it challenging to maximize yield and profit (Moyo et al., 2020). Irrigation farmers may be at greater risk from increasingly frequent droughts if they are less diversified and face a combination of both market and climate risks (Mwadzingeni et al., 2022b). Various factors influence poor yields in Zimbabwe's SISs: small plot sizes; limited fertilizer application; over-irrigation; and conflict that stifles collaborative efforts (Bjornlund et al., 2017). While markets should function to incentivize farmers and focus production on where there is demand, understanding and access are typically extremely limited (Moyo et al., 2020). A persistent government focus on low-value staple crops rather than more profitable crops ensures a continuing failure of farmers to make sufficient profits to pay for the schemes' maintenance and development demands (Bjornlund et al., 2020; Mwadzingeni et al., 2022a).

Adapting smallholder irrigation to climate change is a priority for their livelihood security and has the potential to substantially reduce many of the adverse impacts of climate change and enhance beneficial impacts. Adaptation depends greatly on the adaptive capacity or adaptability of the communities to cope with the impacts and risks of climate change. Enhancement of adaptive capacity is therefore a necessary condition for reducing vulnerability, particularly for the most vulnerable socioeconomic groups (Silici et al., 2021). Adaptive capacity has been described as the ability of a system to take advantage of opportunities and cope with consequences of climate variability and change (CARE, 2010). Adaptive capacity is shaped by individuals' or households' access to and control over various resources/capitals; namely, human capital (for example, knowledge of climate risks and technologies, availability of labour and good health for productive labour); social capital (farmer-based groups or organizations such as savings and loan groups, as well as labour groups); physical capital (such as the availability of good infrastructure, good inputs for example, quality seed, fertility amendments and postharvest facilities); natural capital (such as good fertile land and reliable water sources); and financial capital (such as diversified income sources and micro lending; CARE, 2010). Enhancement of adaptive capacity is therefore a necessary condition for reducing vulnerability (Van de Steeg et al., 2009) and promoting sustainable development.

The capacity and willingness of smallholders to adapt is underpinned by access to new knowledge. Farmers recognize this as a constraint to their adaptability, with extension and other advisory services highlighted as being critical to help them acquire, interpret and utilize relevant information (Mudombi et al., 2017). Similarly, farmers in Nigeria, Ghana and Pakistan identify gaps in knowledge about how the climate is expected to change and the coping strategies they could employ (Popoola et al., 2020). Acquiring new knowledge and information for adaptation is supported by social capital, which is further built as individuals within a network interact, share resources, and create or adapt local norms (Nyahunda & Tirivangasi, 2021). Learning opportunities that facilitate exchange and interaction can be an effective influence on farmers' and communities' adaptability: for example, farmers field schools and demonstration plots (Mudombi et al., 2017; Phuong et al., 2017). Hence, the inclusion of knowledgeable actors in farmers' learning networks enhances adaptive capacity, and the erosion of these social networks increases vulnerability (Muzari et al., 2016).

Household-level vulnerability in Zimbabwe is also influenced by insecure land tenure and inequitable land distribution (Muzari et al., 2016). Land tenure in Zimbabwe is not well defined or understood by irrigators, leading to confusion over management and challenging irrigators' ability to secure loans for investing in their farm operations (Bjornlund et al., 2017; Moyo et al., 2020). The lack of secure land tenure and water rights further exacerbates smallholder farmers' exposure and vulnerability to climate change. Perceived tenure security by farmers and potential investors and lenders influences long-term investment (International Fund for Agricultural Development [IFAD], 2020).

Smallholders in irrigation schemes have access to relatively small plots and the land tenure system restricts farmers' ability to increase their irrigated area to maintain production levels as a climate change response option. This leads to relatively lower contributions of the irrigation systems to household food security and income, leading to vulnerability to climate change and variability. Small plot sizes also limit scheme's ability to be financially sustainable and reinvest in the irrigation systems. Rural to urban migration and cross-border migration have been found to compound vulnerability by leaving agricultural activities to less-productive sections of the rural populations such as the aged and children, who may not be able to make maximum use of the land (Mercandalli et al., 2019).

Climate adaptation can therefore be achieved through initiatives that promote the welfare of the poorest members of society – for example, by improving food security and providing access to other resources. The potential impact of climate change on smallholder irrigation systems depends on a combination of the exposure, sensitivity and resilience of these schemes to potential water supply and demand changes, and hence it varies considerably from one scheme to another. The aim of this paper is to contribute to the understanding of how holistic and synergistic social and technical interventions, promoted by the Transforming Irrigation in Southern Africa (TISA) project, have contributed to transitioning smallholder irrigation schemes into adaptive systems. We investigate how the TISA project has achieved significant success in transitioning smallholder irrigation systems from inefficient (low output and high losses) subsistence systems to more profitable and efficient irrigation schemes characterized by higher water productivity (WP) and increased levels of farmer participation and self-organization in the face of a hazard. COVID-19 presented an opportunity to test adaptation. We use TISA interventions and their contribution to smallholder farmers household security in the face of the COVID-19 pandemic as a proxy for the shocks that climate change will expose farming system to and analyse their ability to adapt to and recover from these shocks. These outcomes were compared to a non-TISA irrigation scheme within the same locality. The study details some of the key adaptive capacities the TISA project has enhanced (compared to the non-TISA scheme) leading to improved resilience to climate change such as extreme events and including droughts (and/or floods) and shocks such as COVID-19.

Methods

The irrigation schemes and their climate change vulnerability

There are two main categories of smallholder irrigation schemes in Zimbabwe, namely supplementary ('part-time' irrigation) schemes and full production ('full-time' irrigation) schemes. In the supplementary schemes individual household plot sizes are usually smaller, typically 0.1–0.5 ha, and farmers in these schemes are usually involved in dryland agriculture as well. In the full production schemes, the individual plot sizes are larger, typically 0.5–2 ha per household, and these are meant to make sure that the households involved are full-time irrigation farmers, with no engagement in dryland agriculture (FAO, 2000).

According to FAO (2000), there are three broad types of smallholder schemes in Zimbabwe, namely government-managed, farmer-managed, and jointly managed schemes. The government-managed schemes were developed and maintained by either the Department of Agricultural Technical and Extension Services (AGRITEX) or by the Department of Irrigation (DoI). Farmer-managed schemes are developed by the government but owned and managed by the farmers' Irrigation Management Committees (IMCs) with minimal government interventions in terms of management. For jointly managed schemes the farmers and the government share the financial responsibility for the operation and maintenance. For such schemes the government is usually responsible for the head works, while farmers take responsibility for the infield infrastructure (FAO, 2000).

