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Institutional arrangements and economic analysis of the management of livestock water infrastructure investments in agro-pastoral areas of Teso and Karamoja in Uganda

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The study aimed to evaluate the utilization, management structures, costs, and benefits of livestock water infrastructure in the pastoral communities of the Teso and Karamoja sub-regions. Data were collected on various water infrastructures, including boreholes, valley dams, and valley tanks. The findings suggest that investing in water infrastructure is economically viable, although functionality and usage differ across regions. Water use associations (WUAs) and community volunteers predominantly managed the water infrastructure, with local governments providing oversight. In Teso, 45%–75% of water use associations were deemed functional, compared to a lower rate of 33%–40% in Karamoja. Generally, users of water infrastructure in Teso demonstrated a higher willingness to pay for various services compared to those in Karamoja. The study also found that, under the *status quo*, co-management and joint efforts between WUAs and volunteers could be more economically viable management structures for boreholes. Valley dams could be better managed by WUAs, while local governments, with community support, could effectively manage valley tanks. The major challenges in managing water facilities included free riding, failure to enforce regulations, the potential for ownership tragedy, inadequacies in managing technologies, and the effects of drought. The research and implications of these findings are further discussed in the study.

KEYWORDS

livestock water infrastructure, institutional arrangements, costs and benefits, agro-pastoral areas, Teso and Karamoja

Introduction

Livestock plays a crucial role in the livelihoods of the drought-prone and agro-pastoral Karamoja and Teso sub-regions. These regions accounted for 16.7% and 9.7% of Uganda's 14.5 million cattle, respectively (Uganda Bureau of Statistics, 2024). Ensuring access to water is vital for both livestock rearing and human wellbeing in these areas. In Karamoja, livestock rely on rivers (45.1%), boreholes (23.1%), and dams (20.6%) as main water sources. In Teso, the main sources of water for livestock are boreholes (40.1%), swamps (36.6%), and wells (8.3%) (Uganda Bureau of Statistics, 2024). However, during the 6-month dry season from October to March, water scarcity significantly impacts livestock production. Seasonal water sources dry up, posing a challenge for livestock access to water (Aklilu, 2016). For instance, cattle in Karamoja and Teso regions are estimated to consume an average of 3.9 and 11.8 L of water per day, respectively (Uganda Bureau of Statistics, 2024). However, these amounts fall significantly short of the optimal daily requirements: 30–50 L for dry cows, 50–100 L for lactating cows (Lardy et al., 2008), and 35–60 L for beef cattle, depending on weight and breed (Parish and Rhinehart, 2010). In the absence of adequate water access, livestock mortality rates can be high, ranging from 14% to 65%, as observed in pastoral communities in Ethiopia, Kenya, and Tanzania (Nkedianye et al., 2011; Catley et al., 2014).

To cope, some herders turn to riverbed sand dugout wells in major rivers and borehole watering, while others move long distances to water their livestock and herds. Unfortunately, these strategies fall short of meeting community water needs. Efforts to enhance equitable access to water through infrastructure development and management are thus essential for the resilience of dryland production systems and agro-pastoral communities (Intergovernmental Authority on Development, 2020). Multi-purpose dams, valley tanks, and wind-powered watering systems can harness water sources for diversified livelihoods, including livestock watering, brick making, aquaculture, and small-scale vegetable irrigation (Intergovernmental Authority on Development, 2020).

Strategic investments in dams, valley tanks, and boreholes can provide a lasting solution for water scarcity in drought-prone regions like Karamoja and Teso. Such livestock water investments have been beneficial in other agro-pastoral communities in Ethiopia and Kenya (Nassef and Belayhun, 2012; Nassef and Ludi, 2012). These structures store water effectively during both dry and lean seasons. However, their limited distribution poses challenges for livestock access to water (Mugerwa et al., 2014). Beyond livestock needs, dams offer additional benefits, including flood and erosion control, grazing land stabilization, and watershed restoration. They play a crucial role in enhancing ecosystem services such as water security and stabilizing grazing (Hartman et al., 2016). Moreover, dams create opportunities for controlled fishing, which could serve as an alternative livelihood source for pastoral communities (Kemigabo and Adámek, 2010). Despite these advantages, silting remains a challenge (Lawrence et al., 2004). Gully erosion and increased demand for land due to population growth contribute to the reduced lifespan of valley dams and tanks, and exacerbate silting (Tamene et al., 2006; Eremugo and Majaliwa, 2018). To ensure sustainable water management, addressing silting and promoting efficient use of these water resources is essential. Boreholes, in addition to supplying clean water for domestic use, also serve as a major water source for livestock.

While pastoralists cope with water scarcity by moving animals over long distances in search of water and pasture, this practice increases feed intake (affecting optimal weight gain) and labor requirements, which could become constraints in the community (Motta et al., 2018; Fust and Schlecht, 2018; Turner and Schlecht, 2019). Additionally, moving animals exposes them to transboundary livestock diseases and creates intra- and inter-community conflicts (Hasahya et al., 2023). Well-sited and carefully managed large dams, supplemented by water sources like valley dams and boreholes, are thus the best strategy for supplying water in pastoral communities.

In response, the Ugandan government, in collaboration with the World Bank through the Regional Pastoral Livelihoods Resilience Project (RPLRP), undertook an initiative to rehabilitate and construct water facilities in the Teso and Karamoja regions (Ministry of Agriculture, Animal Industry and Fisheries, 2013). Similar initiatives were undertaken in Kenya's and Ethiopia's agro-pastoral and pastoral communities. These efforts aimed to improve sustainable management and secure access to natural resources, particularly water, for pastoral and agro-pastoral communities, enhancing their productivity and resilience in the face of drought-related challenges. As part of the RPLRP in Uganda, 8 valley tanks, 2 valley dams, and 92 boreholes were established. These facilities serve as a partial solution and have long-term viability to bolster resilience in the arid and semi-arid regions. Additionally, community members received training on water resource management to prevent misuse and ensure the sustainable utilization of these water reservoirs. This training was crucial because livestock water infrastructure in pastoral communities falls under the category of common-use infrastructure, which can be susceptible to the tragedy of the commons and the free rider problem. The tragedy of the commons and the free rider problem in livestock water use occur when individuals, acting independently and rationally, deplete or misuse the water resources. These effects also include overgrazing common pastures around watering facilities to the detriment of all.

Investments in water infrastructure reduce the distance communities have to travel for water, minimize dry season movement in search of water, and improve water availability during dry periods. Despite these benefits, introducing water

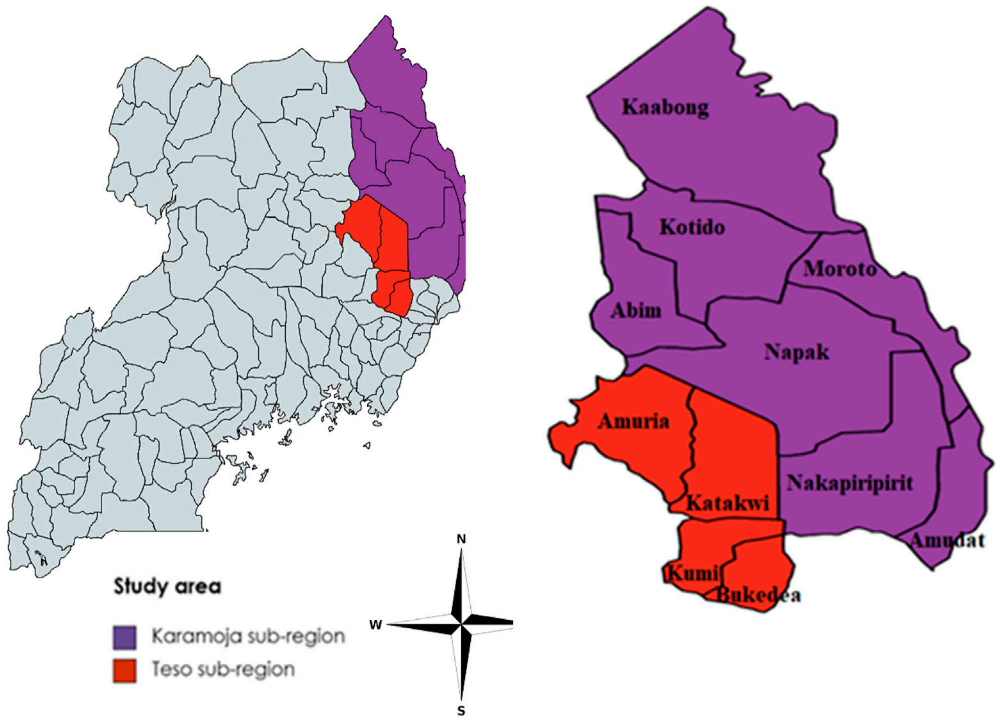

FIGURE 1
A map showing the location of study districts.

infrastructures can adversely affect pastoralists' drought resilience if not carefully managed (Piemontese et al., 2024) and can impose an additional economic burden on poor households if they bear operational costs (Schnegg and Kiaka, 2019). There is a paucity of information on: 1) the availability and sustainability of supportive institutions and institutional arrangements for water infrastructure management, 2) the costs and benefits of managing water infrastructure under current management regimes, and 3) community willingness to pay (WTP) to use water resources to extend their economic life. Such knowledge is essential to ensure effective and efficient use, sustainable management systems and institutions, and replicability of investments.

