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Participatory mapping of irrigation schemes in Tanzania, Mozambique and Zimbabwe and their value for multi-level learning

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ABSTRACT

This paper analyses the capacity of participatory mapping as a multi-level learning process to identify and overcome current barriers to productivity within small-scale irrigation schemes. The analysis is based on thirteen smallholder irrigation schemes in Tanzania, Mozambique, and Zimbabwe, where farmers, project officers and other key stakeholders participated in informal mapping teams to map the schemes. Critically, participatory mapping translated problems generally known by stakeholders into problems that were publicly known, making their resolution a shared responsibility. Hence, problems identified at both the scheme and plot levels led to immediate responses by the farmers, irrigator organizations, and government departments, boosting farmers' agency and confidence and renewing their sense of scheme and plot ownership. It is important that irrigation agencies prioritize participatory processes and the use of informal networks to improve farmers' understanding of their resource and management challenges and to build their sense of ownership and responsibility for effective management of irrigation schemes.

1. Introduction

Public participation in the management of water resources, including irrigation schemes, has in recent years been widely promoted as an important part of water governance (Shunglu et al., 2022; Priscoli, 2004). This process has the potential to bring together a broad range of stakeholders, with different knowledge and expertise, to generate shared knowledge and identify innovative solutions to deal with the increased complexity and uncertainty associated with water issues. This should also increase stakeholders' agency and sense of ownership of the problems, and outcomes and lend legitimacy to implemented solutions (Berkes and Folke, 2002; Pahl-Wostl et al., 2007b, 2009, 2021).

Participatory mapping is one type of process to engage local stakeholders in shaping the discussion and share knowledge of their social-physical environment. It is a direct way of co-producing knowledge with stakeholders and enables engagement in the process while facilitating social learning, and offering a foundation for the creation of social capital and information sharing (Burdon et al., 2019; Damastuti and de Groot, 2018). It is a vehicle for knowledge exchange between participants as it increases community awareness of risks and engages them in identifying solutions (Sullivan-Wiley et al., 2019). Additionally, the impact of participatory mapping on empowerment, inclusion, social capital is extensively reported in the literature (Fagerholm et al., 2021; Saadallah, 2020; Falco et al., 2019; Weyer et al., 2019; Lidon et al., 2018; Hossen, 2016; Chambers, 2006). Participatory mapping has the potential to clarify plot boundaries and size. Trust in the results is built, as the mapping process has transparent agendas, approaches, processes, and techniques and is predominantly controlled by the people whose territories and places are being mapped (Saadallah, 2020; Von Korff et al., 2012). The process makes use of various approaches, including participatory GIS (Fagerholm et al., 2021).

Participatory mapping has been successfully used in natural resource identification and management, neighbourhood identification and problem prioritization in various fields (McCall, 2004). The fact that communities are dependent on a shared resource is a likely contributory factor to this success. It has also been applied for legitimizing resource

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claims and use (Hossen, 2016). Existing literature suggests that participatory mapping can deliver effective solutions to land use and natural resource management conflicts (e.g. Burdon et al., 2019; Sullivan-Wiley et al., 2019; Weyer et al., 2019; Brown et al., 2018; Damastuti and de Groot, 2018; Hossen, 2016; Guilfoyle and Mitchell, 2015; Lipej and Male, 2015; McCall, 2004). Despite the extensive use of participatory mapping for natural resources management, including water management in catchments and river basins, literature is scant on its application in mapping and improving knowledge of ownership structures and infrastructure, assessing problems affecting irrigators and identifying solutions for smallholder schemes in sub-Saharan African (SSA). However, there are some extremely legitimate concerns related to the institutions controlling the process and implementation: for example, why the maps are produced, who controls the process and their outcomes, who benefits, and who controls the final maps and their information (Chambers, 2006; Fox, 2002; Sletto, 2009).

The participatory mapping processes analysed for this paper were carried out in the context of the project 'Transforming small-scale Irrigation in southern Africa' (TISA), which researched how smallholder irrigation schemes in Mozambique, Tanzania, and Zimbabwe can be transitioned into productive and self-sustaining systems. Agricultural Innovation Platforms (AIPs) were a corner stone of the TISA approach, and were introduced as a participatory process to identify barriers to increased productivity and profitability and identify and implement solutions to overcome them. AIPs are forums that foster interactions and engagement among a diverse group of stakeholders who share a common interest, and are particularly useful to facilitate dialogue to address a set of challenges in a system (Makini et al., 2013). They can be established and facilitated by research-for-development projects, government agencies, NGOs or partnerships of diverse organisations. The establishment and functioning of AIPs generally involve four stages: stakeholder identification, visioning, identification of challenges and root causes, and an innovation process that generates solutions (van Rooyen et al., 2017). The AIPs identified participatory mapping as one approach to help clarify and overcome a number of barriers. The broad purpose was also to explore the viability of this approach to improve the sense of ownership of irrigated plots, scheme governance and management, and address irrigators' problems. As further explained in the body of this paper, the process undertaken through TISA alleviates the concerns noted earlier.

Participatory mapping processes can be conceived as multi-level learning processes aiming to contribute to transformative change. There is scope for more research in this area as arrangements are context-dependent and there is limited understanding of how these learning processes transform governance (Pahl-Wostl & Patterson (2019). Pahl-Wostl (2009, 2015) conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes proposes four key areas that require analysis: governance arrangements, including hierarchical arrangements, markets and informal networks; multi-level interactions and actors' roles in change processes; interplay between formal and informal institutions (i.e. rules, norms), and how these change; and how learning processes occur. In regard to the latter, Pahl-Wostl (2009, 2015) makes the association with single, double and triple loop learning, and the interplay between actors gaining agency through learning and then undertaking actions that strengthen or weaken constraints. The progression of learning from single through to triple loop, reflects the resulting change with respect to structural constraints: that is, incremental changes that address symptoms; more comprehensive changes that question structural constraints; and a fundamental re-think of how to address structural constraints (Pahl-Wostl, 2009, 2015).

Drawing on TISA research and experiences, this paper contributes to understanding the enablers of multi-level learning, agency building and change in governance systems and addresses the question: how have participatory mapping processes enabled multi-level learning and change in smallholder irrigation schemes? The paper is organized in four main sections: i) the methodology outlines the five main steps in the mapping process and the variations across countries, including intended purpose and outcomes; ii) a results section outlines the outcomes of the mapping process for each country, including evidence of single, double or triple loop learning; iii) the discussion responds to the research question and synthesises the findings with respect to Pahl-Wostl (2009) four key areas; and iv) a conclusion with implications for policy.

2. Methodology

2.1. Description of study areas

The irrigation schemes in Tanzania, Mozambique and Zimbabwe involved in this study are part of the research-for-development project 'Transforming smallholder Irrigation in Southern Africa (TISA) (Table 1). In Tanzania, six schemes, located in Iringa District, were involved. Kiwere is located at 1300 *masl* in the highland agro-ecological zone. The mean annual rainfall and temperature is 700 mm and 23 °C, respectively (Mziray et al., 2015). The remaining five schemes are located in the lowland agro-ecological zone, which has relatively flat landforms at an altitude of 762–792 *masl* and a mean rainfall and temperature of 600 mm and 25 °C respectively. Potential evapotranspiration is higher (1200–1500 mm) than annual rainfall both for the highland and lowland agro-ecological zones, making irrigation necessary for crop production. Farming is the main household income-generating activity in the schemes. Rice is the main irrigated crop during the rainy season in five of the irrigation schemes (Idodi, Mafuroto, Magozi, Nyamahana and Tungamalenga). Green maize, tomato, onion and leafy vegetables are the main irrigated crops in dry seasons in four schemes (Kiwere, Mafuruto, Nyamahana and Tungamalenga). Rainfed crop production is mainly maize, beans, sorghum and millet in households' unirrigated family lands. Lack of access to functional markets is a common constraint for most schemes in Tanzania and farmers depend on regular traders, farmgate and wholesale as their main market channels for their crops (Mdemu et al., 2017).

In Mozambique, five schemes from four districts of the Maputo Province were involved: Mafuiane; Bloco I; Manguiza and Macuvulana I and II (see Table 1 for districts). The mean annual rainfall varies between 600 and 800 mm, and the average temperature is between 20 °C and 25 °C. The annual reference evapotranspiration is between 1400 and 1600 mm, exceeding the rainfall. This makes irrigation critical for food production. All schemes have mostly flat landforms with elevations below 200 *masl*. Farming is the main source of livelihood for the people in the study schemes. Sugarcane is the main produced irrigated crop for Macuvulana I and Macuvulana II irrigation schemes. In all remaining schemes, vegetables such as green maize, green beans, cabbage, onions, tomato are mainly produced. During the rainy season farmers also grow rainfed crops such as cassava, groundnuts, sweet potatoes, pumpkins and beans outside the scheme for subsistence. Irrigated produce from the schemes are marketed locally in the village and Maputo city markets through retailers.