The TISA approach was first introduced at Silalatshani and Mkoba (Figure 1). In this study, the focus is on Silalatshani (also known as Silalabuhwa). This scheme (20°47′22″S and 29°17′44.59″E) is located in Insiza District in Natural Region IV of Zimbabwe, which has an annual rainfall of between 450 mm and 650 mm. The area is subject to seasonal droughts and severe dry spells during the rainy season (mid-season droughts). The area is found in the hot, low-lying land and is marginal for rain-fed maize (see Table 1). It is, however, ideal for drought-resistant grain and fodder crops and livestock production. The farming system in the semi-arid environment of Insiza is characterized by high population pressure, with over-utilization of existing land resources being prevalent. Crop and livestock production as well as off-farm employment are the main sources of livelihoods for farmers. The scheme has a total of 442 ha, mostly fertile clay soils, and has 845 farmers and each member has an average of 0.5 ha of land for cropping.

The non-TISA scheme surveyed was Siwazi scheme, which was developed in 1992 by the Government of Zimbabwe and is also in Insiza district (Figure 1) The scheme measures

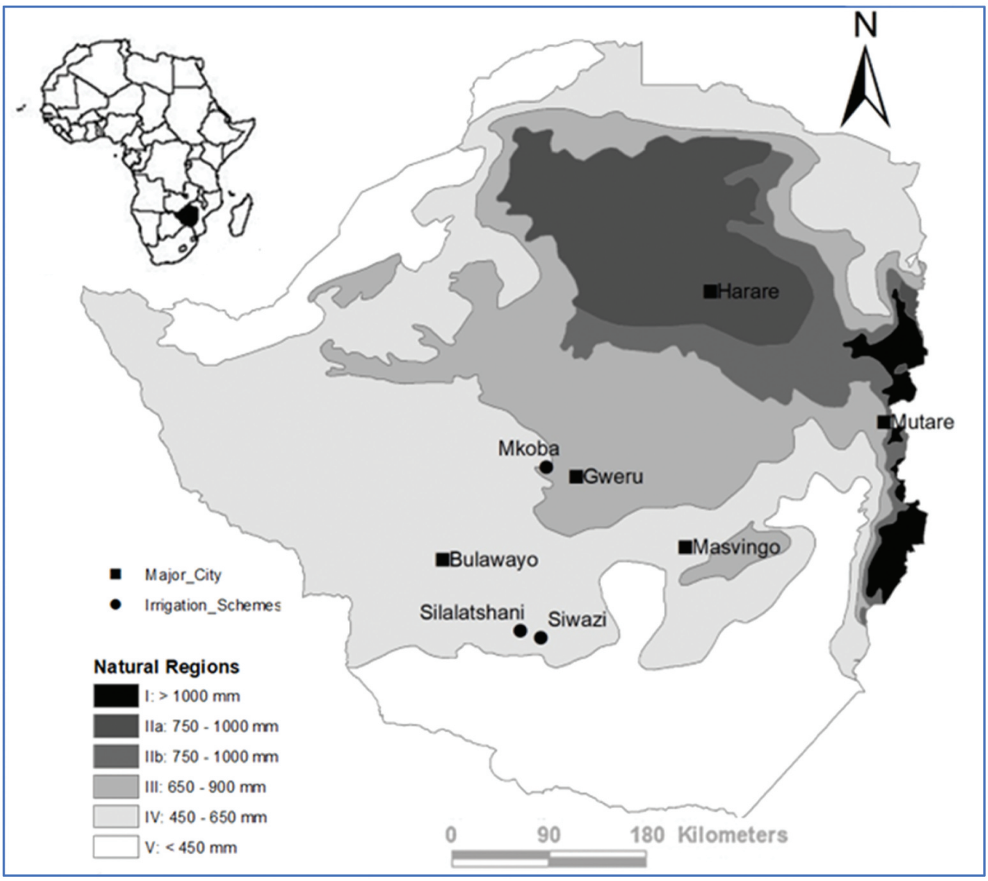


Figure 1. Location of TISA (Silalatshani) and non-TISA (Siwazi) irrigation schemes and natural regions within Zimbabwe. Source: International Crops Research Institute for the Arid Tropics (ICRISAT), GIS Laboratory, Bulawayo, 2024.

Table 1. Changes to irrigation practices at TISA irrigation schemes.

Changes to irrigation practices (% of irrigators)	2017	2021[a]
Changed irrigation practice prior to 2017 due to what was learned from the tools	60	481
Still practising changes made prior to 2017		94
Made further changes to irrigation practices for those that had made changes prior to 2017		78
Changed irrigation practices since 2017		31
Reduced irrigation frequency		
Reduced irrigation frequency (% of irrigators making changes to irrigation practices)	88	100
Irrigation frequency before (days)	7	7
Irrigation frequency now (days)	15	16
Reduced duration of irrigation event		
Reduced duration of irrigation events (% of irrigators making changes to duration of irrigation event)	52	66
Hours of irrigation before (mean)	4	2.9
Hours of irrigation now (mean)	2	1.4
Most important benefits from using the tools (% of irrigators)		
Saving time		74
Saving labour		49
Increase yield		50
Saving water		81

[a]As all the households interviewed in 2017 were not available to be interviewed in 2022, this figure differs from the 2017 figure. The analysis in Figure 4 could only be carried out on those interviewed in both surveys.

23 ha and is made up of 80 members. Its main water source is Siwazi dam, which is gravity-fed through an asbestos pipe that delivers water to a night storage dam. Each plot holder is allocated an average of 0.1 ha through a block system, in which each farmer cultivates about 0.1 ha in each of the three blocks. The method of water supply to the plots is flood irrigation, through a network of concrete-lined infield canals.

Both Silalatshani and Siwazi schemes fall within the jointly managed schemes where the farmers and the government share the financial responsibility for the operation and maintenance. The criteria used for selecting the two irrigation schemes in the study included control of water resources, with both schemes being serviced by surface water dams (both schemes are government-managed); proximity to ICRISAT site (both schemes are within reasonable distance in Insiza district); crop and soil diversity (both schemes have crop diversity); market linkages (both schemes potentially had some good market access); institutional capacity (both schemes generally are functional in terms of production); and method of irrigation (both schemes are flood irrigated).

Silalatshani and Siwazi irrigation schemes are in the semi-arid tropics and the climate is characterized by distinct wet and dry seasons. Climate change is likely to increase the volatility of rainfall received, leading to numerous effects on the irrigation schemes (Mwadzingeni et al., 2022a). First, this could decrease the total volume of water available for irrigation in some years (Mutambara et al., 2017). It could also lead to increased frequency of flooding and crop waterlogging. Second and indirectly, this reduces reliability of dryland agricultural production and thus places greater pressure on irrigated agricultural production for food supply. Silalatshani and Siwazi schemes are therefore useful sites to investigate the resilience of smallholder irrigation schemes to climate change.