To address this knowledge gap, the study assessed the functionality and utilization of livestock infrastructure, identified key actors and institutional arrangements, including their roles and influences in managing the infrastructure, and documented the willingness to pay and economic viability of different livestock water infrastructure under various institutional arrangements. Recognizing functionality and management dynamics is crucial because water infrastructure, developed by government and support agencies, is commissioned for community use. Non-incentivized participation in water resource management indicates limited ownership and community involvement (Mugerwa et al., 2014) yet encouraging community participation and ownership is vital for the sustainable management of water resources (Mati et al., 2006). Assessing WTP was important for the study because several facilities were not charging a fee to support management, or if any payments occurred, they were based on voluntary contributions. Additionally, if a use fee were to be instituted, the amount members were willing to pay was unknown. Knowing WTP is important as it reflects the demand for water services and can help align pricing strategies for water with observed community use, community norms, and livelihood dynamics.

Materials and methods

Study area

The study was conducted in the cattle corridor covering the Teso and Karamoja region where the Regional Pastoralist Livelihoods Resilience Project (RPLRP) was implemented. The regions were chosen because they host a number of water infrastructure investments, including those by the RPLRP, that are important for livestock farming in arid and semi-arid areas. The study collected data from all the seven RPLRP host districts in the Karamoja region (Figure 1). Karamoja is a large, semi-arid, and savannah-dominated (27,528 square kilometers) sub-region in northeastern Uganda with a population of 1.4 million people of mostly Karamojong ethnic group and smaller ethnic communities of Pokot, Tepeth, and Ik (Uganda Bureau of Statistics, 2022). The region receives low and erratic rainfall (averaging between 800 and 1,200 mm per year in Western and southern Karamoja and 500–800 mm in central to northern Karamoja and long dry periods (lasting between 5 and 6 months) (Aklilu, 2016; Egeru et al., 2014; Okia, 2010). The main economic activity is cattle herding on communal and customary land (UIA, 2016). The average household herd size in Karamoja is 9 with 85.3% of cattle keeping households rearing indigenous breeds (Uganda Bureau of Statistics, 2024).

Data was also collected from the four RPLRP host districts in the Teso (Figure 1). Teso sub-region in Uganda experiences a humid and hot climate with bimodal rainfall ranging between 1,000 and 1,350 mm and occurring mostly during the March to May period. The dry season begins in December to February (Egeru, 2012). The region covers an area of 13,030.6 square kilometers and has a population of 2.5 million people of Iteso and Kumam ethnicity (UIA, 2016; Uganda Bureau of Statistics, 2022). The main economic activity is mixed agriculture, with livestock kept in Tsetse-fly-free areas. The region faces challenges such as droughts, water stress, and conflicts (due to crop damage by livestock because of sharing of natural resources in livestock farming and also cattle rustling) (UIA, 2016). The average herd size for Teso is 2.9 with 91.7% of cattle keeping households rearing indigenous breeds (Uganda Bureau of Statistics, 2024).

Sampling livestock water infrastructure, data collection and data

Sampling: The primary sampling frame for the study encompassed all installed and accessible valley tanks, valley dams, and boreholes within the designated study area. This included those established by the Regional Pastoral Livelihoods Resilience Project, totaling 8 valley tanks, 2 valley dams, and 92 boreholes. Accessibility to some water facilities was significantly hindered during the survey period due to security concerns arising from attacks by Karamojong warriors. Consequently, the data gathered for analysis included six valley dams located in the districts of Amudat, Napak, Amuria, and Katakwi. Additionally, nine valley tanks were included, with five constructed by the RPLRP, two by the Office of the Prime Minister, and one by the Ministry of Water and Environment. These tanks were spread across the districts of Amuria, Abim, Kumi, Katakwi, Napak, and Moroto. Additionally, 31 boreholes out of 92 were randomly sampled to ensure a representative distribution. The selected boreholes were situated in the districts of Amuria, Bukedea, Kaabong, Kumi, Katakwi, Moroto, Nakapiripirit, and Napak.

Data collection: Data was collected on three types of water infrastructure (boreholes, valley dams, and valley tanks) for livestock farming in Teso and Karamoja. The data was aggregated at the Parish level. Before the study, a scoping exercise was conducted to collect relevant information for data collection protocols. The scoping exercise involved mapping, mobilizing, and interviewing various stakeholders involved in water infrastructure management. The scoping study collected information on the number, location, type, functionality of water infrastructure and institutional arrangements used to govern them. Following the scoping activity, the study employed a cross-sectional design to collect quantitative data on usage, functionality, costs, benefits, willingness to pay, and institutional arrangement in water infrastructure management for livestock farming. The cross-sectional design was suitable because the study sought to assess the economic feasibility of installed investments under observed management regimes. The data was collected from executive members or knowledgeable members of user groups who were involved in the management of water infrastructure. On average each interview involved two members though some had one and others up to five members collectively interviewed. These were interviewed at the same time which helped in collaborating responses as members' recall was reinforced by another present group member. The response recorded was a consensus among the members. In total, 46 interviews, one per watering facility, were conducted.

Data collected: The focus was placed on eliciting information on the existing infrastructure, including its functionality and integrity (i.e., available installations at each facility and their functionality, the number of people and animals served per day, and the number of livestock keepers served). Additionally, the study examined the institutional arrangements and governance of water infrastructure. Data was also collected on community demographics, including the distance to the water source, transport costs to access the facility, the number of similar installations in the community, and problems accessing water infrastructure. Additional data was collected on various actors involved in the management of the water facility, along with their importance scores, which reflect their perceived significance in the management process. To assess the economic feasibility, information was collected on willingness to pay, costs (e.g., desilting, cleaning/removing trash, salaries for guards, building gullies, fencing, equipment, planting pastures), and benefits (e.g., watering animals, water for domestic use, water irrigation). Data on willingness to pay was gathered through a direct questioning approach. Respondents were asked about their readiness to pay for water usage across various applications, including livestock watering per animal, crop irrigation per acre per instance, domestic use per jerrycan, and fishing per fish.

They were also asked to specify the amount they would be willing to pay for each service. The survey also captured community satisfaction with management, fees, and use, as well as the challenges and opportunities of water infrastructure management.

Data analysis

Costs benefit analysis

In the Cost-Benefit Analysis (CBA), both financial and economic analyses were used to assess the economic feasibility of water infrastructure in pastoral communities under different institutional arrangements. The financial analysis reflected the project-specific profitability, including direct revenues and costs, of managing water infrastructure under specific institutional arrangements at the user level. The revenues collected were utilized by designated water infrastructure managers to meet maintenance and management costs. We analyzed two financial scenarios: one using the actual revenues and costs observed at the time of the study (*status quo*), and another assuming a willingness to pay value was charged for water use. The economic analysis considered the costs and benefits to the regional (pastoral community) economy, accounting for variations in benefits based on the dominant institutional arrangement for managing a watering facility. Since some valley dams and tanks could not estimate costs incurred, we used known operational costs from similar facilities in the same region, assuming that costs would be similar if repairs and maintenance were conducted. The institutional arrangements were: water use associations, co-infrastructure management (local government, community, and private sector including cattle traders and contracted service providers), community volunteers, local government, and co-management between water use associations and volunteers. The study also considered cases where no arrangement was in place, classified as "None" in the analysis. Water use associations were composed of community water users who voluntarily came together to manage the water infrastructure. The dominant types of water use associations included: conflict resolution user associations, livestock water user association, and farmer use association. Livestock water use associations governed water usage for livestock watering. Farmer use associations managed water for crop production. Conflict resolution associations addressed conflicts related to water use for livestock, crops, or domestic purposes. Multipurpose user associations played a dual role, overseeing water use for livestock and crop farming, and supporting conflict resolution. Some associations were formed with the support of the RPLRP to monitor the development process and subsequently manage the infrastructure.

Quantifying benefits

In the analysis of financing management of water infrastructure, the charges for the use of water infrastructure[1] including the payments and collective contributions by the community to use a given water infrastructure were classified as revenues. In the economic analysis, societal benefits included reduced animal stress in sourcing water, leading to higher survival rates, reduced forced offtake of animals during the dry period, weight gain (more beef), reduced milk production losses, healthier animals (more draught power), and reduced treatment expenses. The study quantified the benefits from cattle and goats by attaching a value to weight gain due to the availability of adequate water and better feed conversion for cattle. The study assumed that each adult animal gained an additional 11% of its weight (up to 200 kg[2]) by watering at the facility before being slaughtered, based on Dobes et al. (2021). It also assumed that the same animal used the facility daily and that the replacement and disappearance rates were constant. An annual growth rate of 2% is assumed between years (Uganda Bureau of Statistics, 2024). Uganda Bureau of Statistics (2024) estimated a growth rate of 20.8% for cattle between 2008 and 2021. Since not all livestock-rearing households participate in the market simultaneously, we used a market participation rate of 65% (Feinstein International Center, 2020) in the analysis to adjust these benefits. Goats can lose up to 32% of their weight due to water stress (Geldsetzer-Mendoza and Riveros, 2023). The study assumed that with improved water availability, goat farmers avoid the 32% weight[3] loss, translating into more goat meat. Similar to cattle, it was assumed that the same goat used the facility daily and that the replacement and disappearance rates were constant. Between years, the annual growth rate for goat numbers is assumed to be 2.8% (Uganda Bureau of Statistics, 2024), with a growth of 39.4% between 2008 and 2021. The study priced the weight gain as beef and goat meat based on market rates (UGX 11,000 for beef and UGX 12,000 for goats' meat)[4].