In Zimbabwe, two schemes were involved: Mkoba and Silalatshani, which are located in Gweru and Insiza districts respectively. Mkoba is located in agro-ecological region III where mean annual rainfall is between 650 mm and 900 mm and the mean annual temperature is between 18 °C and 22 °C. Silalatshani is located in agro-ecological region IV with mean annual rainfall between 450 mm and 650 mm and average temperature between 18 and 24 °C. In general, evapotranspiration rates in Mkoba and Silalatshani are higher than annual precipitation thereby making supplementary irrigation critical for crop production, especially during the winter season (Mugandani et al., 2012). Silalatshani and Mkoba are situated at 1412 *masl* and 1424 *masl* respectively. Silalatshani is divided into five blocks namely Landela, Nonoka, Phelandaba, Mbokodo and Vukuzenzele, which are all under different agricultural extension officers. The average land holding for cropping per farmer at Silalatshani is 0.5 ha. In Mkoba, each member has an average of 0.1 ha of

Table 1
Location and main features of the irrigation schemes.

Scheme	Latitude & Longitude	District	Distance to nearest city/ town (km)	Irrigated area (ha)	Scheme management/ administration	Number of farmers	Land tenure	Irrigation method	Water source	Ethnic group
Tanzania										
Kiwere	7°38´15´´s, 35°35´20E	Iringa	25 (to Iringa town)	195	Irrigator's organization (IOs)	168	Customary	Furrow	Little Ruaha River	Predominantly Hehe
Magozi	7°27'49'S, 41°27'19'E	Iringa	65 (to Iringa town)	939	IOs	512	Customary	Furrow	Little Ruaha River	Predominantly Hehe
Idodi	7°77´190 S/ 35°18´1760 E	Iringa	89 (to Iringa town)	660	IOs	379	Customary	Furrow	Idodi River	Mainly *Hehe* and *Bena*
Tungamalenga	7°51'S/ 35°06'E	Iringa	100 (to Iringa town)	659	IOs	357	Customary	Furrow	Tungamalenga River	Mainly *Bena* and *Hehe*
Nyamahana	7°68´610 S/ 35°41´8350 E	Iringa	43 (to Iringa town)	115.13	IOs	300	Customary	Furrow	Mlowa River	Mainly *Bena* and *Hehe*
Mafuruto	7°33´2810 S/ 35°30´4270 E	Iringa	89 (to Iringa town)	127.4	IOs	250	Customary	Furrow	Little Ruaha River	Mainly *Hehe* and *Bena*
Mozambique										
Manguiza	26°4′52.44"S; 32°21'32.32"E	Boane	30 (to Maputo)	22	Farmers' Association (FA)	65	Historical right by occupation	Furrow	River, motor pump	Mainly *Rongas* and *Tsongas*
Mafuiane	26°2′15.96"S, 32°15'14.60"E	Namaacha	43 (to Maputo)	172.02	FA	228	Historical right by occupation	Furrow	River, electro pump	Mainly *Ronga* and *Shangane*
Bloco I	25°34'22.6''S, 32°13′34.3''E	Moamba	75 (to Maputo)	480	FA	122	Historical right by occupation	Furrow	River, electro pump	Mainly *Tsonga* and *Shangane*
Macuvulana I	25°1′35.687''S, 32°41'22.379''E	Magude	155 (to Maputo)	198.77	FA	187	Registered Certificates	Sprinkler	River, electro pump	Mainly *Shangane* and *Ronga*
Macuvulana II	25°2′19.392''S, 32°41'27.852'E	Magude	155 (to Maputo)	78.44	FA (assisted by sugar cane company)	104	Registered Certificates	Sprinkler	River, electro pump	Mainly *Shangane* and *Ronga*
Zimbabwe										
Mkoba	19° 22' 0.07" S, 29° 32' 13.4"E	Gweru	33 km (to Gweru)	10	Government & community	75	Statutory land tenure	Gravity flood	Dam	Predominantly *isiNdebele*
Silalatshani	20° 47' 22" S, 29° 17' 44.59"E	Insiza	69 km (to Gwanda)	442	Government & community	845	Statutory land tenure	Gravity flood	Dam, supplied by ZINWA	Predominantly *isiNdebele*

land for cropping. However, some of the members in the scheme have more than one plot and therefore their total plot size is above 0.1 ha. In both schemes, there are however no records that disaggregate the farmers in terms of gender and age. Farming systems at both schemes are subsistence in nature, with low crop diversity and maize being the dominant crop. The main crops of maize, groundnuts, sugar beans and wheat are predominantly grown for home consumption, with more than 65% of scheme households at both schemes revealing that they consume these crops. Silalatshani irrigation scheme offers a potentially good market catchment, but this is not fully exploited. The indications are that sugar beans generally have a good market locally and farmers also have private arrangements with markets outside of Insiza district. Mkoba irrigation scheme generally has good market linkages because of its proximity to the City of Gweru. However, there are problems with marketing the horticultural crops as the market is usually flooded. It seems that the production of various crops is not linked to any market research; hence, the scheme usually produces crops that are under intense competition from other producers. Generally, the farmers market their produce individually, meaning individual irrigators face high transaction costs in marketing their produce.

Scheme management varies between countries. In Tanzania they are managed by irrigator organizations (IOs), in Mozambique by farmers' associations (FAs), and in Zimbabwe jointly by the government and irrigation management committees (IMCs). Scheme land tenure also varies. In all countries land belongs to the state and farmers have various rights to use the land. In Tanzania, farmers have customary land tenure under the Village Land Act, 1999. In Mozambique, farmers have two different rights under the Land Law, 1997. The FAs at Macuvulana I and II are formally registered legal entities and have a formal certificate that grants them the right to use and benefit from the land in the schemes. Farmers in the other schemes, under the Article Nr. 12, have the right to use and benefit from the land by historical occupation. In Zimbabwe, farmers have statutory land tenure under the Communal Land Act, 1982 (FAO, 2002), according to which rural district councils allocate land for occupancy and use in consultation and cooperation with the chiefs (Sithole, 2002).

All schemes depend on surface water irrigation using a mix of extraction, conveyance, and flood irrigation methods (Table 1). In Tanzania, the water is diverted from a river using a weir and conveyed to the farms by gravity through canals and is applied using furrows or flooding for rice. Schemes' IOs are responsible for planning and managing water distribution and scheduling especially when the river flows is low in the dry season and during the drought spell between February and March in the rain season. In Mozambique, water is extracted from the rivers using pumps and then transported by gravity in canals or pipes and applied to the fields by furrow and sprinkler. In Zimbabwe, both schemes are flood irrigated. Silalatshani's water is supplied by Zimbabwe National Water Authority (ZINWA) from the Silalabuhwa dam, which is large, has a very good catchment, and is able to sustain the water requirements of the scheme. The dam supplies some commercial entities (a mining town and schools) and ZINWA is strict on the collection of the levies from Silalatshani because of the commercial importance of the supply dam. Mkoba's water is supplied from a small dam, which has siltation problems and cannot sustain the irrigation water requirements of the scheme. At both schemes, water is transferred through lined primary canals; the secondary and tertiary canals are predominantly lined. There are no water quality problems in all the schemes in the three countries.

2.2. Selection of schemes and purpose of mapping

The selection criteria for the schemes to be part of TISA included the potential for implementing the TISA interventions, such as participatory mapping. It was also important that the farmers and scheme leaders through their organizations were willing to collaborate with the project officers to implement the interventions such as mapping and operational irrigation infrastructure.

Participatory mapping was identified through the AIPs as a relevant intervention to generate plot and scheme level information, enable multi-level learning and address some of the productivity barriers. The challenges included incomplete scheme infrastructure, unreliable markets, capital constraints for farming, and lack of formal land titles (Chilundo et al., 2020; Mdemu et al., 2020; Moyo et al., 2020). The purpose varied across the countries. In Tanzania, unreliable data on irrigation areas and lack of secure tenure were identified as obstacles for scheme management and for farmers to obtain credit. The mapping process was used in Mozambique as an entry point with schemes that joined the project at a later date and prior to implementation of other activities. The purpose was to establish baseline conditions, and develop rapport with farmers and stakeholders. The mapping exercise in Zimbabwe had slightly different objectives, and the focus was to establish the magnitude and location of the problems identified through the AIP, and to identify solutions and how to implement them. In Tanzania and Zimbabwe, the mapping was undertaken with schemes that had been part of the TISA project for one to six and eight years, respectively, and already had an AIP in place. Overall, it was anticipated that the process would build consensus around barriers and solutions related to scheme productivity and generate useful plot- and scheme-level information: for example, clarifying plot boundaries, supporting collection of operation and maintenance (O&M) fees, and improving access to credit for irrigated farming.

2.3. Mapping methodology

A generic diagram of the informal and multi-level network engaged in the mapping process is shown in Fig. 1. This illustrates that interaction in the process spanned plot, village/scheme, and higher levels of governance. Broadly, AIPs identify problems and the strategies to address them, which includes forming working groups with a selection of stakeholders who then implement the strategies (van Rooyen et al., 2017). Participatory mapping was one such strategy. The mapping process was coordinated by a working group—the mapping team—and constituted an informal network comprising TISA project officers and data collectors and collaborators from the plot and village/scheme level. Fig. 1 also shows the participatory nature of the process with the plot, village and scheme level, in particular, interacting in the majority of the mapping process. The participatory environment assisted with resolving issues identified by the stakeholders. While the approach taken in each country included the steps shown in Fig. 1, the stakeholders and process varied to accommodate the local context. The steps and actors engaged are outlined in subsections 2.3.1 to 2.3.3; however, the steps were sometimes combined together and did not necessarily take place in separate meetings.