TISA interventions

The TISA project adopted a two-pronged approach to transforming small-scale irrigation schemes, which combined technological and social interventions. The project introduced agricultural innovation platforms (AIPs) and soil water and nutrient monitoring tools. The project was carried out in two phases: Phase I from 2013 to 2017, during which the two interventions were introduced and implemented in close collaboration with project staff, and a Phase II from 2017 to 2023, during which the focus was on out and upscaling and the intensity of the presence of project staff declined significantly as roles were transitioned to local stakeholders.

Agricultural innovation platforms

AIPs were introduced at the Landela block of the Silalatshani scheme in 2014, and to other blocks of Silalatshani in 2017. The aim was to foster interaction among stakeholders around shared interests in irrigated agriculture and food value chains. In Zimbabwe, these included farmers, government authorities, extension agents, water regulators, input suppliers, and traders.

Through a series of AIP sessions, participants: (i) undertook a visioning exercise in which they assessed the existing situation and developed a vision of how their schemes would look in five years; (ii) identified barriers that needed to be overcome to achieve the vision, mainly factors affecting the productivity and profitability of farming such as marketing and value-adding opportunities; (iii) identified solutions to overcome the barriers; and (iv) identified relevant stakeholders to implement the solutions (van Rooyen et al., 2017). Several AIP activities were implemented after 2014, including gross margin training, experiential demonstration plots, collaborative mapping, and market linkages.

Soil moisture and nutrient monitoring tools

The second intervention involved the introduction of soil moisture and nutrient monitoring tools, with the aim of facilitating farmer learning on soil moisture and nutrient dynamics. Two tools were introduced: Wetting Front Detectors (WFDs) and Chameleon soil moisture sensors (Stirzaker et al., 2017; Figure 2).

Assessing ability of farmers to adapt to climate change

This study uses a comprehensive set of measures to assess the ability of the TISA approach to increase farmers' resilience and hence their ability to adapt to climate change. These measures can be assessed at four levels (domains of adaptation): field, household, scheme/community, and markets (Figure 3).

Within each domain, a range of quantitative and qualitative data were available to assess changes that have occurred following the implementation of the TISA interventions:

(1) Three household surveys within Silalatshani: (i) a baseline survey in 2014 providing data on the situation when TISA started and how farmers perceived changes over the last four years; (ii) an end-of-phase I survey in 2017 providing data on the interventions taking place and their impact; and (iii) an end-of-phase II survey in late 2021 providing data on the impact of TISA during phase II and how the COVID-19 pandemic impacted outcomes.
(2) A household survey in 2021 within a non-TISA scheme (Siwazi) to assess how the COVID-19 pandemic impacted farmers within the scheme relative to the TISA farmers (Silalatshani) and verify that TISA has improved farmers' ability to cope with shocks.

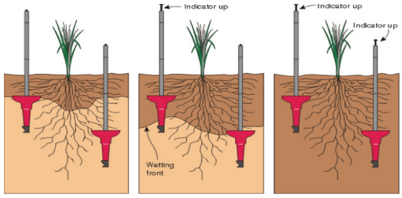
Tool	FullStop Wetting Front Detector	Chameleon Soil Moisture Sensor
		
Measures	• Depth of wetting front in soil • Salinity and nitrate levels	• Soil moisture • Illustrates distribution of soil moisture through the profile using intuitive readings: blue = wet, green = desirable moisture, red = dry.
Feedback and learning	• Identifies over irrigation where deep drainage below the rootzone occurs. • Identifies optimal irrigation volumes by detecting the wetting front reaching a desired depth. • Identifies leaching of nutrients below the rootzone.	• This informs optimal timing and volume of irrigations by identifying if soil is sufficiently wet and no irrigation is needed, or if soil is dry in the rootzone. • Combined with the WFD, farmers learn that when the chameleon is consistently blue fertilizer leaches below the root zone and is lost to the plants.

Figure 2. Soil monitoring tools deployed at irrigation schemes.

(3) Field books in which farmers recorded farm operations, monitoring tool readings, input use, purchases, harvest, and prices received. These records were critical in establishing accurate yield estimates and computing gross margins.
(4) Focus groups and workshops with farmers and stakeholders during the eight-year period.
(5) Field observations by the project field officer and researchers when visiting.
(6) Minutes of AIP meetings.

Ethics declaration for research with human participants

This confirms that the study was approved (or granted exemption) by the appropriate institutional and/or national research ethics committees, i.e., in 2013/14 by the

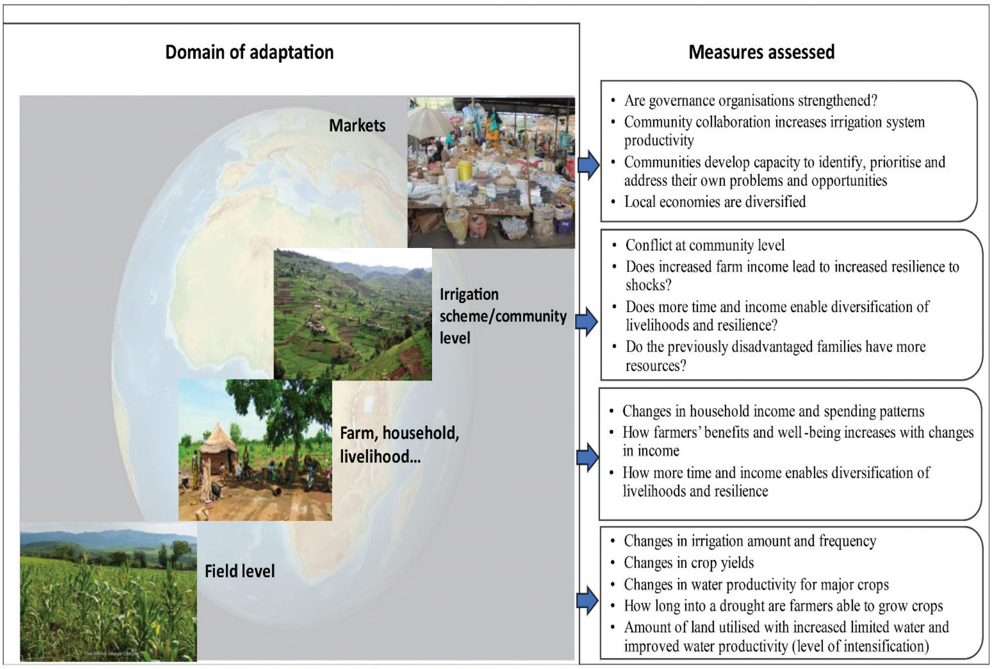


Figure 3. Climate change adaptation domains used as a framework for analysing the adaptive capacities of irrigation schemes.