The second benefit identified was the gains from reduced mortality, which refers to the avoided loss of animals. To quantify gains from reduced mortality, we applied the average mortality rate of animals during the drought season to the watering herd. The study assumes a mortality rate/avoided loss of 29.8% for cattle and 27.1% for goats, based on Nkedianye et al. (2011).

1 The payments (the contribution by the users) towards maintenance of the water infrastructure were not for personal use by the designated water infrastructure managers and neither were they a revenue stream for government. They were ploughed back into management of a given facility

2 An average animal is assumed to gain up to 250 Kg often used in Tropical Livestock Units calculations (Rothman-Ostrow et al., 2020)

3 An average Small East African (SEA) goat, the dominant breed in Teso and Karamoja attain a weight of between 25 and 30 kg at maturity (Nantongo et al., 2024).

4 1 USD was equivalent to UGX 3,568 at the time of the survey

Nkedianye et al. (2011) found mortality rates ranging from 13% to 45% (average 29.8%) for cattle and from 17% to 44.5% (average 27.1%) for shoats in the Maasai Mara, the Kitengela plains, the Amboseli, and the Simanjiro plains, depending on drought intensity, forage shortage, and water availability. Catley et al. (2014) reported higher estimated animal losses of between 25% and 60% during extended dry/drought periods in pastoral communities of Ethiopia. The study did not include savings from avoiding forced sales of animals at lower prices during drought periods, as this is implicitly captured in beef production and would constitute double counting. While livestock owners may spend money on supplemental feed to keep their animals alive during droughts, this practice is not common among poor livestock keepers in Teso and Karamoja. The common practice is to move animals to swampy areas in search of water and feed. This would constitute an upkeep cost during the transhumance journey, but we did not collect data to account for these costs.

The third benefit identified was milk production, assessed per cow utilizing the facility. We calculated this by considering the milk gained or the loss avoided due to the availability of watering facilities for the milking herd. The valuation was based on the average milk price per district. During water scarcity periods, milk production from cows decreases by an average of 27%, according to Burgos et al. (2001), which could be avoided with improved watering. On average, a cow in Karamoja produces 1.7 L of milk per day, while a cow in Teso produces 1.8 L per day. Although only 23% of the milk is sold by households in the study area, we quantified the entire milk production to account for the opportunity cost of home consumption, which could enhance household members' nutrition. The lactating length for East African zebu cattle, the dominant breed in the study site, was 239 days, according to Galukande et al. (1962). Another source of revenue was domestic water usage. This calculation considered the following factors: The number of domestic users, assessed as the total number of households using water from a specific facility, the average water consumption per household per day (as reported by UBOS in 2023) and the price per liter of water.

Quantifying costs

Ensuring sustainable access to water for livestock and domestic use involves use charges, community contributions, investment, and operational costs. For this study, the main costs included: The initial costs of establishing each facility by the Government of Uganda, charges to the community for using watering facilities, and total annual costs, including repair and maintenance costs, operational costs, and the depreciation charge. Operational and maintenance costs included, where applicable: desilting, cleaning/removing trash, salaries for guards, building gullies, fencing, equipment, and planting pastures. The depreciation charge was calculated using the straight-line method, with the asset salvage value set at 5% of the initial asset cost and a useful life of 20 years for dams, tanks, and boreholes (as provided by the facility developer). The study assumed annual operational costs would increase by 2% per year for the first 5 years, 5% per year for the next 5 years (up to the 10th year), and 10% per year for the remainder of the asset's useful life.

For outputs (e.g., water used for watering animals and domestic use) that could not be valued using market prices, adjustments were made to the market-price valuation analysis by attaching shadow prices/costs. This was based on their contribution or savings to consumption or investment, as outlined by Squire and van der Tak (1975). The financial and economic analysis to compare institutional arrangements was possible due to variations in the number of animals watered, differences in willingness to pay, and the costs involved.

Computation of net present value (NPV) and benefit-cost ratio (BCR)

The CBA measures used were the Net Present Value (NPV) and Benefit-Cost Ratio (BCR). The NPV was calculated as the total sum of the present value of expected future costs and benefits of using livestock water resources and was obtained as shown in Equation 1.

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \tag{1}$$

where *Bt* is the benefit each year, *Ct* is the cost each year, *i* is the interest (discount) rate, is the lifespan of the water investment. The BCR was computed by the ratio of Present Value of Benefits (PVB) to the Present Value of Costs (PVC). The PVB and PVC were computed as follows:

$$PVB = \sum_{t=0}^{t} \frac{B_t}{(1+r)^t}$$

and

$$PVC = \sum_{t=0}^{t} \frac{C_t}{(1+r)^t}$$

One caveat of our CBA results is that the water investments under different IAs could have had different capacities and thus handled different herd sizes which makes the results non-comparable. That notwithstanding, the CBA was used to show the feasibility of having different water investments in place and managed under different institutional arrangement regimes.

Choice of discount rates and sensitivity analysis

A social discount rate (SDR) of 5%, based on the economic growth rate of low- and middle-income countries (Fay et al., 2014; Haacker et al., 2020), was used. However, given the fact that valuation results can change with the choice of discount rate, a sensitivity analysis was conducted with a SDR rate 10% for low-

TABLE 1 Functionality and use of water infrastructure.

Functionality and use	Teso region			Karamoja region		
	Valley Dams (n = 3)	Valley tanks (n = 4)	Boreholes (n = 20)	Valley Dams (n = 3)	Valley tanks (n = 5)	Boreholes (n = 11)
	Count of infrastructure			Count of infrastructure		
Fully functional and in use	2	3	13	2	1	10
Not functional	0	0	5	1	2	1
Partially functional and in use	1	1	2	0	1	0
Partially functional and not in use	0	0	0	0	1	0

income countries (Castillo and Zhangallimbay, 2022) and a Risk-Adjusted Discount Rate (RADR) of 15% with a risk premium of 5%.

The analysis of infrastructure use, functionality and integrity, community satisfaction, and willingness to pay

The study used frequencies, percentages, importance scores, means, standard deviations, and t-tests to analyze data on various aspects of water infrastructure management, such as: Functionality and use, integrity, community involvement, actors and their importance, institutional arrangements, rules, conflicts, and conflict resolution, community satisfaction, and willingness to pay. An importance score based on the communities overall rating of the importance (based on actor roles and how their performance in the management of water infrastructures). An average was obtained from ratings obtained from a five-point Likert scale captured as 5 = Very Important, 4 = Important, 3 = Neutral, 2 = Somewhat important, and 1 = Not important.

Results

Status of functionality, use, and integrity of livestock water infrastructure

The study sampled boreholes, valley dams, and valley tanks in the Teso and Karamoja regions. It found that most of the boreholes were in use (Table 1), but some were not functional due to various reasons, including being incomplete, having low water levels that are difficult to access, damaged parts like handles, insecurity in some sites, limited accessibility due to bad roads, vandalism, and faulty water pumping systems. Additionally, the study found that some of the valley dams and tanks were not in use due to a lack of water, perceived design errors, poor siting, droughts, or the availability of alternative options.

The integrity of watering facilities, defined as the availability of various installations deemed important for optimal functioning, is crucial for facilitating their use. Information on the integrity of various water infrastructures sampled is shown in Table 2. For boreholes, four installations are critical for sustainable use: a functioning pumping system to access water, a drainage system to reduce muddiness around the facility and contamination, water troughs to avoid direct watering, and fencing to protect the installation. Few boreholes had these installations, but when available, the majority were functional and used.

For valley dams, several important installations were missing, mostly in Karamoja, as shown in Table 2. For example, none of the valley tanks in Karamoja were reported to have a drainage/excess flow system, water troughs, or grazing pasture. How animals access water from infrastructure determines the longevity of services. In Karamoja, for boreholes, 84.5% of the animals were watered using troughs (water is collected and animals are watered a distance away from the borehole in troughs or basins), while 18.2% were watered within the facility (water is pumped and animals' water directly). For valley dams, 66.7% of the facilities reported that animals are watered within the catchment area, while 40% and 80% reported watering animals outside (water pumped to troughs) and within the valley tanks (in the catchment area), respectively. In Teso, 45% of the boreholes reported that animals are watered from outside in troughs or basins. Additionally, 66.7% and 50% of valley dams and tanks, respectively, reported that animals are watered within the facilities. Watering animals within facilities is a detrimental practice that may degrade the quality of water, cause silting, and reduce the lifespan of water infrastructure (Eremugo and Majaliwa, 2018).