2.3.1. Mapping familiarization

Meetings were conducted to familiarize community members with participatory mapping in Tanzania and Mozambique. In Tanzania, six meetings, one in each scheme, were conducted between July 2014 and October 2019 (Table 2) and included farmers, representatives from scheme irrigator organizations, extension officers, and the mapping team. The mapping team included a field officer from TISA who acted as facilitator, six third year students from Ardhi University, the Village Executive Officers and four to six farmer members from scheme management committees, depending on the size of the committee. The scheme management committee representatives were selected by the leaders of the IOs.

In Mozambique, eleven meetings were conducted in four irrigation schemes between February 2018 and August 2019 (Table 3). The mapping team met with farmers, FA leaders and representatives of the local authorities, including the District Economic Activities Services (SDAE). The involvement of SDAE was important as it is the government entity responsible for supervising agricultural activities in the district. The meetings were used to create awareness of the participatory mapping process, build working relationships between the mapping team and stakeholders, and establish contacts to facilitate mobilization and structuring of farmer participation in the mapping process. In Tanzania and Mozambique, the mapping team held meetings with the farmers as necessary to clarify the mapping procedures during the mapping process and ensure that other members of the scheme fully understood the exercise.

In Zimbabwe, a five-day mapping pre-test was conducted in 2021 to familiarise scheme members with the mapping process and plan the mapping activities. The seven IMC members for each block, as well as four other farmers, (one male and three females) participated in the exercise. During the pre-test, seven questions were addressed in the following order; i) why do we want to map, ii) what do we want to map, iii) where do we want to map, iv) who will conduct the mapping, v) who will produce the map, vi) who will access the map and vii) what do we want to use the map for? The exercise helped to refine the mapping data collection tools. The participatory mapping team consisted of Agricultural Technical and Extension Services (AGRITEX) officers from each irrigation scheme and their supervisors, farmers, IMC members and secretaries, and TISA data collectors. The farmers guided the process of identifying the plot and scheme boundaries for mapping. Mapping at Silalatshani was done from the last week of March and first week of April 2021, with these five blocks undergoing separate mapping processes. At Mkoba mapping was conducted during the second week of April 2021.

2.3.2. Identification of boundaries, key features and problems

In Tanzania, the mapping team divided each scheme into zones based on farm access roads, irrigation canals and natural features, such as valleys, in order to facilitate systematic identification of spatial and non-spatial details. Two Garmin GPS map 62 s, and one Magellan (eXplorist 510) handheld GPS were used to collect geographical coordinates. The GPS were configured to record in metric units, Arc 1960 (as the Datum and Coordinate System) and UTM for the location format.[1] Details collected included GPS coordinates of irrigated plots, plot ownership, scheme infrastructures (e.g., canals, farm access roads) and scheme boundaries. For every plot boundary mapped, plot holders of neighbouring plots had to confirm their boundaries before the team recorded the coordinates. For plots lacking clear boundaries, the neighbours were given room to negotiate, and coordinates were taken only when an agreement between the two neighbours had been established.

In Mozambique, a differential GPS (GNSS Leica) with 0.08 mm accuracy was used to collect geo-referenced spatial data in the UTM-WGS

[1] The accuracy of these units was 2–3 m, which was considered acceptable for mapping of the schemes.

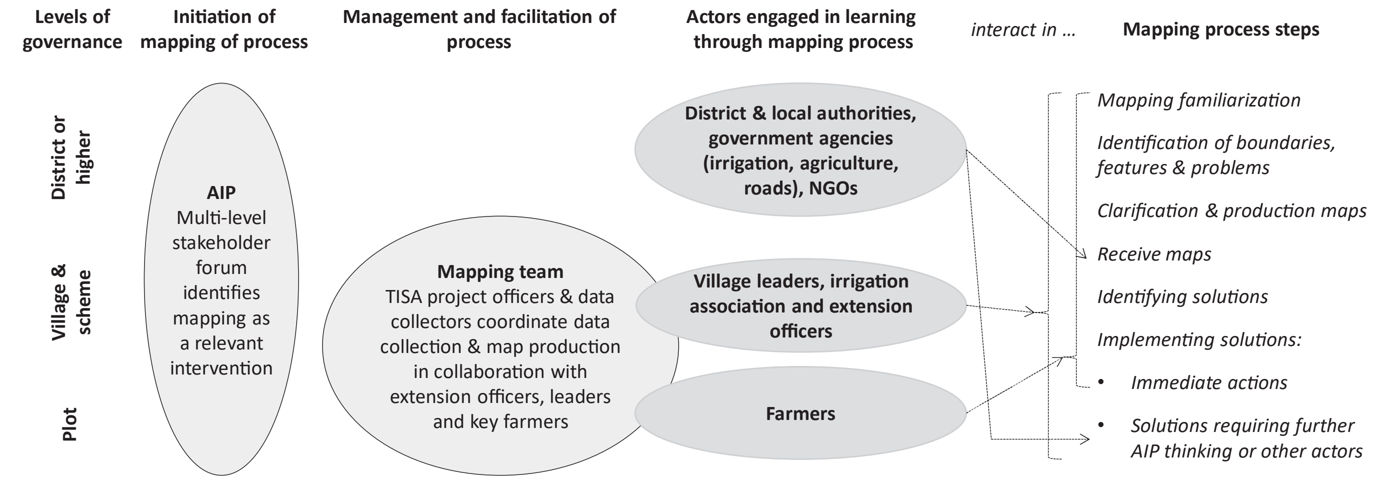

Fig. 1. Informal network for participatory mapping process.

Table 2
Participatory mapping familiarization meetings in schemes.

Scheme	Meeting date	Participants		Composition of participants
		Male	Female	
Kiwere	14 July 2014	60	21	Farmers, extension officers, scheme leaders, village chairperson, village executive officer, and mapping team
Magozi	30 July 2014	79	31	
Nyamahana	23 July 2019	42	27	
Mafuruto	2 Aug 2019	43	18	
Idodi	1 Oct 2019	75	45	
Tungamalenga	16 Oct 2019	31	19	

Table 3
Participatory mapping familiarization meetings in schemes in Mozambique.

Irrigation Scheme	Date	Number of Participants		Participants
		Male	Female	
Manguiza	April 10, 2018	5	1	SDAE at Boane
	April 11, 2018	11	5	Leaders of the FA,
	April 13, 2018	38	25	Members of Farmers Association
Mafuiane	February 01, 2018	5	1	SDAE at Namaacha
	February 01, 2018	79	48	Leaders of the FA and the scheme Extension officer
	February 28, 2018	109	84	Members of Farmers' Association and the scheme extension officer
Bloco I	August 28, 2019	5	3	SDAE at Moamba
	August 2, 2019	45	76	Leaders of the FA and the scheme Extension officer
Macuvulana I & Macuvulana II	January 10, 2019	6	1	SDAE and Head of extension at de Magude
	January 10, 2019	83	49	Leaders of Macuvulana I and Macuvulana II FA and SDAE Head of the extension services
	February 26, 2019	115	97	FA, SDAE' Head of the extension services and local extension officer

1884 configuration. Existing community scheme base-maps were appraised to obtain basic information in terms of the size and layout of the plots before planning the mapping process with the farmers. Data collected included geo-referenced coordinates of irrigation scheme and farm block or plot boundaries, irrigation infrastructure (intakes, canals, farm access roads), physical or social infrastructure (e.g., settlements, schools, cemeteries) and plot attributes including the status of plot as abandoned, fallow or cultivated. The Mozambique mapping team used the same process to engage farmers in verifying the plot boundaries as in Tanzania. Coordinates for plot and scheme boundaries were recorded once agreed by farmers and scheme management, respectively.

In Zimbabwe, the following data were recorded using handheld Garmin 60 units (accurate to 3 m): GPS coordinates of scheme, plot and block boundaries, and unutilised plots. As indicated in Section 2.3.1, the IMC members and four other farmers partook in the mapping exercise. Plot related information such as crop, planting date, harvest date and farmer details (such as name, age and gender) were collected from the IMC secretaries and extension staff of each block during the mapping exercise. The farmers were also key in identifying plot boundaries. Unutilised plots were included for scheme management purposes such as future expansion of the cropped area and reduction of land use conflicts between crop production and grazing of livestock.

Satellite images from April 2021, accessed through ArcGIS from Google Earth, were used as base-maps to create the final maps. The main difference between the different GPS systems adopted in the three countries was the accuracy of the geo coordinates, with the differential GPS being more accurate than the GPS handheld devices. Notebook computers installed with GIS software and field books were used to record non-spatial data such as the name, age, sex, and phone number of the plot holders.

2.3.3. *Clarification, production and distribution of maps*

The GPS coordinates collected for Tanzania and Mozambique were transferred into Excel, organised, and merged at the end of each day of fieldwork. ArcMap 10.1, Google Earth and Global Mapper were used to produce shape files of the features in the scheme (access roads, boundaries for plots and schemes, valleys or inundated areas, rivers or streams, and irrigation canals). Each plot was assigned a number for identification purposes. The plot number, size of plot (acres) were determined in ArcMap from the shape files, and plot owners' information (name, sex, mobile number) was recorded in an Excel database of farmers for each scheme. The database was needed by IOs for effective operation and management of the schemes. In Zimbabwe, shape files were created for current crop types, plot and scheme boundaries using Global Mapper 15, ArcMap 10.1 and 10.2 and Google Earth. Final scheme map files, with all spatial details, were converted into PDF and JPEG formats for printing and sharing with the farmers and key stakeholders.