University of South Australia, Human Research Ethics Committee and the protocol name is 'Increasing irrigation water productivity in Mozambique, Tanzania and Zimbabwe through on-farm monitoring, adaptive management and agricultural innovation platforms', protocol number 0000032704. Similarly, the 2016/17 and 2020/21 surveys and focus groups were approved by the Australian National University, Human Research Ethics Committee, and the protocol is called 'Transforming smallholder irrigation into profitable and self-sustaining systems in southern Africa', protocol number 2017/263. There was verbal consent from individual farming households to carry out the surveys.

Results

This section details some of the key results from the study. This analysis provides evidence of TISA's transformative impact in small-scale irrigation schemes. It also provides evidence of how the TISA approach has increased farmers' adaptive capacity, profitability, and resilience to climate change compared to non-TISA scheme. The study details some of the key adaptive capacities the TISA project has enhanced in the face of extreme events, including droughts (for the irrigation households, and/or floods), their schemes, and shocks such as COVID-19.

Field domain

Changes to timing and duration of irrigation events

The results of the end-of-phase I survey show evidence of farmer-to-farmer learning. Only 20% of the farmers were given the tools but almost 60% changed irrigation practice by the end of Phase I (2017) and 77% of these farmers made further changes between 2017 and 2021, while almost all of them (94%) were still using the new practices in 2021. A further 31% made their first changes after 2017 (Table 1). By 2021, cumulatively 81% of the farmers interviewed in both 2017 and 2022 had changed irrigation practices. Hence, there is evidence of ongoing and sustained change in irrigation practices due to learning from the monitoring tools and associated AIP interventions (Figure 4).

Most farmers lengthened the period between irrigation events but many also reduced the duration of each event (Table 1). This reduced water use, saved time, and reduced fertilizer leaching. The results from the end-of-project survey (2022) show the same trend as the 2017 results (Moyo et al., 2020), with evidence of ongoing learning and improvements in irrigation scheduling and time taken. This suggests that the irrigators are adapting to prevailing climatic changes. In 2017, the time between irrigation events had increased from 7 days in 2014 to 15 days in 2017, and by 2022 this further increased to 16 days, with a reduction in the duration of each irrigation event from 5 hours in 2014 to 2 hours in 2017 and to 1.4 hours in 2021.

The time farmers saved irrigating their plots was diverted to other uses such as enhanced crop management or off-farm income-generating activities that help the TISA farmers cope better with shocks. The farmers indicated that the main benefits from the reduction in irrigation frequency (increasing the time between irrigation events) and the reduction in duration of each irrigation were saving of time (74%) and saving of water (81%; Table 1).

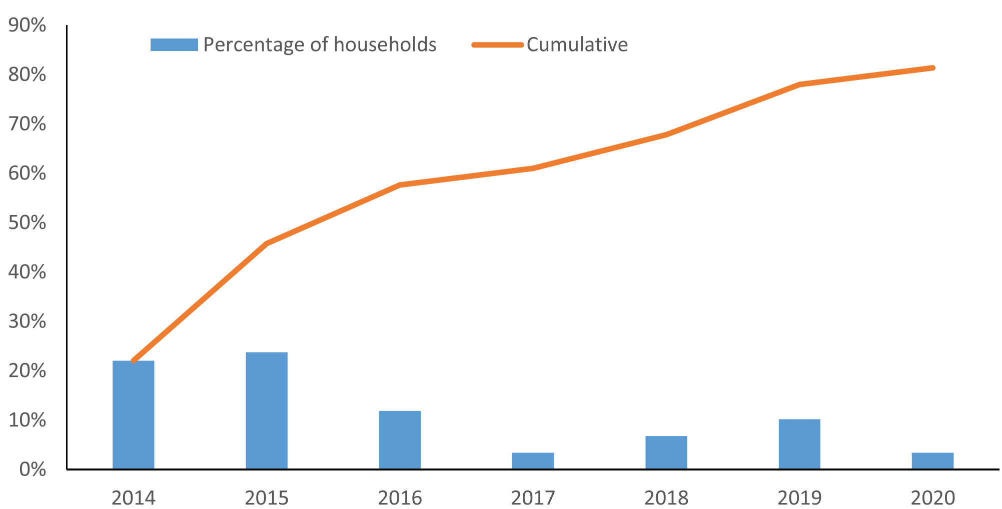


Figure 4. Percentage of households at TISA irrigation schemes surveyed in both 2017 and 2022 reporting a change in irrigation practice from 2014 to 2021.

Table 2. Changes in irrigation practices and WP from using the tools.

Variable	Units	Silalatshani (2013/14)	Silalatshani (2016/17)	Silalatshani (2021/22)
Amount of irrigation water used	mm	779.16	163.53	114.47
Total rainfall in the crop growing season	mm	215.5	204.1	280.2
Total amount of water used (per plot) (Seasonal rainfall + amount of water applied through irrigation)	mm	994.66	367.63	394.67
Maize yield for the farmers	kg/ha	2000	4693.28	3856
WP	kg/m^3	0.20	1.28	0.98

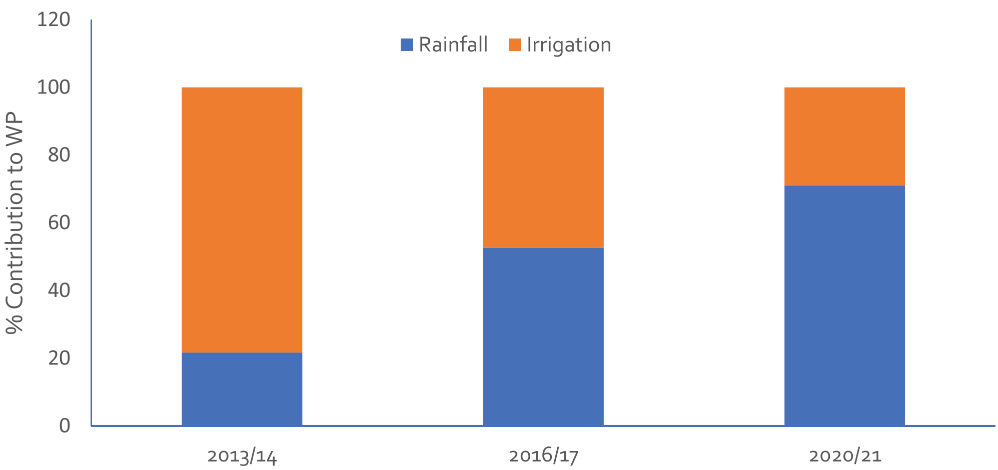


Figure 5. Contribution of water from both rainfall and irrigation to WP at the Silalatshani irrigation scheme.