According to the users, when equipment is not available, it could have been vandalized or may not have been installed. There is a need for the presence of watering points to align with pasture availability to prevent altering pasture dynamics and intensifying

TABLE 2 Integrity of livestock water infrastructure.

Installation	Boreholes (n = 20)		Valley dams (n = 3)		Valley tanks (n = 4)	
	Available	Functional/used	Available	Functional/used	Available	Functional/used
	Percent	Percent	Percent	Percent	Percent	Percent
Teso Region						
Pumping system	45.0	66.7	33.3	100	100	75.0
Solar system			33.3	100	75.0	100
Drainage system	55.0	90.1	33.3	100	25.0	100
Water troughs	45.0	44.4	66.8	50	75.0	100
Grazing pasture	20.0	100	0.0	0	0	0
Fencing	35.0	71.4	33.3	100	75.0	100
Erosion control			66.8	100	50.0	50.0
Tree around			100	66.7	0	0
Latrine	35.0	100	100	100	75.0	100
Karamoja region	**Boreholes (n = 11)**		**Valley dams (n = 3)**		**Valley tanks (n = 5)**	
Pumping system	18.2	50	0	0	40.0	100
Solar system			0	0	20.0	100
Drainage system	54.5	83.3	0	0	0	0
Water troughs	45.5	60	33.3	100	0	0
Grazing pasture	0	100	0	0	0	0
Fencing	63.6	87.1	0	0	20.0	100
Erosion control			0	0	20.0	100
Tree around			33.3	100	20.0	100
Latrine	27.3	100	33.3	100	0	0

Notes: For boreholes, the pumping system was manual, operated by hand, and if not available, then the borehole was not put to use. For Dams and valley tanks, the pumping system was solar powered, when the pumping system is not in available, then water cannot be pumped to the trough which increases direct watering from the facility and the facilities may be in use.

livestock concentration effects (Mugerwa et al., 2014). Strategic location of water points, particularly in vulnerable dry pastures, and regulated access through traditional user systems can protect pastures while serving pastoral communities (Magda and Mulugeta, 2012).

Characterization of the use of water infrastructure

Valley dams served the highest number of people (on average 23,430) in Karamoja, while valley tanks served more people in Teso (on average 2,840) per day (Table 3). The number of cattle watered varied significantly between Teso and Karamoja. For example, boreholes in Teso were used to water an average of 260 cattle per day, while boreholes in Karamoja watered an average of 420 cattle per day. The number of goats that used valley tanks was significantly different between Teso and Karamoja, with Karamoja having significantly more goats using the facility (Table 3). Due to insecurity in Karamoja, the use of dams and tanks was quite restricted, affecting their total potential and the number of animals watered. Some communities in Karamoja bundle animals and keep them collectively in kraals, which makes boreholes a convenient source for watering animals. Bundling animals in kraals near manyattas is a coping strategy to avoid cattle rustling, which often happens when animals aggregate at watering points with few attendants. The kraals are located within homesteads, creating an additional layer of security and reducing the possibility of animal losses due to rustling.

Users of valley tanks traveled the furthest distance, on average 37 km, to access the watering facility. The distance traveled to access valley tanks was significantly higher in Teso

TABLE 3 Characterization of the use of water infrastructure.

	Teso region			Karamoja region		
	Boreholes (n = 20)	Valley Dam (n = 3)	Valley Tank (n = 4)	Boreholes (n = 11)	Valley Dam (n = 3)	Valley Tank (n = 5)
	Mean (SD)					
Average number of parishes served	2.0† (1.89)	5.5 (1.00)	30.0 (30.1)	1.18 (0.40)	20.0 (30.35)	1.80† (1.095)
Average number of people (000) served/Day	0.19††† (0.21)	0.36 (0.14)	2.84 (4.790)	0.46††† (0.43)	23.43 (38.61)	1.02 (0.73)
Average number of cattle (000) watered per day	0.26 (0.38)	2.50††† (0.87)	30.5 (46.38)	0.42 (0.62)	0.03††† (0.06)	1.36 (1.33)
Average Number of goats (000) watered per day	0.43 (0.46)	1.21 (0.65)	2.17† (1.50)	0.18 (0.17)	1.44 (−)	7.93† (11.06)
Average number of livestock keepers watering animals (00)	0.52 (0.97)	3.77† (1.16)	304.5 (597.0)	0.25 (0.0.31)>	1.00† (1.73)	1.35 (2.31)
Average distance (KM) traveled to access the water source	1.75 (1.74)	3.00 (1.00)	77.88††† (148.09)	2.20 (3.40)	4.17 (5.11)	4.22††† (4.74)
Average distance (KM) to an alternative water source	1.68 (2.17)	0.33† (0.58)	1.42 (1.38)	1.20 (1.05)	8.75† (5.30)	1.12 (1.11)
Average amount (000 UGX) spent on transport to access infrastructure	2.50 (4.39)	1.33 (2.31)	0.0	0.27 (0.65)	0.0	0.0
Average number of domestic users (00) per day	1.06 (1.39)	2.77 (2.48)	0.50 (1.00)	1.03 (1.99)	0.38 (0.66)	1.33 (0.22)
Average number of similar installations in the parish	4.10 (3.77)	1.00 (0.00)	1.00 (0.00)	2.91 (1.64)	3.00 (2.64)	1.00 (1.00)
Problem accessing water for animals (1 = Yes)	0.65	1.00	0.25	0.54	0.00	0.40
Average age of water infrastructure	3.05 (2.3)	2.3 (0.6)	3.25 (0.5)	5.1 (4.2)	8.0 (7.1)	5.8 (3.6)

Notes: ††† significant difference at 1%, †† significant difference at 5%, and † significant difference at 10% between the use of facilities in the Teso and Karamoja Regions.

(77 km) compared to Karamoja (4.2 km) (Table 3). This could be because valley tanks were the preferred watering system in Teso and served on average up to 30 parishes compared to 2 parishes in Karamoja. Keeping the distance traveled by animals searching for water to a minimum is important as it affects feed intake by the animal and labor requirements for the community (Motta et al., 2018; Fust and Schlecht, 2018; Turner and Schlecht, 2019). It also reduces exposure to diseases and intra and inter community conflict.

Institutional arrangements that govern the use and management of water infrastructure

The study found a mix of institutional arrangements governing the use of water infrastructure. In Karamoja, the common governance systems included water use associations/groups/committees, local government management, and community volunteers. In Teso, water use associations and community volunteers were the dominant institutional arrangements (Table 4). Despite their dominance, the community reported that only 36.4%, 33.3%, and 40% of the borehole, valley dam, and valley tank user associations were functional in Karamoja, respectively. In Teso, the functionality ratings by communities were 45%, 66.7%, and 75% for boreholes, valley dams, and valley tanks, respectively. The key attributes used to assess the functionality of user associations included: Regular meetings (achieved by 42.8% in Teso vs. 85.7% in Karamoja); official recognition (64.3% vs. 71.4%); meetings honored by the community (78.5% vs. 85.7%); decisions and resolutions respected (85.7% vs. 85.7%); and imposing sanctions that are respected (64.3% vs. 57.1%).

Under these institutional arrangements (IAs), the main actors involved in the management of livestock water infrastructure can be grouped into three categories: 1) Beneficiaries, 2) Government employees, and 3) non-government entities. Beneficiaries: This group includes individuals, community leaders, community volunteers, group chairpersons, group executives, and group members.

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TABLE 4 Dominant institutional arrangements and types of user association in the management of water infrastructure.

IAs	Teso region				Karamoja region			
	Boreholes (n = 20)	Valley Dam (n = 3)	Valley Tank (n = 4)	Pooled	Boreholes (n = 11)	Valley Dam (=3)	Valley Tank (n = 5)	Pooled
	Count by the number of infrastructure investments using							
Water use associations	8	3	3	14	7	1	1	9
Local government	1	0	1	2	4	1	2	7
Community volunteers	3	1	1	5	3	0	1	4
Co-infrastructure management[a]	2	0	0	2	1	0	0	1
Conflict management committees	1	0	0	1	1	0	0	1
Private contractors	0	0	0	0	1	0	0	1
No defined method known	3	0	0	3	3	1	3	7
Type of water use association								
Livestock water user association	0	1	3	4	4	0	0	4
Farmer user association	0	0	0	0	0	0	1	1
Conflict resolution user association	2	0	0	2	4	1	1	5
Multipurpose user associations								

[a]Co-management between the community, private entity, and local government.