In Tanzania, draft maps for each scheme were printed on A0 paper and taken to the schemes for validation. The main feedback from the farmers, provided through the IOs, included adjustments of farmers plot boundaries, gap filling for unmapped plots, correct labelling of infrastructures such as canals and other features. The feedback on non-spatial data was mainly about names of plot owners. In all schemes, farmers were very delighted to see the maps produced with their participation. The adjustments made by the farmers to the draft maps were incorporated into the ArcMap and final maps were produced. The final maps in print format were distributed to irrigation schemes through scheme IOs, District Council Office and National Irrigation Commission (NIRC). Soft copies of the maps were also shared with the scheme and the district through WhatsApp and electronic file storage devices.

In Mozambique, a meeting was organised in each scheme where the draft maps were presented to farmers, district and local authorities, and other stakeholders involved in the mapping process. During these meetings, farmers', validated the map features and made suggestions for improvements such as the inclusion of missing information. Following this, the maps were updated to ensure they reflected the spatial knowledge of the farmers and local authorities. Final maps were printed and given to the farmers and the local authorities.

In Zimbabwe, farmer feedback was provided in a participatory manner throughout the mapping process, with draft maps being presented for validation. Following this process, the maps were given to the extension staff responsible for the schemes who shared them with the IOs. The maps were also given to the Insiza District Agricultural Extension Officer and presented to the District Development Coordinator for their appreciation of the mapping exercise and how it could be utilised.

3. Outcomes of the mapping process

As noted earlier, problems were identified during the mapping process. In some instances, solutions and how to implement them were also agreed on during the mapping process. In other instances, implementation of solutions was beyond the remit or power of the stakeholders involved, and required financial or technical capacity residing at higher government levels or further exploration and negotiation through the AIPs. These issues are discussed further in Section 3.1.

3.1. Identified problems and solutions

3.1.1. Tanzania

In Tanzania, the participatory mapping recorded problems associated with scheme infrastructure, as detailed in Table 4. While most of the identified issues were known by the affected people and others within the community, the participatory approach made these issues public knowledge. Hence, nobody could now claim that they did not know about the issues, those impacted, and the impacts. Hence, the need to find and implement solutions became a common responsibility. Working with the stakeholders, the participatory mapping team proposed solutions to each of the identified challenges as described in the next sections. These solutions were taken over by the AIP, scheme IOs, District Council and other stakeholders.

3.1.1.1. Large volumes of irrigation water lost through leaking unlined canals. The consequences associated with unlined canals (81% of all canals within the six schemes, Fig. 2) were water seepage, siltation along the canal bed and plant growth in the canals, which all reduced the flow of water to tail end farmers (Table 4). Farmers in these schemes have been unable to extend the lined portion of the canals partly because of inadequate collection of O&M fees. Critically, there is an absence of sufficient funds allocated for irrigation infrastructure development from

Table 4
Identified problems, consequences, solutions and change and evidence of learning in Tanzania.

Scheme	Identified Problems	Consequences of identified problems	Proposed solution and change and evidence of learning (S=single loop; D=double loop; T = triple loop)
Kiwere, Magozi, Nyamahana, Mafuruto, Idodi, Tungamalenga	Unlined canals	Leakage and seepage in earth canals cause water loss, siltation and weed growth along the canals, which causes low flow of irrigation water. Erosion deepens the primary canal. This increases demand for water due to the need for increased ponding depth to generate sufficient head to allow gravity into secondary and field canals.	Cleanliness of canals and spot maintenance of leaking areas (short term) (S) Increase collection of O&M fees (D) Lining of the canals (T)
Idodi, Tungamalenga, Magozi, Mafuruto, Kiwere, Nyamahana	Farm access roads not existing in 65% of the irrigable area	Restricted use of farm machinery (power tillers) during land preparation and transportation of harvested crops. Movement of farm machinery through one farmer's plots to reach neighbouring plots cause conflicts between farmers	The timing of fieldwork requiring the transportation of machinery across neighbouring plots, needs to be agreed between the neighbouring farmers ahead of the planting season so the transportation does not interfere with the neighbors fieldwork (temporary solution, D)
		Drudgery in farm activities as farmers hand carry inputs to the fields and harvested crops out of the fields	Farmers to voluntarily allocate land from their plots for access roads in the scheme (T)
Kiwere, Mafuruto, Idodi, Nyamahana	Poor condition of access roads connecting the scheme to village or towns	During the rainy season this affect the flow of traffic Costly transport of crops from the farm plots to scheme or village main roads and of input to the scheme Farmers offered lower prices for their crops than in other places	Improve the roads using own O&M fees (D) Seek support from Tanzania Rural and Urban Roads Agency and the NIRC (T) Install access structures on water crossing points for easy movement from the scheme to the village and vice-versa (T)
Magozi, Tungamalenga, Idodi, Mafuruto	Fields above the gradient of the irrigation canal	Land cannot be supplied with water	Planting rainfed crops such as maize (S) Use some of the

(*continued on next page*)

Table 4 (*continued*)

Scheme	Identified Problems	Consequences of identified problems	Proposed solution and change and evidence of learning (S=single loop; D=double loop; T = triple loop)
		Plots cannot be farmed	areas for temporary shelters during bird scaring (D) Levelling irrigable land to enable water supply (T)
Idodi, Magozi, Kiwere, Mafuruto	Poor vegetation management along riverbanks and valleys	Surface run-off from higher ground on the eastern part floods and erode low laying areas of the scheme Underutilized plots	Maintain vegetation on riverbanks (D) Construct a dyke along scheme boundary (T) Construct a water storage dam to capture runoff on the upper eastern part of the scheme (T)

the District Council, NIRC or the Ministry of Agriculture and Food Security. It will take a long time for the farmers and IO's to build their own financial capacity to line the canals. However, lining was identified as the long-term solution to this problem. Cleanliness of the canals and spot maintenance of leaking areas was identified as short-term solutions, which were implemented by the farmers on a seasonal basis.

3.1.1.2. Farm access roads. Lack of farm access roads was identified as one of the major challenges. The negative consequences emanating from this challenge include increased drudgery, as some of the plots become inaccessible to equipment for farming operations and transport. Lack of access for farm equipment necessitates using manual labour for land preparation, and complicates bringing inputs to plots and taking harvested crops to storage or markets. It has contributed to conflicts between farmers: for example, one farmer must move farm machinery through another farmer's plot to get to his plot. Sequencing of the use of farm machinery across the plots was identified as a solution to avoid trampling and damaging crops. In Magozi and Idodi where combine-harvesters are used, some of the farmers have been unable to use the harvesters because of lack or poor condition of farm access roads. Voluntary allocation of land from farmers' plots for farm access roads was recommended as a long-term solution. Roads connecting the schemes to the villages or town were poor especially during the rainy season. This contributes to costly transport of inputs and crops to and from the farm to the village or town, which encourages farmers to sell their crops at the scheme at low prices. Suggested solutions were seeking support from Tanzania Rural and Urban Roads Agency and the NIRC.

3.1.1.3. Multiple uses of information generated. A database for each scheme was developed to manage the information generated through the mapping: plot identification numbers, names of plot owners and their mobile numbers, plot size, and the distribution of electronic and hard copies of scheme maps. There were several important and interesting outcomes arising from the database and maps that were specific to Tanzania. The IOs were immediately able to use this information to more effectively collect O&M fees, as fees could now be based on actual plot sizes. Previously, the fees were based on plot sizes as reported by owners, most of which were proven to be incorrect. The information and maps have enabled a convenient tracking of farmers' plots and canal maintenance because the identity and contacts of plot owners are readily available. Further, financial institutions such as the Cooperative and Rural Development Bank (CRDB) have recognized the mapping database as adequate proof of ownership. It enabled them to issue a guarantee tied to the scheme IO, to provide credit to the farmers. In December 2020, Idodi and Tungamalenga schemes secured loans from CRDB for 154 and 65 farmers respectively. The Bank extended the loan service to the Magozi and Mlenge schemes for 2021/2022 cropping season, with 411 male and 204 female farmers from six schemes benefiting from the loans by December 2022. The participatory mapping has therefore been valuable beyond the immediate use of the maps, including facilitating farmers' access to Certificates of Customary Right of Occupancy (CCRO).