Changes in crop yields and water productivity

The reduction in irrigation frequency at Silalatshani reduced fertilizer leaching and hence improved crop yield and therefore improved WP (crop yield relative to water applied; Table 2). WP, both in 2016/17 and 2020/21, was well above pre-intervention levels. WP in the 2020/21 season was lower than in the 2016/17 season due to more effective use of rainfall being received during the maize growing period and lesser yields being attained in 2020/21 (Table 2). The drop in crop yields is likely to be linked to challenges faced by farmers in accessing inputs and paying increased prices due to the impact of COVID-19 on supply chains.

In the 2016/17 season, there was more effective use of rainfall received, with higher yields attained from a smaller volume of irrigation water used within the system. In both seasons, there was reduced irrigation volume, which means that the contribution of rainfall increased as a proportion of total available crop water (Figure 5). This represents a reversion of the irrigation schemes to their original intended purpose: as being supplementary to rainfall during the summer season (Mudimu, 1999).

Changes in irrigated area and in crops grown at the scheme

From 2019 to 2021, a greater proportion of TISA farmers (32%) changed their irrigated area compared with non-TISA farmers (15%; Table 3). This reflects a larger reliance on temporary access to land in the TISA scheme, potentially representing farmers responding

Table 3. Changes in the irrigated area and new crops at TISA and non-TISA schemes.

	TISA	Non-TISA
Change in area irrigated in the last four years ago		
Decreased	29	7
Unchanged	39	78
Increased	32	15
New crops		
Other cereals	13	2
Other vegetables	13	4
Other legumes	2	na
Irish potato	na	6
Reasons for growing new crops		
Demand was good	51	11
Prices were good	79	22

to improved market signals facilitated by the AIP. Both increases and reductions in irrigated areas may relate to improved WP (Table 3). Saved water at previously over-irrigated fields may have facilitated farmers actively engaged in the AIP activities to get temporary access to other farmers' plots, which could not fully benefit from farming due to poor water access and lack of resources to buy inputs.

There was a significant difference between the proportion of the TISA farmers (28%) taking on new crop types compared with non-TISA farmers (12%) as either a result of good demand for the crop or better market prices (Table 3). This reflects greater willingness and capacity of TISA farmers to respond to market dynamics because of the AIP intervention (van Rooyen et al., 2020). The new crops that households took up included quinoa and garlic, mainly as a result of interactions with other farmers and development agencies. Conversely, for the non-TISA schemes, the decision to introduce new crops was mainly influenced by extension officers. The different reasons between the two schemes clearly reflect the influence of the AIP in building market linkages and increasing farmers' agency (van Rooyen et al., 2017). TISA farmers were found to be more responsive to market changes and hence more likely to be resilient to shocks than non-TISA farmers.

Household domain

Changes in household income and expenditure on household basics

At the end of Phase I, 49% and 41% of the farmers indicated that their farm incomes and off-farm incomes had improved since project inception, respectively. From the end of Phase I in 2017–2020, before the first COVID-19 restrictions, the number of households that experienced positive change in household income increased. More households experienced increases in on-farm compared to off-farm income during Phase II (Table 4). A similar pattern was observed in the non-TISA scheme between 2017 and 2020, and for both schemes the change in on-farm income was attributed mainly to better output prices, access to improved inputs and increased farm production levels. That a larger percentage of TISA farmers perceive their farm and off-farm income to be unchanged during 2017–2020 compared to the non-TISA farmers probably reflects that the TISA farmers saw significant increases during Phase I, which they were able to retain until COVID-19.

Table 4. Survey respondents' change in farm income and capacity to meet household basics (%).

	TISA Scheme			Non-TISA Scheme	
	2014–17	2017–20	Since COVID-19	2017–2020	Since COVID-19
Change in farm income					
Worse	38	10	62	12	68
Unchanged	13	28	25	16	18
Improved	49	62	13	73	15
Change in off-farm income					
Worse	26	7	50	13	67
Unchanged	33	40.	33	18	15
Improved	41	48	12	59	9
Change in capacity to pay school fees					
Worse	46	15	58	10	76
Unchanged	23	30	22	20	12
Improved	31	50	14	51	4
Changes in capacity to buy food					
Worse	11	6	30	12	48
Unchanged	25	51	60.0	38	28
Improved	64	45	11	50	15

Post the COVID-19 restrictions, there was an increase in the proportion of households in the two schemes that experienced a decline in household income when compared with the period prior to the restrictions. There were, however, relatively more households in the non-TISA scheme, indicating that their on-farm and off-farm incomes were adversely impacted by COVID-19 than in the TISA scheme. We speculate that the greater crop diversity and more off-farm economic activities of TISA scheme farmers enhanced their resilience to respond to the shock better than the non-TISA scheme.

At the end of Phase I, a third of the TISA households perceived that their capacity to pay school fees had improved compared to the baseline. This trajectory increased during TISA II, with 50% reporting increased capacity in 2020 on the TISA scheme, just before the first COVID-19 restrictions. A similar proportion of farmers during the same period also reported improved capacity to pay school fees in the non-TISA scheme. After the first COVID-19 restrictions, both schemes had a significant proportion of households whose capacity to meet their children's education diminished. In the TISA scheme almost 60% were adversely affected compared to almost 80% in non-TISA scheme (Table 4).

The impact of the interventions on food security of households was significant during Phase I, with over 60% of farmers experiencing positive changes to their household food security compared to four years prior. Most households maintained their food security status during Phase II and there were additional households whose food security improved until the COVID-19 pandemic. The impact of COVID-19 on household food security was more severe in the non-TISA scheme, where almost half of the farmers experienced a decline compared to a third in the TISA scheme (Table 4). The higher proportion of households in the TISA scheme whose incomes withstood the COVID-19 shock compared to those in the non-TISA scheme demonstrated that the TISA interventions had enhanced the resilience of the TISA scheme to shocks.