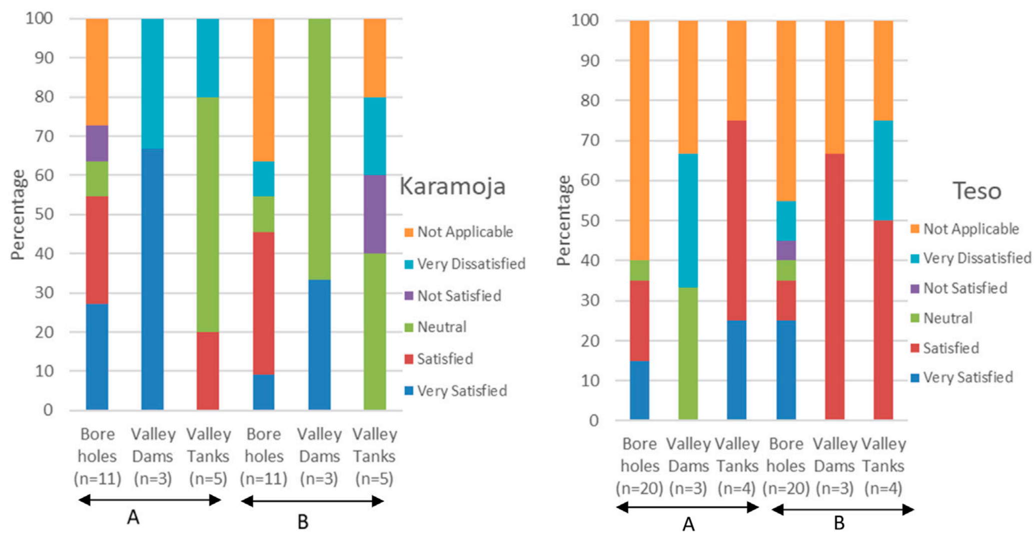

FIGURE 2
Community Satisfaction: (A) with fees collected and (B) with use of collected fees.

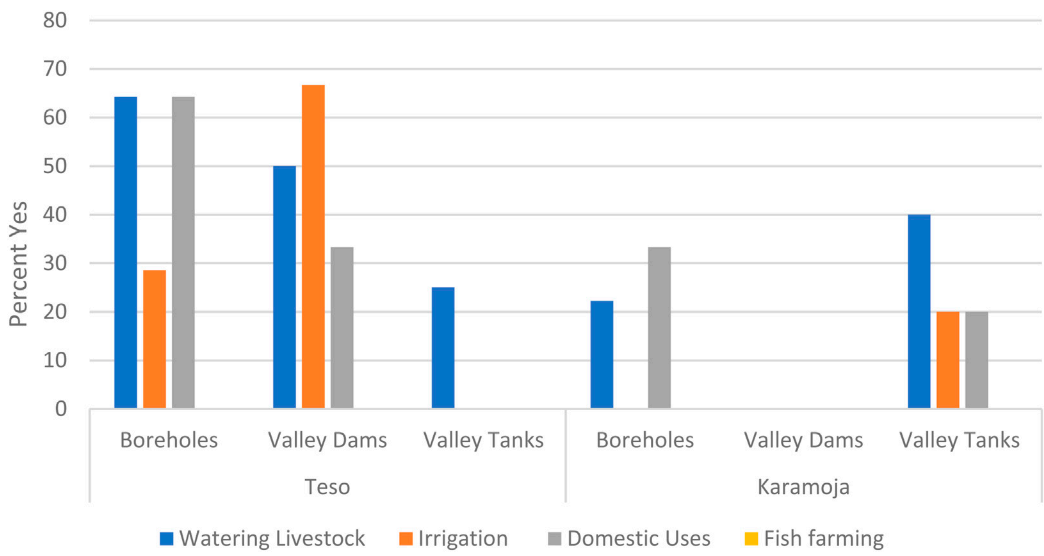

FIGURE 3
Willingness to pay for the use of watering services.

Government Employees: This category comprises district veterinary officers, town clerks/sub-county chiefs, chief administrative officers, district engineers, para-vets, health inspectors, and town council members. Non-Government Entities: These are private sector actors, including traders and service providers. The descriptions, roles, and importance scores of each actor are detailed in Supplementary Appendix 1. These actors are also involved in setting and enforcing rules, among other responsibilities (Supplementary Appendix 2).

Within the water use associations, distinct types of user associations governed the use of water infrastructure (Table 4). These associations served various commodities and purposes, primarily focusing on regulating water use, maintaining cleanliness and hygiene of facilities, carrying out repairs and maintenance, setting and enforcing rules, resolving conflicts, and collecting revenues. When local government was involved, mostly as an overall overseer, its key roles included conducting maintenance and repairs, setting and enforcing rules,

TABLE 5 Amounts (UGX) farmers are willing to pay to use water infrastructure.

Type of water use	Teso region			Karamoja region			Pooled		
	Valley Dams (n = 3)	Valley tanks (N = 4)	Boreholes (N = 20)	Valley Dams (n = 3)	Valley tanks (N = 5)	Boreholes (N = 11)	Valley Dams (n = 6)	Valley tanks (N = 9)	Boreholes (N = 31)
	Mean (Std. dev)								
Watering PER animal	50.0 (70.7)	1250 (2500)	196.1 (297.5)	0.0	40.0 (54.8)	66.7 (165.8)	33.3 (57.7)	577.8 (1658.9)	145.43 (257.8)
Irrigation PER acre per use	0.0	0.0	NA	0.0	0.0	NA	0.00	0.0	
Domestic use PER jerrycan	100 (141.1)	0.0	76.4 (79.0)	0.0	20.0 (44.7)	27.8 (44.1)	66.7 (115.4)	11.1 (33.3)	57.4 (70.6)
Fishing PER fish	0.0	0.0	NA	0.0	0.0	NA	0.0	0.0	

and ensuring that facilities were clean and hygienic. Even with local government participation in the management of water facilities, the community continued to play a supportive role.

Infrastructure valuation: user fees, contributions, willingness to pay, and cost-benefit analysis

Use fees and contributions for water infrastructure use

Charging a fee for the use of water infrastructure could improve user experience and increase the care given to these facilities. Fees can be used to maintain water facilities, keep them in good shape, improve water quality, and extend their longevity. However, fees need to be modest to reduce the burden on poor households and can be based on users' willingness to pay (WTP) or existing payment and contribution norms where communities offer resources and in-kind support for water facility management. Among the sampled water infrastructure, very few facilities charged user fees. In Teso, only 6 out of 20 boreholes reported having user fees, 1 out of 3 valley dams, and no valley tanks charged user fees. In Karamoja, 2 out of 11 boreholes sampled had user fees, 1 out of 3 valley dams, and none of the valley tanks charged user fees. In both regions, when charged, the fees were for watering animals and water for domestic use.

In addition to user fees, users of water infrastructure sometimes make contributions for facility maintenance. In Teso, 4 out of 20 boreholes (20%) had members making these contributions. On average, members reported paying a total of 96,500 UGX per month for borehole management. Members of only one valley dam made contributions (500 UGX per member per month), and none of the users of valley tanks made contributions. In impoverished communities, households often struggle to survive and may be unable to afford contributions for water use. Additionally, due to the lack of mechanisms to regulate water usage based on varying herd sizes and challenges in fee collection and accountability, compliance with water use regulations remains poor. Figure 2 shows community perceptions of fees collected and their utilization. While fewer users were paying for water use, in Karamoja, users were satisfied with the fees collected for boreholes and valley dams. In Teso, satisfaction levels varied, with higher satisfaction observed for valley dams and tanks. The community's day-to-day management and oversight influenced the rating for valley tanks.

Willingness to pay (WTP) to use water infrastructure

Due to low user support for infrastructure management funding, the study assessed user willingness to pay (WTP) to use water infrastructure investments. User WTP varied by region, type of facility, and intended use (Figure 3). More users in Teso expressed willingness to pay for using various water facilities. For boreholes, 66.7% of users in Teso were willing to pay for domestic water use, compared to 33.3% of users in Karamoja.

Additionally, some Teso communities (but not Karamoja) were open to using valley dams for irrigation purposes. Fishing and irrigation were not popular uses of water infrastructure due to restrictive rules, lack of knowledge, or availability of alternative options. Users were willing to pay more to use valley dams and tanks for irrigation purposes, but none were willing to pay for using the facilities for fishing (Table 5). The WTP amount was modest: about 100 Uganda shillings (UGX) per 20-liter jerrican in Teso and 20 UGX in Karamoja for domestic use. Willingness to pay values were higher for watering animals, ranging between 50 UGX to 1259 UGX in Teso and 0 UGX to 67 UGX in

TABLE 6 Financing analysis of the management of various infrastructures by Institutional arrangement.

Parameter	Institutional arrangement						Institutional arrangement					
	None	Water Use Association (WUA)	Co infrastructure management	Community volunteers	Local government	WUA + Volunteers	None	Water Use Association (WUA)	Co infrastructure management	Community volunteers	Local government	WUA + Volunteers
	Status quo						If charged according to willingness to pay					
Boreholes												
Total Revenue	0.0	2.14	7.1	0.0	0.0	3.2	65.6	100.6	90.2	21.9	5.1	37.2
Total Costs	0.0	2.04	2.9	1.2	0.0	0.03	6.0	2.04	2.9	1.2	—	0.03
Gross Income	0.0	0.11	4.2	−1.2	0.0	3.1	59.6	98.5	87.3	20.7	5.1	37.2
Valley Dams												
Total Revenue	—	2.8	0.0	0.0	0.6	0.0	—	138.2	107.6	—	75.1	112.2
Total Costs	—	0.3	0.0	0.0	0.0	0.0	—	0.3	0.3	—	0.3	0.3
Gross Income	—	2.5	0.0	0.0	0.6	0.0	—	137.9	107.3	—	74.8	111.8
Valley Tanks												
Total Revenue	0.0	0.0	0.0	0.0	0.0	0.0	74.1	300.0	117.5	—	370.3	308.1
Total Costs	0.0	0.0	1.62	0.0	0.0	0.0	3.2	3.2	3.2	—	3.2	3.2
Gross Income	0.0	0.0	−1.62	0.0	0.0	0.0	70.9	296.8	114.3	—	367.0	304.8

Notes: All values are in Million Uganda shillings per year.