3.1.2. Mozambique

The familiarization and implementation process as set out in Table 3 resulted in a smooth mapping process and ensured the collection of accurate data. This allowed a clearer understanding of plot locations within the schemes and provided: (i) details and explanation of current land tenure, the actual and recognized plot boundaries, ownership of the plots and current crops; (ii) details about the status of land use (i.e., cultivated, uncultivated or abandoned); (iii) the identity of the most productive and dynamic farmers; and (iv) preliminary ideas about the productivity of the irrigation scheme, and the key factors affecting it. Other information collected included farm access roads and roads connecting the scheme to the village or town, flood or water inundation

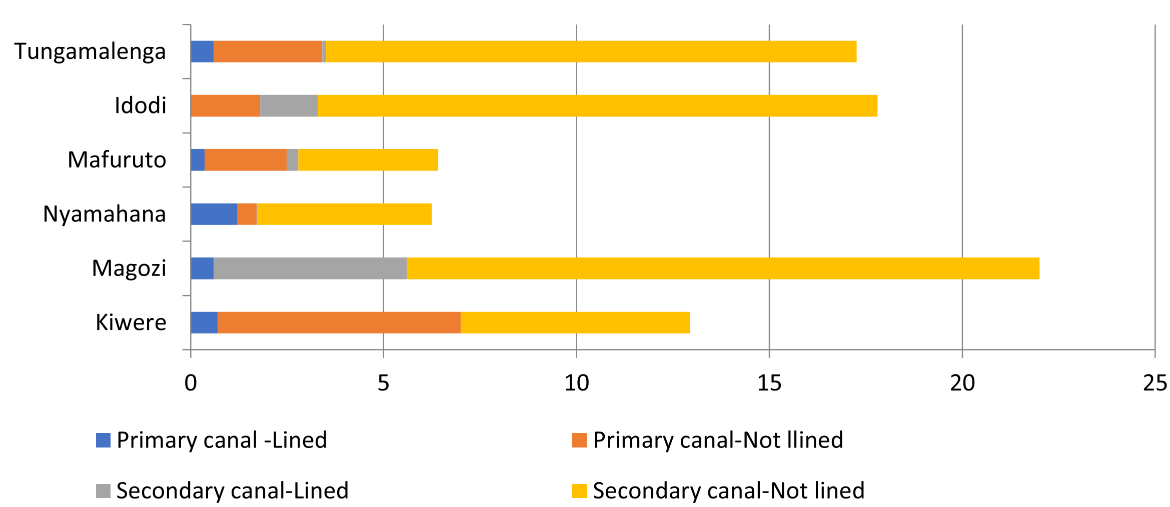

Fig. 2. Length of lined and unlined primary and secondary canals in Tanzania (measured in kilometres).

affected areas, soil salinization, and areas not supplied by irrigation water (Table 5). The problems and their impact were identified and analysed by the mapping team together with the farmers, leading to solutions to address them.

3.1.2.1. Farm plot boundaries. Farmers use a variety of features to set out their plot boundaries in Manguiza and Bloco I. The main features included irrigation and drainage channels, water hydrants, footpaths, farm roads and trees. However, reliance on features that are not entirely fixed has contributed to variations between current plot sizes and those identified when the irrigation scheme was constructed. Out of the five schemes that were mapped, three schemes (Mafuiane, Macuvulana I & Macuvulana II) had blocks of plots with clear boundaries defined by access roads. However, the identification of individual owner's plots at Macuvulana I & II was not possible because the sugar company responsible for supporting the irrigation scheme management had amalgamated plots belonging to different farmers to form single joint production fields and facilitate effective fieldwork. Despite this, the FA in each scheme had records of the size of land that each member initially had access to and these plots are still registered to the individual farmers. However, farmers' inability to identify their plots was a critical issue since plot size determined profit sharing after selling the harvested crop. The mapping process ultimately encouraged farmers to pay more attention to the boundaries and size of their plots. This was particularly evident at Manguiza and Bloco I, where many plots have irregular boundaries. Manguiza scheme is surrounded by a growing settlement area that has been encroaching on irrigated lands, due to the lack of visible fixed boundaries along the irrigated perimeter. The encroachment has caused conflicts between the FA and the neighbouring residents.

Table 5
Identified problems, and their consequences, and solutions and change and evidence of learning in Mozambique.

Scheme	Identified problems	Consequences of identified problems	Proposed solution and change and evidence of learning (S=single loop; D=double loop; T = triple loop)
Manguiza Bloco I	Poorly defined farm plot boundaries	Variation between current plot sizes and those determined at time of scheme construction which affected income distribution	Farmers advocate the use of fixed features to establish clear boundaries and size of plots
Manguiza	Lack of clear scheme demarcation	Settlements encroach onto scheme land reducing the potential irrigable land and causing conflict	Installed physical demarcation of scheme boundaries to restrict encroachment
	Inadequate farm access roads and irregular shaped plots	Restricted access of farm machinery, farmers, and inputs to the plot, and farm produce to the market	Expanding some paths to facilitate access within the scheme (S); and opening the main farm access roads to allow passage of vehicles into the scheme (D)
Manguiza Bloco I	Poor connector roads from the scheme to villages or towns	Restricted access to input and output markets (Boane, Moamba and Maputo) during the rainy season. Affected farming and trading activities	Rehabilitation of the roads by municipal council (T)
Bloco I	Poor drainage system	Flooding of low-lying areas during frequent flash floods in the Incomati River and causing inundation of 17 ha of the irrigated area	Constructing dykes to protect the scheme from Incomati River floods (T); and rehabilitating (D)and constructing drainage channels (T)
	Deficient drainage system	Salinization of 24 ha	Rehabilitating (S) and constructing (D) drainage channels; and rehabilitating main canals (S)
	Poor water distribution system	86 ha lacked access to irrigation water due to reduced flow in the Incomati River; destruction of small dams by floods; and breakdown of pumps	Rehabilitating main canals and dams (D); constructing a dam on the Incomati River for water conservation (T); and rehabilitating the pumping station (D)

3.1.2.2. Access roads. Mafuiane, Macuvulana I and Macuvulana II schemes have well-structured 3–8 m wide farm access roads. These were developed during scheme construction and have been well maintained, and facilitated easy movement of agricultural machinery, farmers, inputs, and harvested produce. In the Manguiza scheme, most farmers depend on a narrow footpath to access their plots. Farm access roads are inadequate due to the irregular scheme layout and plot distribution. This restricts access to plots by farm machinery, and farmers moving inputs and produce. During the participatory mapping process, farmers realized the need to expand some paths to facilitate movement within the scheme, and some farm access roads were widened to allow vehicle circulation.

In terms of roads connecting the schemes to villages or towns, Mafuiane, Macuvulana I and II are located close (less than 10 m) to the main tarred roads that connect them to the market in Maputo and the sugarcane company Xinavane (Tongaat Hulett). These roads facilitate the transport of produce from the schemes to the markets, enabling farmers' access to retailers, input distributors and suppliers. In contrast, Manguiza and Bloco I are located 4 and 13 km, respectively, from the main roads that connect them to the surrounding markets of Boane, Moamba and Maputo city. The connecting roads are unpaved, providing limited access during the rainy season and affecting farming and trading activities. The participatory mapping team proposed rehabilitation of the roads by local municipal authorities and the national road administration.

3.1.2.3. Flooded, water inundation and unused plots. Within Bloco I, 17 ha were identified as being affected by floodwater inundation caused by frequent flash flooding of the Incomáti River (Fig. 4). Deficiencies in the drainage system caused inundation of farming plots and contributed to soil salinization, which affected about 2 ha of irrigable land. Construction of dykes to protect the scheme and rehabilitation of the drainage canal were recommended.

Flooding in Bloco I was reported to have contributed to the destruction of water storage ponds or micro-dams within the scheme. These ponds are used to improve irrigation water supply and distribution when there is low availability of water in the Incomáti River. During the participatory mapping, 6 ha of land was not being farmed due to poor access to irrigation water.

At Manguiza, only 41% of plots were being farmed at the time of mapping, as many farmers were focused on their rainfed crops as water supply was disrupted due to a breakdown of the pump. Similarly at Mafuiane, only 48% of the 272 plots were farmed as a breakage of the pump had reduced the scheme water intake. This restricted farmers' willingness to invest in farming, as they feared a loss of production because of the uncertain water supply. This information on broken pumps was shared with the National Irrigation Institute (INIR) and SDAE, who negotiated with other organizations to finance repair of the pumps.