Changes in gross margin (grain maize)

From 2017 to 2021, the average maize (main staple) gross margin realized by farmers within the TISA scheme showed an upward trend (Figure 6). This was attributed to

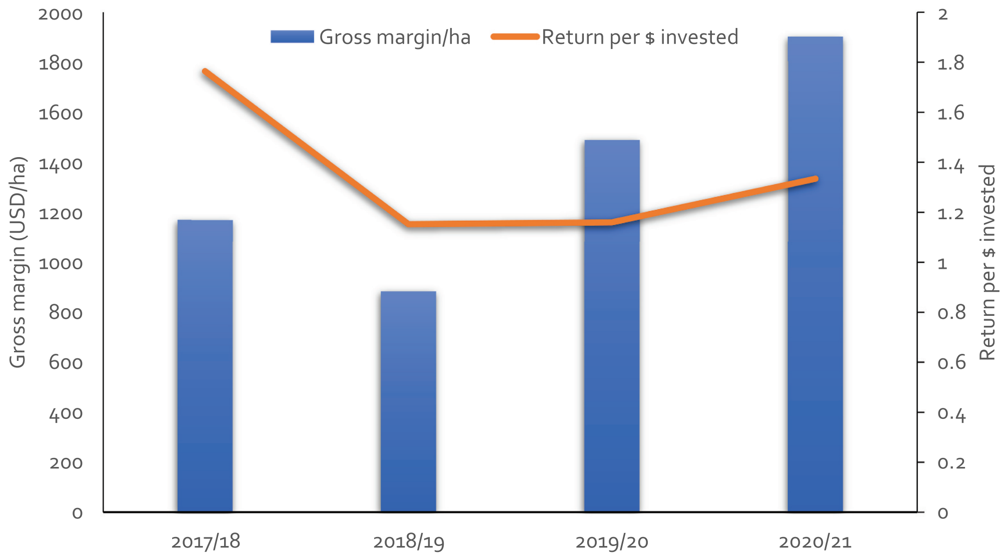


Figure 6. Average grain maize gross margin (USD/ha) TISA Scheme: 2017–2021.

improved productivity levels arising from more efficient water and input (fertilizer) use linked to the use of soil moisture and nutrient monitoring tools and improved access to both input and output markets facilitated by AIPs. The return-per-dollar invested has fluctuated above 1 since 2017, ensuring a net increase in farm income, which is a necessary development for enhancing the capacity of the household to cope with climate-induced shocks.

Importance of AIP activities to TISA farmers

Table 5 shows the level of awareness of AIP activities and outcomes by farmers since 2013. The level of awareness varied from activity to activity, with between 40% and 85% of farmers being aware of all activities except access to finance. The awareness was either through direct participation in the activity or word-of-mouth from peers within the scheme. This demonstrates the importance of social learning in enhancing farmers' knowledge on improved technologies. A significant proportion of farmers were aware of activities influencing farm income such as gross margin analysis, business planning, access to input and output markets. Experiential demonstration plots were ranked as

Table 5. AIP activities.

Activities 2013–21	% of households aware of the activity	Who participated in the household?			% Households ranking each activity 1–3 in order of importance (1 most important, 2 second most important . . .)		
		Male member	Female member	Joint			
Introduction of new high-value crops	85	20	71	9	22	31	20
Experiential demonstration plots	76	27	50	23	30	8	13
Collaborative mapping	66	25	50	25	14	14	24
Gross margin workshop/training	58	18	71	11	7	21	12
Business plan	59				16	12	13
Improved output market linkages	49	22	55	23	5	10	13
Improved input market linkages	42	21	72	7	6	5	3

the most important AIP activity by the highest number of farmers, followed by the introduction of high-value crops. Farmers also highlighted the demonstration plots during focus group discussions as being critical in the acceptance of the monitoring tools as an option to improve water management. The AIP activities were crucial in building knowledge among irrigators as well as preparing them to cope better with shocks.

The study found that participation within various AIP activities was dominated by female members of the farming households (more than 75%). This was more pronounced in AIP activities associated with improving farm income such as gross margin analysis and production of high-value crops, where 71% of the households were represented by females. These findings demonstrate how the TISA interventions, and the AIP activities in particular, have enabled female farmers to further assert their agency. Participation in gross margin analysis training, high-value crop production and improved linkages to output markets had positive impact on household incomes. Demonstration plots and improved linkages to input markets contributed to increased production levels, as a result of their influence on adoption of improved technologies. Participatory mapping, on the other hand, was found to decrease the level of conflict related to boundary disputes within the scheme. The mapping exercise clarified boundary issues related to reserved areas between blocks (Mdemu et al., 2024).

Community domain

Changes in conflict over water

At the end of Phase I, 42% of TISA farmers perceived that conflict over water use had declined. This reflects that water savings caused by using the tools had increased water supply for tail-end users and therefore reduced competition over water. This was observed between farmers within the Landela Block, but also between blocks as well as with other water users who depend on water from the main dam. Conflicts also decreased within households (69%) as incomes were increasing, and conflicts over resource allocation declined (Moyo et al., 2020). However, by 2019, 48% of the farmers felt that the conflict over water had increased (Table 6). This coincided with severe shortages water experienced during that year because of drought. In response, the water authorities introduced water rationing, which could have been the source of the upsurge in conflicts. For many households (72%), the perception about conflict over water did not change after the first COVID-19 lockdown. These findings reflect the contested nature of water access, especially during drought. They also demonstrate the influence that external policies can have on conflict. The reduction in conflict prior to 2017 meant that community cohesion was better during the 2019 drought period than it may have been otherwise.

In 2017, at the end of Phase I, more than three-quarters of farmers within the TISA scheme were more willing to pay for water than they were at the start of the intervention. In Phase II most (78%) of the farmers' position on willingness remained unchanged (Table 6). Prior to the COVID-19 restriction, the positive trajectory in the number of farmers who increased their willingness to pay continued, as indicated by 21% of the farmers. A similar pattern was observed in the proportion of farmers willing to participate in scheme maintenance and those willing to participate in scheme meetings. Building on

Table 6. Changes in conflicts over water, in willingness to pay for water and willingness to participate in scheme maintenance and meetings (% of irrigators).

	2017–2020	After COVID-19
Changes in conflict		
Decreased	12	6
Unchanged	40	72
Increased	48	22
Willingness to pay for water		
Decreased	12	16
Unchanged	78	81
Increased	10	3
Willingness to participate in scheme maintenance		
Decreased	11	16
Unchanged	75	76
Increased	14	8
Participation in irrigation scheme meeting		
Decreased	14	31
Unchanged	65	66
Increased	21	4

the high proportion of farmers that increased their willingness in Phase I, there were a further 14% and 21% of farmers who increased their willingness to maintain the scheme and participate in various meetings at scheme level in Phase II, which was just before the COVID-19 restrictions.

Since the COVID-19 restrictions, the attitudes of at least 66% of the farmers remained unchanged. The high proportion of farmers that remained willing to be engaged in scheme maintenance, pay for water and attend scheme meetings reflected increased social capital and stronger governance capacity, which are key to the sustainability of the scheme.