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TABLE 7 Benefit-cost ratio (BCR) of various water infrastructures by institutional arrangement.

Parameter	Institutional arrangement					
	None	Water Use Association (WUA)	Co infrastructure management	Community volunteers	Local government	WUA + Volunteers
Boreholes	3.2	16.4	6.0	39.6	33.6	17 .7
Valley Dams	—	6.0		—	5.1	3.1
Valley Tanks	23.3	61.3	27.6	—	80.6	50.7

Karamoja. The higher willingness to pay in Teso could be attributed to the fact that it is less rural, has a slightly more educated population, and a lower share of people living in poverty compared to Karamoja.

Generally, willingness to pay (WTP) for livestock water infrastructure could be low due to several factors. Many pastoral households have limited financial resources, making it difficult for them to afford additional expenses in the form of watering fees. Additionally, some watering facilities are considered communal resources and have traditionally been provided by the government and support agencies, making the concept of paying for water less acceptable. Furthermore, limited awareness and understanding of the long-term benefits of well-maintained water infrastructure could be affecting WTP. Weak institutional arrangements and lack of supportive policies, coupled with past experiences with poorly managed or non-functional water infrastructure, could be contributing to a lack of trust in new projects. This lack of trust could also be affecting WTP. The availability of alternative water sources, such as rivers, streams, or seasonal ponds/swamps, reduces the perceived need to pay for water provided by this infrastructure. If free or low-cost alternatives are accessible, communities may prefer them over paid options. In the context of fishing, some reasons for limited willingness to pay include regulations imposed for the use of the facility, such as limited direct access to water in tanks (which are fenced off and have gates). Additionally, fishing would only be possible if the facilities were stocked with fish and the fish were fed, which requires technical expertise that most users reported lacking.

Cost-benefit analysis of livestock water infrastructure

Financial analysis

The resources generated from members should ideally not be a profit for infrastructure managers, but rather a contribution for the sustained management of watering facilities. Co-management of infrastructure was found to be the most feasible institutional arrangement (IA) under the *status quo* scenario, as it collected fees and had some savings of 4.2 million UGX to meet future costs (Table 6). This was followed by joint management between water user associations (WUAs) and community volunteers. Under the willingness to pay (WTP) scenario, WUAs and co-management could be the most feasible arrangements to manage boreholes as a source of domestic and livestock water. Water use associations were the most feasible for managing valley dams under both the *status quo* and WTP scenarios. No valley tank collected fees or had contributions, but some incurred costs in the form of salaries/wages for security purposes. For example, under co-management (community, local government, private sector), about 1.62 million UGX per year was paid by the local government to guard facilities without charging fees. Under the WTP scenario, local government would be the most feasible IA to manage valley tanks, as it could attract the highest resources and savings, followed by joint management between WUAs and volunteers (Table 6).

The collective effort among community members in managing water resources is critical for sustainability (Mittra et al., 2014). If we consider a scenario where users are willing to pay, water user associations (WUAs) emerge as the better infrastructure arrangement. WUAs serve as intermediaries, ensuring the inclusive and sustainable management of livestock water infrastructure within communities. These cooperative groups, comprising farmers and other water users, have a direct stake in the water infrastructure, including livestock water sources. Their sense of ownership fosters a strong commitment to responsible decision-making aligned with community needs. Currently, some boreholes are managed by community volunteers. To ensure their continued dedication, there should be a mechanism for compensating volunteers, as they had a negative gross income (Table 6) for their contributions to water infrastructure management. In certain watering facilities, volunteers played a crucial role: they donated land for establishing the facilities, resided near the facility which allowed for convenient monitoring, and provided security.

Economic analysis

The Benefit-Cost Ratios (BCR) of institutional arrangements (IAs) used for managing water infrastructure were greater than one, indicating feasible infrastructure and management arrangements (Table 7). In the management of boreholes, the BCR shows that community volunteers were the most effective.

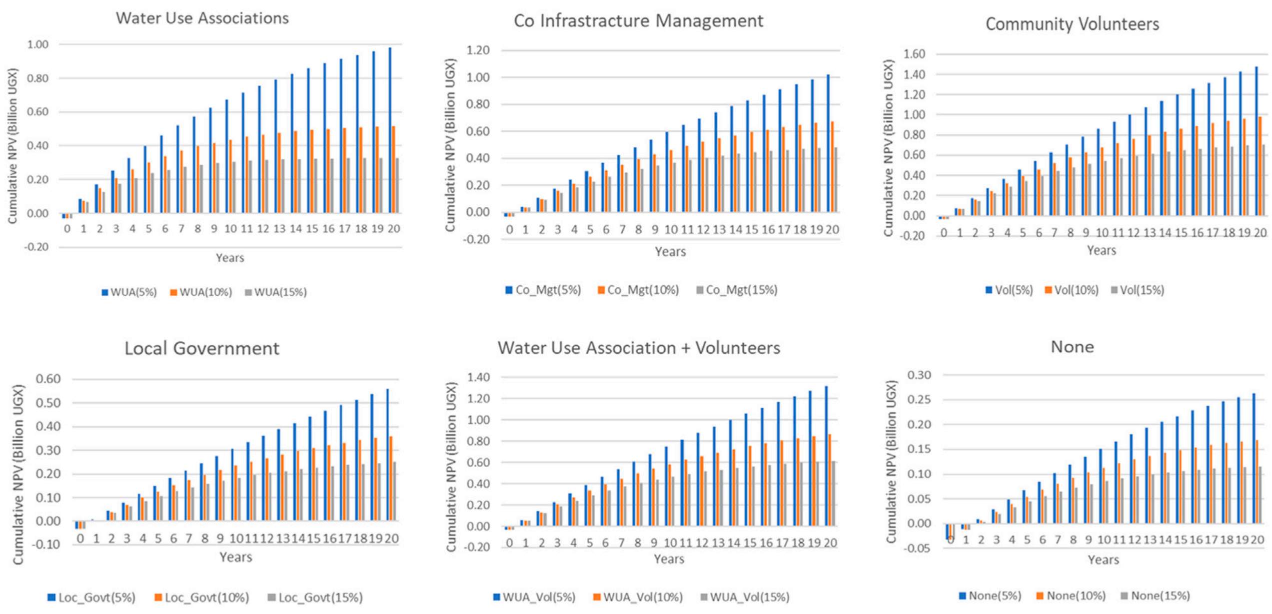

FIGURE 4
Cumulative NPV for the Management of boreholes under different IAs.

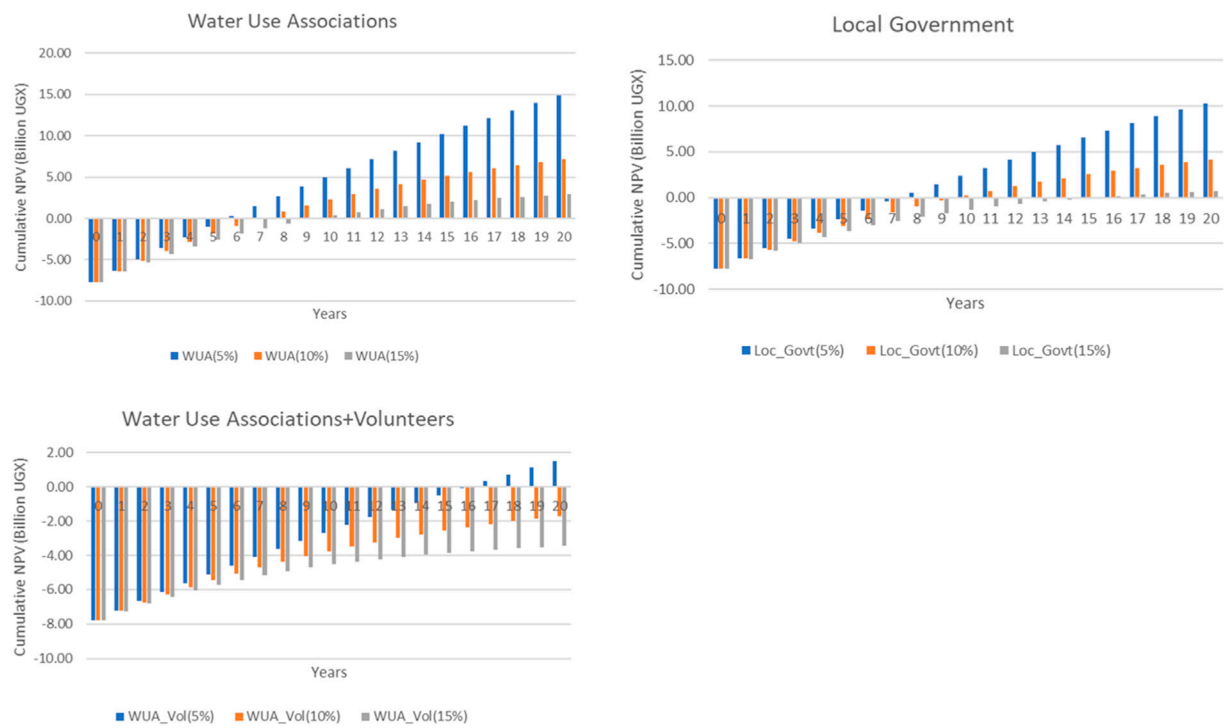

FIGURE 5
Cumulative NPV of Valley Dams Under different IAs.