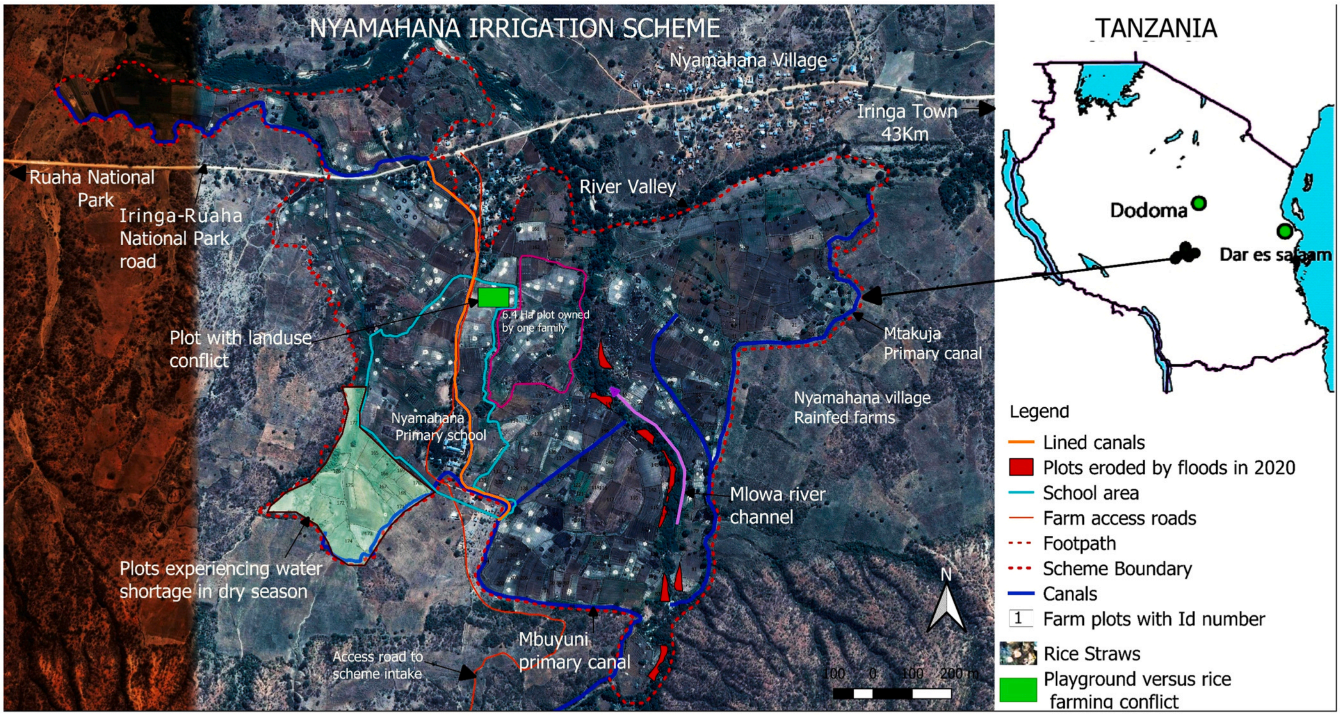

Fig. 3. Nyamahana irrigation scheme participatory map in Tanzania.

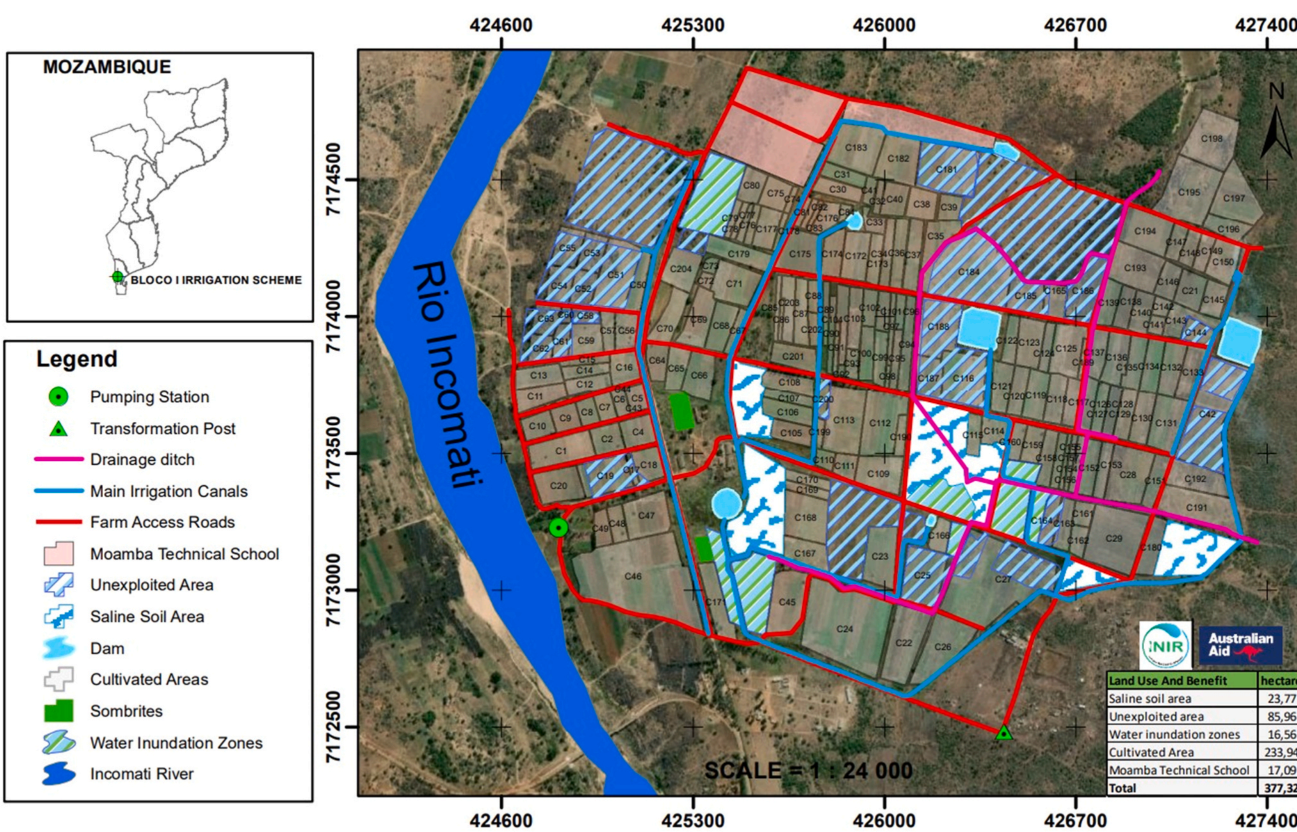

Fig. 4. Bloco I irrigation scheme participatory map in Mozambique. Note: Transformation post refers to a stepping down electric power transformer. Unexploited areas are plots in the scheme which are not farmed and Sombrites refers to plant nurseries.

3.1.3. Zimbabwe

The participatory mapping in Zimbabwe focused on identification of problems and solutions to canal related water leakages, water logging, salinization, utilization of irrigated plots and scheme/block boundary conflicts (Table 6). Some of the problems revealed during the mapping process led to the immediate calling of farmer meetings so that they

Table 6
Identified problems and their consequences, and solutions and change and evidence of learning in Zimbabwe.

Identified Problem	Consequences of identified problems	Proposed solution and change and evidence of learning (S=single loop; D=double loop; T = triple loop)
Uncertain boundaries between blocks and reserved areas	Conflicts over resource use Loss of income for households and scheme linked to products harvested from reserved areas	Clearing of access pathways along the block boundaries (S) Creating firebreaks around the scheme boundaries (S) Extend the duties of the irrigation maintenance committee to maintain the boundaries of the reserved areas that separate different blocks (D) Conflict resolution on vegetation resource use of reserved areas (T)
Cracks in lined canals and filing of cracks with stones and other materials such as plastics in an effort to prevent water leaks	Inundations due to water leaks caused inundation and water logging	Clean the internal lining of canals (S) Clear access pathways (S) Canal repair through farmers contributions (D) Create a firebreak around scheme boundaries. (D) Planting of reeds in water-logged plots to generate income for scheme maintenance (T)
	Vegetation growth in canals reducing downstream water supply causing conflicts between irrigators	Clear blockages in the canals (S)
Poor fertilizer application practices in the upper parts of the scheme	Poor soil management practices	Improved soil management practices such as addition of manure (S) Planting of reeds in water-logged plots to generate income for scheme maintenance (D)
	Salinization, poor yields, contributing to plot abandonment and underutilisation	Deploying soil water monitoring tools to improve efficiency of irrigation water use (T)
Lack of support options for elderly irrigators and lack of scheme succession planning	Un- or underutilized plots	Re-allocation of unused plots to active willing farmers and youths by the District Development Coordinator in consultation with the Irrigation Management Committee and AGRITEX (D)

could be solved at a scheme or block level and were dealt with before the mapping exercise was completed.

3.1.3.1. Boundary conflicts. One of the top issues identified and in need of resolution was boundary conflicts between blocks within the irrigation scheme. The conflicts included those relating to the use of resources in the reserved areas located on the boundary between the blocks. Reserved areas are set aside for future development. Many of the conflicts were because part of household and scheme income was derived from these areas (Table 6). To address these conflicts, the farmers agreed during the participatory mapping to extend the duties of the irrigation maintenance committee to maintain the boundaries of the reserved areas that separate different blocks within the scheme. The mapping of the block boundaries also led to the resolution of boundary conflicts related to the management of vegetation in the reserved areas and canal maintenance. For a number of years, Phelandaba irrigators managed the vegetation within the reserved area on the boundary between their block and the Mbokodo block, and they had even planted some gumtrees in an area that belonged to Mbokodo as they assumed it was part of their reserved area. The issue was settled right away, and management of the gumtrees was transferred to Mbokodo.

In Mkoba, some farmers were not aware of their reserved area. The area is separated from the current scheme boundary by a fire break. During a farmers' committee meeting it was decided to extend the area under irrigation into the reserved area. According to the farmers, this decision would have allowed some families who do not have plots in the scheme to get access to irrigation plots. However, limited dam capacity to support the expansion of the irrigation area was identified as an obstacle by the participatory mapping team. Deploying soil water monitoring tools was therefore proposed in order to improve the efficiency of irrigation water use and enable the existing capacity of the dam to support the expansion of the irrigated area (Moyo et al., 2020).