Market domain

Changes in amount of farm output consumed and sold

Prior to the first COVID-19 lockdown, the non-TISA scheme saw a bigger shift towards consuming more of their crop than they sold, while within the TISA scheme more farmers shifted towards selling more than they consumed (Annexe 1). That more farmers within the TISA scheme increased how much they sold likely reflects the emphasis the AIP puts on shifting the farming system from subsistence to being more market-oriented and the improved productivity levels as a result of adoption of improved technologies.

TISA approach and increasing farmers' ability to cope with COVID-19

A greater proportion of TISA households than non-TISA households reported that the COVID-19 pandemic had no effect on them. It was also observed that almost 60% of non-TISA households experienced moderate to severe impacts as a result of COVID-19 compared to less than 50% of TISA farmers (Annexe 2). These results reinforced observations of other indicators that showed that the interventions in the TISA scheme enhanced their resilience to cope with shocks better than the non-TISA scheme. The main adverse impact of COVID-19 in TISA schemes related to children not being able to access education, while more non-TISA farmers reported breakdown of social networks and the loss of transport and access to food and off-farm income.

A much lower proportion of TISA households reported insidious impacts such as a decline in household food security and in farm and off-farm income (Annexe 2). In terms of access to markets, information, and effect on production, the COVID-19 pandemic had similar impacts on farmers in both TISA and non-TISA schemes. However, the magnitude of the impact differs, being lower in TISA schemes. For example, access to output markets and information was reported at lower levels in TISA schemes (Annexe 2).

Community/scheme domain

At the scheme level, COVID-19 had similar impacts on farmers in both TISA and non-TISA schemes, but just like at the household level, the magnitude of the impact differs, with far more farmers in the TISA scheme reporting no effect (Annexe 2). At the TISA schemes, the indication is that there are fewer maintenance jobs not being carried out compared to non-TISA schemes. This means that the non-TISA schemes are more likely to face infrastructure decay, compromising their sustainability. In terms of access to extension services, the access was far more impacted in the non-TISA schemes, compromising their coping ability. More land was farmed due to returning family members in the TISA schemes. Overall, responses indicate that the TISA scheme generally suffered less acute and deleterious impacts of the COVID-19 pandemic than non-TISA scheme, suggesting they have greater capacity to respond to shocks.

Discussion

Agricultural systems in Zimbabwe are vulnerable to climate change and variability due to their dependence on natural resources. The challenges related to unpredictable rainfall patterns have seen the Government of Zimbabwe embark on investments in new irrigation developments to supplement rainfed agriculture and allow continuous crop production and facilitate increased productivity. Although irrigation developments have been presented as a panacea to offset the impact of climate change and variability, its relative dependence on surface water makes the livelihoods of communities more vulnerable to climate change and variability, as the existing resources often dry up and lead to water stress (Mutambara et al., 2017; Muzari et al., 2013; Nkomozepi & Chung, 2012).

Evidence from this study indicates that the synergistic social and technical interventions introduced by TISA have the potential to contribute to transitioning smallholder irrigation schemes into adaptive systems. The use of soil monitoring tools, and associated learning processes, has improved WP of irrigated agriculture (Figure 4), which is critical to improve water management under climate variability and predicted climate change (Target 6.4 of the Sustainable Development Goals). Improvement of crop production, alongside a reduction in total irrigation water applied (Figure 4), means that irrigators have greater adaptive capacity to future water shortages (Moyo et al., 2020). Hence, production losses will be lower as climate change makes water availability more volatile. Improved WP is critical for enhancing the adaptive capacity of irrigation systems and helping the process of transitioning existing unproductive systems to more productive systems, which in turn could justify investment in increasing the area under irrigation (Moyo et al., 2020; Senzanje et al., 2003).

In Zimbabwe, lack of technical knowledge for managing water and irrigation infrastructure is one of the main barriers of reduced productivity and profitability in smallholder irrigation schemes (Moyo et al., 2020). The study found that farmers made a range of changes to their irrigation practice resulting in reduced water use. Farmers lengthened the period between irrigation events and reduced the duration of the event (Tables 2 and 3). Such changes have been attributed to learning from the monitoring tools, which has spread via farmer-to-farmer learning as irrigators saw and implemented what other farmers were doing as part of building the social capital from the TISA project. Individual farmers' interactions with and learning from others are important in adaptation to climate change and variability (Nyahunda & Tirivangasi, 2021). Investment in farmer learning and networking has increased irrigators' adaptive capacity at the field, household, scheme/community, and market domains.

Small size of irrigated plots and lack of secure tenure are major disincentives for irrigators to invest and are therefore among the primary factors leading to low performance of irrigation schemes. Access to productive land, and enhanced land tenure, have been found to improve farmers' productivity and empowerment, particularly women, and build adaptive capacity within smallholder agriculture (Jacobs et al., 2013). Farmers take a long-term view of investment; they are more likely to build permanent productive structures if they have secure tenure. IFAD (2020) indicates that small plot sizes limit the ability for schemes to be financially sustainable, thus putting into question reinvestment into the irrigation systems. In Zimbabwe, smallholders in irrigation schemes have access to relatively small plots; hence, they cannot cultivate larger plots to maintain production levels as a climate change response option. This leads to relatively lower contributions of irrigation to household food security and income, leading to vulnerability to climate change and variability. The evidence from this study points to a greater proportion of TISA farmers (32%) increasing land area compared to non-TISA farmers (15%; Table 6). This reflects a larger reliance on temporary access to land in the TISA schemes. Increases in irrigated areas may also relate to improved water productivity (Figure 4), as water saved from previously over-irrigated fields may have been utilized by farmers who previously struggled with water access.

Producing crops with less water, in varying conditions, and adapting to changing market conditions, enhances resilience and enables better adaptation to climate change. This was demonstrated by the irrigators' capacity to adapt to changing policy and social conditions during the COVID-19 pandemic. Farmers were able to maintain production and adapt agronomic practices to accommodate more uncertain input supplies. The results from the study reflect a stronger willingness to adjust farming approaches in the face of change among TISA farmers, which is a key characteristic of adaptive capacity. Mwadzingeni et al. (2022b) note the need for diversified production within irrigation schemes as well as market linkages for enhanced adaptive capacity to climate change and variability. The yields from this study range between 50% and 70% of yield potential, which is fair considering that Jacobs et al. (2013) argue that irrigated cropping should achieve about 80% of yield potential. The yields from both schemes are generally fair, although lower than the yields from commercial schemes, which may yield up to 8000–11,000 kg/ha (Muzerengi & Mapuranga, 2017).

Improved irrigation practices translated to more diversified income and time allocation at the household domain. Importantly, time saved on agricultural activities and further income received, both from agricultural and off-farm enterprises, were used to improve households' livelihoods by paying for children's education, food security and health. These changes enhanced the agency and livelihoods of female farmers. The diversification of household activities improved resilience to perturbations caused by the COVID-19 pandemic and by inference to climate change. Further research and innovation in activity diversification beyond irrigated agriculture at the household domain are likely to further improve resilience to shocks (Silici et al., 2021).