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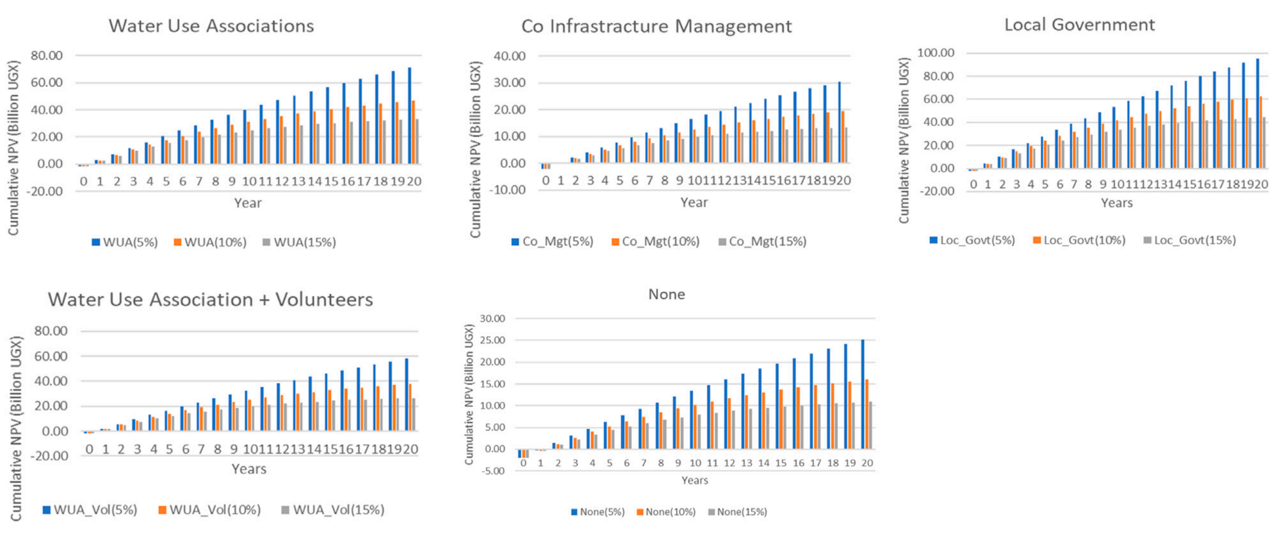

FIGURE 6
Cumulative NPV for Valley Tanks Under different IAs.

This is because they are close to the facility and have a vested interest in keeping it in good condition for their watering needs. Additionally, members tend to have social ties and easily collaborate with their peers, which can be extended to the management of watering facilities. Management of boreholes by local government was also highly feasible because they have the necessary resources, such as local council structures, to enforce use rules.

Similar to the Benefit-Cost Ratio (BCR), in the longer term, community volunteer management and joint management between Water User Associations (WUAs) and the community could generate the highest returns if used to manage boreholes. The Net Present Value (NPV) for boreholes turns positive after 1 year when managed under WUA, co-management, community volunteers, WUA combined with volunteers, and local government. Under no defined IA, NPV turns positive after 2 years (Figure 4). The value of cumulative NPV decreases with an increase in the discount rate from 5% to 10%, and 15%. However, the trend in NPV remains the same for the IAs regardless of the choice of discount rate.

For valley dams, water user associations (WUAs) or committees were better placed to manage the dam, with a Benefit-Cost Ratio (BCR) of 6 (Table 7). The Net Present Value (NPV) would turn positive by the 6th year at a discount rate of 5%, and by the 8th year for rates of 10% and 15% (Figure 5). Although the NPV under WUAs follows the same trend as the discount rate increases, the NPV is sensitive to changes in discount rates, more than halving for every 5% increase. For local government management, the NPV turns positive after 8 years of use if a discount rate of 5% is applied, and takes 10 and 14 years if the cost of capital is 10% and 15%, respectively. When management was held jointly by WUAs and volunteers, the NPV turns positive after 17 years if a rate of 5% is used, and never turns positive within 20 years if rates of 10% and 15% are used. It is thus important to offer development support for valley dams at lower rates (low borrowing rates for loans) given their sensitivity to discount rates.

For the valley tanks evaluated, five institutional arrangements were used for the management of facilities: Water User Associations, co-infrastructure management, local government management, joint management between WUAs and community volunteers, and no specific IA. The Benefit-Cost Ratios were highest when WUAs were used, followed by local government (Table 7), making these the most important IAs for managing valley tanks. The Net Present Values under local government management were highest and turned positive after 1 year (Figure 6). All NPVs for other IAs also turned positive after 1 year, indicating worthwhile investments. This could be attributed to the number of animals served per valley tank facility. For valley tanks under no specific IA, the NPV takes about 2 years to turn positive. The NPV for various IAs in managing valley tanks followed the same trend for different discount rates and was more sensitive to higher discount rates, more than halving the NPV value.

A caveat on the cost-benefit analysis of valley dams and valley tanks is the different sizes/capacities of the facilities, the diversity of community herd sizes, technical specification issues, and prevailing security issues in communities, which may make economic estimates variable.

Challenges affecting effective management and sustainability of water infrastructure

Free riding: The free rider problem arises when some members of a community intentionally fail to contribute their fair share to the costs of a shared resource. In the context of water installations surveyed, this issue becomes evident when communities do not fully participate in funding and managing water facilities. Despite the need for user fees and other payments to sustain water installations, some communities contribute minimally. This lack of financial support hinders effective management. Specifically, in the case of Karamoja, there is limited contribution to use fees and willingness to pay for using water facilities. It is also possible that some households cannot pay because they are poor or refuse to pay a contribution that is considered unfair. However, for the facilities under consideration, water use associations and other community groupings reported unwillingness by several community members to actively contribute in kind (labor and time) to the management of water resources, leading to difficulties in maintaining and protecting water investments. Managers also reported challenges such as damages and vandalism by the community, undefined user fees, a lack of effective mechanisms for regulating water consumption, and an undefined number of animals using water per household, resulting in some livestock consuming more water than they contribute. To address the free rider problem, it is crucial to foster community mobilization and collective awareness, build institutions, and encourage social norms that discourage free riding (Breier and Visser, 2006).

Ownership tragedy: A likely ownership tragedy arises when the defined guidelines to regulate water use in watering facilities are not enforced, leading to overuse and misuse. Enforcement of guidelines and regulations was weak because the cost of enforcement (human resources, time, and money) was high for the Teso and Karamoja settings. Enforcement often relied on local councils and community volunteers who were poorly facilitated. Ownership would create strong incentives for users to improve the value of investments and maintain them, but this was not evident from the sampled watering facilities. Often, water associations and volunteers carried a disproportionate burden in regulating use and maintenance. When involved, Water User Associations (WUAs) only supported labor-based maintenance where no cash outlays or spare parts were needed. Additionally, the hosts, where present, had a strong vested interest in how facilities were used. However, given the communal nature of the resources, their influence may not be sustainable (Braimah and Filmua, 2011).

Technological challenges and limits of knowledge: The current pumping and watering systems in valley tanks and some dams face significant challenges, primarily due to the limited flow of water to the troughs. Animals often exhaust the water from the troughs because of the low replenishment capacity, which affects optimal watering and intake. The deterioration of water facilities further exacerbates this problem. Additionally, the community's lack of training in maintaining or handling minor repairs worsens the situation. This knowledge gap necessitates training for water facility users to manage minor repairs on clogged points, broken pipes, and faulty taps.

Governance challenges: Committees often struggle to mobilize resources for repairs and maintenance after facilities are handed over by contractors. They also have limited authority to enforce laws regarding water infrastructure access. For maintenance purposes, a private company is more suited to undertake maintenance than the community, which lacks expertise and resources, and the district engineering department, which is often constrained due to a lack of allocated budgets for water management. The funds for paying the contractor could be co-mobilized from the local government and users, either on a monthly basis or as a one-off payment in case any urgent repair is needed.

Prolonged drought and poor siting: Poor siting, exacerbated by prolonged drought, was the primary reason most dams dried up, forcing herders to walk long distances in search of pasture and watering points for their animals. The facilities were reported to mainly store water during the rainy season and were inadequate to meet the community's needs during dry periods. It was also noted that cattle rustling is more common during prolonged droughts because many animals congregate at the same watering points. Therefore, efforts to improve pasture production to reduce distress to herders should go hand in hand with addressing the constraints associated with limited water and extreme temperatures.