3.1.3.2. Canal cracks, water leakages and blockage. In some blocks, pronounced cracks were identified in the lined canals causing massive leakages of irrigation water. In some blocks, where cracks were concentrated, water inundated the adjoining fields causing water logging. Furthermore, materials such as stones and non-biodegradable plastic bags were used to block the leaks and had formed dense silt blockage, enabling growth of grasses and shrubs in the canals. The vegetation reduced the flow of irrigation water to downstream irrigation blocks such as Mbokodo. This was a serious problem especially in the later stages of winter when water supplies are reduced. Water shortages resulting from reduced flow in the canal was identified as one of the water related problems that caused water use conflicts between farmers. To address these issues, the irrigation block committees called combined meetings before the end of the mapping exercise; solutions were identified, and arrangements were made to address each issue. The immediate actions were to clear blockages and water pathways in the canals to facilitate water flow.

3.1.3.3. Salinization and plot utilization. The participatory mapping process revealed that increasing salinization in the lower blocks, especially at Nonoka and Phelandaba, is partly due to excessive irrigation causing fertilizer run-off resulting in water logged conditions and salt build-up in lower lying areas. Consequently, farmers in low-lying areas had to regularly apply lime and it became of paramount importance that farmers of the upper plots improved their fertilizer management. Salinization was very intensive in Mbokodo, which is at the tail-end of the scheme, with the most affected plots located in the upper half of the block. Salinization led to poor yields, which contributed to plot abandonment and underutilisation. The Phelandaba block had one of the highest frequencies of unutilised plots. Apart from salinization, low plot underutilization was also attributed to the lack of access to inputs and old age of irrigators. Youth in the scheme have not taken over plots from old farmers as many of these farmers are reluctant to give up their plots as they have no other livelihood options, and many youths are migrating to urban areas. Except for the Landela Block at Silalatshani (Fig. 5), where landholding is 0.5 ha per farmer, the rate of plot abandonment and underutilization is much higher than at Mkoba, where land holding per farmer is 0.1 ha. This suggests that there was less competition for farmland in Silalatshani. Effective plot utilization in Mkoba was also attributed to more organised management of the irrigation scheme as reflected by the existence of a better network of internal roads, better plot boundary clarity and a scheme firebreak. The network of internal roads contributed to better movement of goods and services.

The active involvement of irrigators and their leaders in the participatory mapping exercise created a sense of scheme and plot ownership

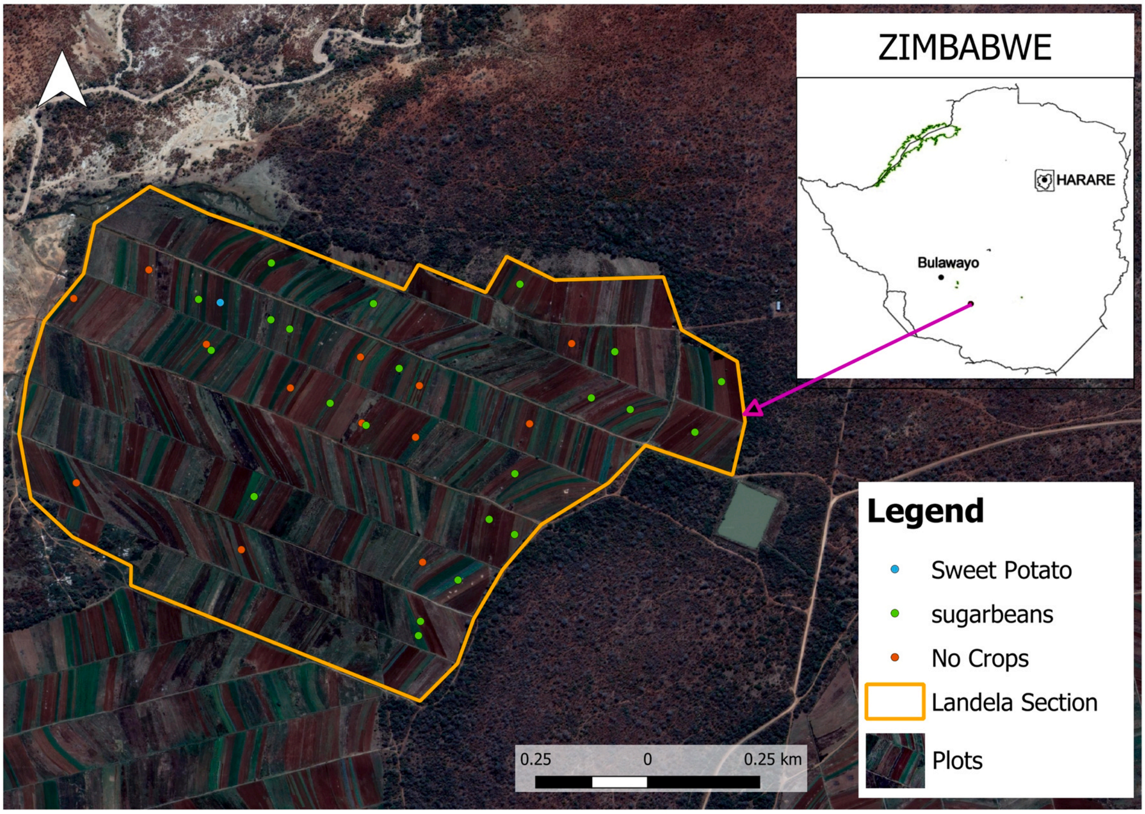

Fig. 5. Block boundary, plot boundaries, and plot crop status in the Landela block. A blue rectangle on the south at the head end of the scheme is a night water storage.

at both Silalatshani and Mkoba. This is a critical outcome as a sense of ownership encourages farmers to improve the management of the system. Before the participatory mapping process, farmers were reluctant to engage in scheme and plot maintenance as there was confusion and uncertainty about ownership and responsibility for scheme maintenance, many believing that it rested with the government (Moyo et al., 2017). Participatory mapping therefore paved a pathway to solve irrigation scheme maintenance problems beyond the individual farmers' plots. The irrigators also appreciated the value of the mapping exercise, as the issues identified were resolved prior to concluding the mapping process.

3.2. Importance of participatory mapping

At the end of phase two of TISA, a household survey was conducted to assess the impact of the interventions. Household heads were asked how many of the TISA AIP interventions they were aware of, whether they had participated actively in the interventions, and how important they found the interventions for their viability. In the schemes where both the participatory mapping (PM) and survey took place, 50–90% of the farmers knew about the participatory mapping (Table 7) and more than 80% of them found the mapping process was important or very important. This indicates farmers' increased sense of ownership and responsibility in addressing challenges in the irrigation schemes as a result of increased understanding of plot size and scheme boundaries, reduced conflict, and increased willingness to pay for irrigation water.

Table 7
Households engagement in mapping and perceptions of importance.

Country and scheme	Knew about PM (%)	Proportion of those who knew about PM and had participated (%)	Importance of PM to farm viability (%)	
			important	Very important
Tanzania				
Kiwere	60	72	17	79
Magozi	73	73	19	74
Idodi	92	70	12	88
Zimbabwe				
Silalatshani	65	40	63	24
Mozambique				
Manguiza I&II	79	22	29	71
Mafuiane	50	20	64	27
Bloco I	70	17	60	25

4. Discussion

The problems identified across the schemes through the participatory mapping process reflect the long-term challenges experienced by smallholder irrigation schemes. For example, poor access to machinery; road and transport limitations affecting access to inputs and markets; leaking or blocked water delivery structures; land and water management issues such as flooding, salinity, and erosion; and conflict between farmers. While these issues have not been specifically identified through research using participatory mapping of irrigation schemes in eastern and southern Africa, our findings are consistent with Hohenthal et al.'s (2017) mapping work in Kenya and broader research on smallholder schemes (Nakawuka et al., 2018; Kanda, and Lutta, 2022). Our research shows that the challenges arise from: i) poor collection of O&M fees and inadequate maintenance; ii) inadequate protection and conservation of irrigation infrastructures; iii) poor O&M governance structures; iv) inadequate knowledge and lack of land use plans for the schemes and surroundings; and v) inadequate technical and financial support by district or provincial authorities and national agencies. In Tanzania, the mapping improved the collection of O&M fees and enabled farmers to access credit from banks for farming inputs. In Mozambique, mapping was used as an entry point to create a working relationship prior to intervention and establish baseline conditions while in Zimbabwe the process was important for the resolution of boundary conflict between blocks. In all three countries, the participatory mapping met the expectations by generating plot- and scheme-level information, enabling multi-level learning and providing ways to address some of the challenges in the irrigation schemes.

In the remainder of the discussion, we synthesise how the mapping process has enabled multi-level learning and change in the smallholder irrigation schemes. We draw predominantly on Pahl-Wostl (2009, 2015); Pahl-Wostl and Patterson (2019) and structure the discussion into the four key areas identified in Pahl-Wostl's conceptual framework for analysing adaptation and multi-level learning.