The AIP and the tools have created participatory farmer-to-farmer learning processes which have resulted in water savings at the field domain, increased yield, gross margins, and income diversification in the household domain and reduced conflict in the community domain. This has built trust and farmers' agency, contributing to increased willingness to engage in collective action such as paying for and participating in scheme maintenance and scheme meetings. This has built agency and social capital and stronger governance capacity. This is consistent with findings in the literature that learning platforms for multiple stakeholder interactions, including farmer field schools and similar practical demonstration training and other participatory communication solutions, exert a strong influence on individual as well as community adaptation patterns (Mudombi et al., 2017; Phuong et al., 2017). Also, Muzari et al. (2016) note that farmers' social structures, and especially networks structured around knowledgeable actors, can help enhance adaptive capacity as the breakdown of social networks affects vulnerability. In the future, these community changes may lead to the formation of collective action groups or cooperatives for purchasing of inputs, marketing of outputs, or management of natural resources.

Greater communication within communities has translated to better outward-facing communication, including stronger linkages with markets. Compared to non-TISA farmers, TISA farmers showed evidence of much more active response to market signals by increasing their area under irrigation on a seasonal basis and starting to grow new crops. Reflecting this, they also made more substantive increases to the portion of their production that they sold relative to what they consumed; hence, shifting from subsistence to commercial farming. This improved capacity to adapt to changing market needs will be important for climate change resilience.

As interest in intensification of southern African irrigation schemes increases, the scaling up and scaling out of innovations beyond the TISA schemes must be considered. The large number of schemes and irrigators means scaling must be cost-effective. In this context, it is critical that the TISA project proved that intervening with social and relatively cheap technologies, engaging intensively with a smaller number of farmers, has proven effective in having an impact across the entire farmer group. In addition, during Phase II, the intensity of the TISA interventions was reduced significantly, transferring many roles to local stakeholders. That TISA farmers were able to further improve or maintain the gains during Phase II, until the impact of COVID-19, is evidence that the TISA approach has been able to manage the transition from project to ongoing operation. This illustrates the sustained and ongoing process of improving farmers' and schemes' capacity to adapt to climate change. Changes to agronomic practices by farmers who did not receive direct interventions demonstrates the potential of peer-learning to drive innovation. Similar peer-based diffusion of innovations among service providers such as extension agents and water regulators may enable scaling of these changes across Zimbabwe. Further social research on the perceptions of scaling among all stakeholders will inform future investment into climate change adaptation for the irrigated agriculture sector in Zimbabwe.

Lastly, smallholder irrigation development is not peculiar to Zimbabwe alone. The irrigation ‘problem’ in sub-Saharan Africa is systemic in that there is failure at several levels including technical capacity, institutional arrangements and market linkages (Inocencio et al., 2007). In response to such complex problems, the FAO (2012) report calls for the introduction of adaptive management approaches that will lead to social and institutional learning. Several sub-Saharan Africa countries could therefore benefit from similar synergistic social and technical interventions introduced by TISA, helping to contribute to transitioning smallholder irrigation schemes into adaptive systems. For example, Lankford (2005) detailed how governments in sub-Saharan Africa have sought investment to increase irrigated areas to six times the current rate under the Comprehensive Africa Agricultural Development Programme (CAADP) initiative. This means that results from this study could be replicated across geographies as most of the sub-Saharan Africa countries are the most affected by climate change and other extreme events. The impact of climate change (and other extreme events) on sub-Saharan Africa is likely to be severe because of adverse direct effects, high agricultural dependence, and limited capacity to adapt.

Conclusion

Although smallholder irrigation schemes have been portrayed as a panacea to climate change adaptation, there is a need to build the resilience of the farmers in these schemes to protect investments in light of a more variable climate. Irrigated agriculture in Zimbabwe must prepare for increasing disturbances arising from climate change, which may include reduced and more volatile water availability, and changing market dynamics as dryland agriculture becomes less reliable. The TISA project has demonstrated that technological and social interventions can have pervasive impacts on adaptations in farmers’ fields, households and communities, and the wider food markets. For example, results from the TISA scheme showed a 30% deterioration in capacity to buy food due to COVID-19, whereas non-TISA farmers suffered a 48% deterioration. Better water productivity and diversification of household income-generating activities have enhanced adaptive capacity, as demonstrated by improved food security. For example, in terms of water productivity, with a reduction in total water use from 994.66 mm to 367.63 mm, maize yield increased from 2000 kg/ha to 4603 kg/ha. Improved WP has also improved participation in irrigation association meetings and willingness to pay for and contribute to scheme maintenance. These findings from Zimbabwe point to ways in which climate adaptation and resilience in agriculture in Africa can be greatly enhanced at modest costs with appropriate social institutions, such as AIPs, and associated social capacity building processes as well as technologies such as soil monitoring tools.

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Appendices

Annexe 1. Changes in amount of farm output sold and consumed in 2017–2019 at TISA and non-TISA schemes

Compared to four years ago how are you now:		Decreased a lot	Decreased	Unchanged	Increased	Increased a lot
TISA (% of irrigators)	Selling a larger proportion of my crop relative to consuming it	4	19	47	21	9
Non-TISA (% of irrigators)	Selling a larger proportion of my crop relative to consuming it	6	38	35	12	9

Annexe 2. Impacts of COVID-19 pandemic on households at TISA and non-TISA schemes

	TISA	Non-TISA
How did COVID-19 impact your household/farm/scheme?		
Impacted it positively	2	2
No impact	18	4
Minor negative impact	34	37
Moderate negative impact	26	40
Severe negative impact	20	18
How did COVID-19 and the lockdown affect you and your household?		
Family members lost off-farm income jobs	30	43
Loss of transport	38	69
Children could not attend school, tertiary education	53	52
Reduced access to food as shops closed, or transport unavailable	28	44
Breakdown of social networks	20	40
The three biggest impacts of COVID-19 on household:		
Household food security	18	37
Health of household members	7	6
Declining farm income	68	81
Declining off-farm income	35	56
How did the lockdowns affect you and your farming operations?		
Access to output markets	64	82
Access to information	21	35
Reduced production and farm income	26	31
How did COVID-19 and the lockdowns affect your scheme?		
Maintenance jobs have not been carried out	12	38
Extension officers could not get to the scheme and help	26	46
Other stakeholders who provide advice could not come to the scheme	28	24
More land farmed as family members returned to the scheme	10	4
No effect	46	29