Discussion

The analysis of water infrastructure management and usage reveals several noteworthy findings. The functionality of such infrastructure is influenced by the nature of administrative management and community involvement. The study suggests that the most effective administrative management of water infrastructure occurs when control is given to the users, such as community volunteers, user associations or committees. District and sub-county local government structures should primarily serve supportive and oversight roles. This finding was consistent across all types of water infrastructure examined in this study. Given that the community reaps the most significant benefits, and no direct fees are charged for using the water infrastructure, it is sensible for users to assume a larger role in managing the facility. For boreholes, the community that uses and is in close proximity to the infrastructure is best suited for its management, maintenance, and usage monitoring. The community can impose modest user fees amongst its members, when they deem fit, as was the case for some boreholes, to generate funds for maintenance. As noted by Mugerwa et al., 2014; Schnegg and Bollig, 2016, water use associations/committees play a vital role in managing water resources for livestock watering. However, these committees are underdeveloped in some pastoral areas, such as Uganda (Mugerwa et al., 2014), and face overwhelming pressure during challenging times like prolonged droughts (Schnegg and Bollig, 2016).

Local political administrative bodies, including local council chairpersons, community councilors, and parish leaders, can aid communities and user associations by supervising usage, establishing rules, and implementing penalties for misuse of water infrastructure. Instances of vandalism were reported when the community showed reluctance in managing facilities, indicating a failure on the community's part, given that they are the primary beneficiaries of the water infrastructure. To ensure the effectiveness of user associations, extension officers should also be tasked with ensuring that the associations are adequately trained in the use, management, and maintenance of water facilities.

The sustainable utilization of water resources for livestock, in order to prevent free-riding and the tragedy of the commons, necessitates clearly defined user and property rights. The tragedy of the commons and the free rider problem in the use and management of livestock water resources stem from inadequately defined and enforced property rights (Libecap, 2009). Inefficient management structures, weak institutional arrangements, the provision of resources as public goods, and insufficient sanctioning could also lead to free riding, resulting in the tragedy of the commons (Breier and Visser, 2006). Additional factors exacerbating the free rider problem include limited community involvement, social intermediation, and institution building (Breier and Visser, 2006). Without effective use rights and laws, the motivation to manage water resources - whether privately, communally, or publicly - will remain low. This was the case for most watering facilities surveyed.

To circumvent the free rider problem and mitigate the tragedy of the commons, various resource governance strategies have been suggested. Centralized and self-governance, along with local water user associations, are crucial for enforcing water use and distribution rules (Engler et al., 2021). In some cases, individual commitment and voluntarism are more important than established design principles for managing communal water supply (Menestrey Schwieger, 2020). Since we found a strong presence of WUAs and voluntarism in the management of water facilities in Teso and Karamoja, this is a positive sign and precursor for strong institutional development, In Uganda, water resource management has been decentralized from ministries to local government institutions and water user committees to support the community-based management approach. However, the integration of cultural institutions into this approach and the functioning of different institutions remain unclear. While the community and specific user groups should handle administrative issues, it's important to have the local government on board to support establishment of user rules, monitor water resource use, and undertake major repairs when necessary.

Despite the long-standing effectiveness of customary water resource management, it is being replaced by a statutory system (Adjakloe, 2021; Ramazzotti, 2008). For example, the management of water for rural communities involves national institutions like the Ministry of Water and Environment (MWE) and the Ministry of Agriculture Animal Industry and Fisheries (MAAIF). MAAIF is responsible for the development of hydraulic infrastructure, water use management, and stakeholder capacity building (MWE, 2019). At the local level, a decentralized community-based management (CBM) system implements water resource policies through district local governments, district and sub-county water use committees, water user group associations, and water user committees. Additionally, non-governmental organizations (NGOs), community-based organizations (CBOs), and private-sector partnerships also contribute to the management and development of water infrastructure. Therefore, a balance is needed to ensure new systems safeguard indigenous water governance systems by incorporating some of their structures and mechanisms. Statutory system including WUA are only strong because they operate within the realm of indigenous water governance systems. Without the coherence created by indigenous water governance systems, statutory systems would also probably be weak in the context of these livestock communities.

Financial and economic analysis for feasibility showed that investing in the facilities was worthwhile since NPVs were positive and CBR was greater than one. Generally, findings showed that all water infrastructure investments, regardless of the institutional arrangement in Management, were economically feasible, returning positive economic gains within a short time. Improving existing AIs, retooling user associations to equip them with the knowledge required to manage water infrastructure, and regular maintenance of facilities should continue delivering these gains and benefits to the community. The cost of capital, implied through discounting rates, was important and affected water facility valuation. Proper negotiations when obtaining support for water facilities os thus key to ensure high return on investment.

Conclusion and recommendations

The study was designed to explore the functionality, use, management, willingness to pay, costs, and benefits of livestock water infrastructure in the pastoral communities of the Teso and Karamoja sub-regions. Most boreholes were functional and in use in both Teso and Karamoja. For valley tanks, when not functional or not in use, factors such as design errors, poor siting, and drought impacted water availability and use, mostly in Karamoja. The presence of alternative watering facilities also affected the use of some water infrastructure. Communities highly value the role of water infrastructure in pastoral livelihoods. Community volunteers and user associations predominantly manage and regulate the use of water infrastructure, with local governments playing a supportive role. To prevent misuse, mismanagement, and vandalism, policies and programs are needed to enhance community vigilance and engagement in water infrastructure management. The government, through local governments, should oversee the enactment and implementation of these user rules, ensure functional legal institutions and regimes, undertake major repairs and maintenance when necessary, and monitor the use of water resources.

Water infrastructure users, particularly in Teso, are open to paying modest fees for domestic use, animal watering, and irrigation. Charging these fees could generate revenue for maintaining and ensuring the long-term sustainability of the facilities. Such fees could also ensure that all users contribute their fair share to the costs of maintaining the water infrastructure, help regulate water usage, encourage users to use water more efficiently and responsibly, and increase the valuation and care of the infrastructure. However, the fees should be acceptable and manageable for users, and mechanisms for collecting and reinvesting these fees are needed to ensure compliance and accountability, which are currently lacking for most infrastructure. Equitable fees ensure that the poor, who dominate the Teso and Karamoja regions, are not marginalized and that water is not overpriced. Implementing a fee system with clear mechanisms for collection and reinvestment ensures transparency and accountability. Users can see how their contributions are being used, which builds trust and encourages further participation. This approach also promotes a sense of ownership among the community members, leading to better care and management of the water infrastructure.

To increase community participation in the management and financial support of livestock water infrastructure, it is essential for local leaders, extension agents, and government officials to effectively communicate the value and benefits of these infrastructures. Education and training on water resource management are crucial to highlight the importance of sustainable practices. The government should also enact policies that support the development of local institutional arrangements and integrate community and traditional systems into sustainable water infrastructure management. This is important because traditional practices and social norms can significantly influence willingness to pay (WTP) for water services. The primary goal of collecting fees from members should be to ensure the long-term sustainability and maintenance of the water infrastructure. This means that the funds collected should be reinvested into the facilities for repairs, upgrades, and operational costs, rather than generating profit for the managers. This approach helps maintain the infrastructure in good condition, ensuring reliable water access for the community. Financial analysis shows that setting fees based on users' willingness to pay can make water infrastructure projects economically viable. WTP prices reflect the value that users place on the water services, ensuring that the fees are fair and manageable. By aligning fees with WTP, infrastructure managers can secure the necessary funds for maintenance without overburdening the users. A cost-benefit analysis also justifies investment in water infrastructure based on positive net present values and benefit-cost ratios. This analysis helps decision-makers prioritize projects that offer the greatest return on investment and long-term benefits for the community.

We present a case study on livestock water infrastructure, demonstrating its sustainability through community involvement and the generation of maintenance resources via user contributions, use fees, or, if feasible, modest charges based on willingness to pay (WTP). When community members participate in the management and maintenance of these facilities, they develop a sense of ownership and responsibility, leading to better care and upkeep. Furthermore, infrastructure costs can be minimized by encouraging communities to use and manage facilities responsibly and by identifying attractive incentives for the private sector, including community members, to invest in the management of livestock water infrastructure.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

PA: Conceptualization, Data Curation, Methodology, Formal analysis, Visualization, Writing - original draft, Writing-review and editing, Investigation, Validation. JI: Conceptualization, Methodology, Writing-review and editing, Validation, Investigation, Interpretation, and Project administration. FB: Conceptualization, Data Curation, Methodology, Writing-review and editing, Investigation, Validation. FL:

Conceptualization, Data Curation, Methodology, Writing-review and editing, Investigation, Validation. SW: Conceptualization, Methodology, Writing-review and editing, Investigation, Validation. PN: Conceptualization, Methodology, Writing-review and editing, Validation, Project administration, and interpretation. JO: Conceptualization, Methodology, Writing-review and editing, Validation, and interpretation. BN: Conceptualization, Writing-review and editing, Validation, Investigation, and Project administration. RS: Conceptualization, Methodology, Writing-review and editing, and Project administration.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/past.2024.12891/full#supplementary-material

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