Firstly, informal networks have been a critical part of the governance arrangements that have enabled adaptation and change (Fig. 1). In the Tanzanian and Zimbabwean schemes, the AIPs functioned to bring key stakeholders together from different levels of governance and this forum identified participatory mapping as a relevant intervention to fill gaps in information and find solutions to productivity barriers. Hence, we might say that the mapping process had a measure of 'buy in' at the outset, which Pahl-Wostl and Patterson (2019) observe is helpful to secure rapid and transformative action. Within the Mozambique schemes that joined TISA in its second phase, the mapping process was used as an entry point. In all cases, the mapping teams comprised stakeholders across different levels of governance, and have played a critical role as an informal network to facilitate the steps in the mapping process. This informal and temporary 'working group' has either maintained and/or fostered buy-in during the mapping process. That the process ultimately identified problems and subsequent solutions, has been enabled by the public sharing of the impact on irrigators, engendering a shared responsibility among stakeholders for identifying and implementing solutions appropriate to the local context. We speculate that the 'right' representation on the mapping team enabled knowledge in the process to be shared more widely, confidence in the process was built and maintained, and innovation could arise either within one level or combined levels of influence.

Secondly and as alluded to in the previous paragraph, the multi-level interactions between stakeholders supports public knowledge sharing and taking responsibility for action. With mixed stakeholder representation, the mapping teams have been a key element of facilitating multi-level interactions (Fig. 1). Importantly, the mapping process requires the engagement of all farmers either to interact with the mapping team or their plot neighbours, with the latter interactions often culminating in a negotiated consensus of plot boundaries. This is evidence of significant building of trust between farmers. We also found that the participatory mapping assisted the process of creating trusting relationships between farmers and scheme management, enabling adaptation and integrated solutions to sustainability problems: for example, protection of scheme infrastructures from flooding and erosion and rehabilitation of canals and drainage systems. Similarly, von Korff et al. (2012) and Fagerholm et al. (2021) found improved trust opened up opportunities for change. In our research, solutions were subsequently implemented because the opportunity for dialogue between those involved allowed for a locally embedded understanding of geographic information. This is consistent with Hossen's (2016) findings.

Thirdly, Pahl-Wostl (2009) notes the importance of the interplay between formal and informal institutions. She discusses the existence of strong environmental regulations on paper but lack of implementation in practice. Our findings relate more to rules that are missing and, consequently, were creating conflict over land uses, boundary, tenure and rights to natural resources, which is consistent with Lipej and Male (2015). In our research, the reserved land areas in Zimbabwe were directly connected to incomes and there was a significant imperative and impetus to avoid resource use conflicts. In Mozambique, encroachment of human settlements on irrigated land was the main source of conflicts. These conflicts were addressed by improving the bylaws governed by scheme organisations. In Zimbabwe, the scope of the responsibilities of IMCs was expanded to include the maintenance of boundaries between irrigation blocks and control of access to resources within reserved area. In Mozambique, the physical demarcation and installation of permanent plot and scheme boundaries was introduced. These changes relating to resource use and land use conflicts are consistent with Hossen (2016). Consistent with Saadallah (2020), this study found that creating maps can provide individuals with an empowering sense of competency and authority. Importantly, stakeholders from different levels of governance gained a better understanding of where they had a common responsibility. In this way, the farmers, who often lack agency, have been part of creating the impetus for change at scales where they have less control. As Brown et al. (2018) found, the publicly explicit and engaging nature of informing decisions embedded in the participatory mapping process was a key factor in enabling farmers at Phelandaba to relinquish management and handover reserved areas not belonging to them to Mbokodo farmers.

Fourthly, we find evidence of single, double and triple loop learning: for example, cleaning canals (single), collecting O&M fees to improve maintenance (double) and lining canals (triple) (see also Tables 4 to 6). In cleaning canals, farmers exert agency by taking action to fix an operational problem that is within their immediate sphere of control (level of governance) and income constraints. The collection of fees for regular maintenance reflects understanding that an institutional change would be a more efficient approach, but this requires learning and acceptance at the village/scheme level of governance and farmers acceptance that this additional cost is sensible and manageable. A more efficient solution is to line the canals, which is more costly and the responsibility of actors at the government level. We speculate that farmers have long known that lined canals are the best option, but they have not had the agency to effect this change. Similar to Pahl-Wostl and Patterson (2019), we think it is more realistic to think about a continuum of learning and less as a clear distinction on whether structural constraints are tweaked, questioned or addressed. Learning is evidenced by action and change. As in the examples provided, stakeholders may learn and arrive at several solutions that represent evidence of single to triple loop learning and the challenging of deeper structural constraints. However, not all solutions will be within farmers' sphere of influence to address, and require engagement of other actors, including those with resources, and longer timeframes to enact. Hence, the process of learning needs to also take place among those who have the agency to effect change at other levels of governance. Importantly, we found that stakeholders from different levels of governance were engaged and learnt about where they had a common responsibility. In this way, the farmers, who often lack agency, have been part of creating the impetus for change at scales where they have less control.

In Tanzania, the mapping process generated an impetus among the farmers in the schemes to immediately implement some solutions. For example, lack of or unreliable data about scheme and plot boundaries and relative plot sizes were identified as key societal challenges leading to poor collection of O&M fees and weak enforcement of management activities (Mdemu et al., 2020). Hence, farmers were keen to participate in the mapping to resolve this lack of data, and the interim solution of cleaning the canals. Other solutions—such as construction of dikes along scheme boundaries as flood protection; lining or rehabilitation of canals, construction of storage dams and drainage systems; levelling of irrigated farm plots; and installation of culverts for water crossings—became public knowledge and solutions were identified but it was outside the local capacity to implement them due to lack of financial and technical capacity. This is also consistent with the literature (e.g. Cambaza et al., 2020; Harrison and Mdee, 2017). As a result of poor collection of O&M fees, farmers in the schemes needed the support of government agencies to address these issues and fix some of the identified problems such as access roads to markets which are actually not farmers' responsibility and rest with governments. In Tanzania, farmers had control over the mapping outputs, including the printed maps and plot ownership databases and these outputs made it possible to determine the seasonal or annual O&M fees based on actual plot sizes. In this context, it is critical that the participatory mapping process made these challenges transparent to the scheme actors and the regional and national agencies, increasing the urgency of addressing them and thereby improving the sustainability of the schemes. This is consistent with the findings of Hohenthal et al. (2017) and Hossen (2016).

The multi-level interactions assisted with increasing farmers' capacity, empowerment and agency, and the progression of longer-term solutions that weakened or addressed system constraints. Examples of these solutions include: farmer's decisions in Tanzania to voluntarily allow the use of a portion of their plots for access roads and open some of the main access roads to allow movement of vehicles in the scheme; and the designation of other roads in Mozambique to be rehabilitated by the local municipal council.

Our research had some limitations, including the reliance on unrepeated runs of the participatory mapping process. This limited our ability to observe more detail on the learning processes and institutional changes taking place and to sufficiently track the responses of government agencies for some of the identified solutions: for example, those requiring second and triple loop learning. Further research could explore, for example, perspectives on what are the additional significant changes taking place that lead to the implementation of solutions.

5. Conclusion

This study revealed two different but critical outcomes and benefits from using participatory mapping. First, the process in all schemes stimulated changes in irrigation management at scheme level. The process was found to increase a sense of ownership, both at the plot and scheme level, as well as the local authority level. In most countries in Africa, the issue of plot and infrastructure ownership and associated responsibilities, is often uncertain as seen from the perspectives of the farmers and FAs, IMCs and IOs. This confusion and uncertainty often reduces the willingness of irrigators to pay for costs and participate in scheme operation and maintenance. Processes such as participatory mapping that increase stakeholders' sense of ownership are critical, and can lead to improved functioning and management of smallholder irrigation schemes. Also in all three countries, the process was important in identifying the major issues impacting farmers in different parts of the schemes. Most problems are known by many individuals, but are not publicly and collectively acknowledged. A critical learning, and one we have not seen in the literature, is that the process made these issues, their consequences, and those who suffered them, public and shared knowledge; hence, it generated a level of collective ownership of the issues and responsibility for identifying and implementing solutions. All the three case studies showed the importance of placing new learning or knowledge into immediate practice. The process did not only identify problems and potential solutions, but also resolved problems and implemented some of the solutions as part of the process and prior to the conclusion of the mapping process. This is testament to the value of the mapping process.

Each of the case studies in the three countries provide important contributions to the literature on participatory mapping for small scale irrigation schemes. Our research shows that participatory mapping can incorporate the four key dynamics of multi-level learning that are required to support development of adaptive capacity and bring about system change in smallholder irrigation schemes. We show that the mapping team, as an informal network and temporary governance arrangement, successfully facilitated multi-level interactions between a diversity of stakeholders to engender societal learning that identified many agreed solutions to problems, including the need for new formal and informal institutions. The AIP process, also a multi-stakeholder learning process, supported 'buy-in' to the process and ensured that the mapping process had farmer participation from the outset, which was sustained by the mapping team. Hence, the concerns over participatory mapping (Chambers, 2006; Fox, 2002; Sletto, 2009), were alleviated by the informal mapping process as the map production, management of the process, beneficial outcomes and distribution and use of the final maps all had multi-stakeholder participation. This is consistent with Pahl-Wostl (2009) summary that informal networks have a critical role in multi-level learning processes.

This study demonstrates the value of informal networks and the need for government irrigation management agencies to prioritize policies that integrate participatory processes to improve farmers' understanding of their resource and management challenges. Such understanding is important for building a sense of ownership and responsibility for addressing critical challenges and systemic neglect of infrastructure in irrigation schemes. As the mapping process was successful in a range of schemes, the process and experiences from this study can be easily transferred other areas and adapted to suit the local context.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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