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ORIGINAL PAPER

Assessing sustainability and management challenges in small-scale irrigation: Insights from the Amiba Garno scheme in Upper Blue Nile Basin

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Abstract: Irrigation development is crucial for economic growth, rural development, food security, and poverty reduction in Ethiopia. Despite its significance, little attention is given to the sustainability of the already developed irrigation projects. This study assesses the sustainability of the Amiba Garno small-scale irrigation scheme in the Upper Blue Nile Basin, Ethiopia. The study considers socio-cultural, environmental, technical, economic, and institutional factors. Key sustainability indicators include the scheme's technical performance, level of maintenance, system stability, environmental protection, productivity, and institutional support services and management. Data were collected through household surveys, interviews, group discussions, field observations, and literature reviews. The sustainability index was found to be 1.53, nearing unsustainability due to weak institutional, support services and management, and poor maintenance. Major challenges include irrigation water shortages during the crops peak water demand season, unequal water distribution among beneficiary farmers, siltation of the headwork, and apron damage. Immediate solutions are needed to address these issues. Improving the scheme's economic and environmental sustainability requires stronger institutional support, farmer training on improved crop production and water management, and regular supervision and monitoring.

Keywords: Condition index, sustainability indicator, scheme sustainability, Upper Blue Nile.

Introduction

Agriculture is the mainstay economic sector of Ethiopia and it is mainly based on rainfall, which is temporally and spatially highly variable (Suryabhagavan, 2017; Kibret et al., 2021; Habtu, 2024). Irrigation development has been recognized as a key tool to promote economic growth and rural development, and it is considered as a basis for food security and reducing poverty. In many parts of the country, agricultural development and performance are weak due to the occurrence of droughts which result in frequent crop failures. Crop productivity is also affected by the progressive degradation of natural resources, especially

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in highly vulnerable areas of the highlands, together with climate variability, which aggravates the incidence of poverty and food insecurity (Bishaw et al., 2013; Enyew, 2024). These factors negatively affect the food supply of the rapidly growing population and aggravate poverty in the country (Miyan, 2015).

Ethiopia possesses vast land and water resources with great potential for irrigation development (Berhe et al., 2022; Temesgen, 2023). According to estimates by Awulachew and Ayana (2011), the total irrigable land in the country is approximately 5.3 million hectares (Mha), which includes 1.6 Mha potentially irrigated through rainwater harvesting and groundwater. However, the currently irrigated area is only around 640,000 hectares, comprising small, medium, and large irrigation schemes (Awulachew, 2019). This reflects a significantly low level of irrigation utilization (Mulugeta and Ayele, 2022; Nuru et al., 2024). Progress in improving agricultural water management has been hampered by various constraints, and many irrigation schemes have underperformed relative to their design expectations (Gebul, 2021; Sintayehu et al., 2022). As a result, smallholder farmers dependent on rain-fed agriculture are highly vulnerable to spatial and temporal rainfall variability, land degradation, soil fertility depletion, and the impacts of climate change (Gebul et al., 2021; Berhe et al., 2022; Zargar et al., 2025). To address these challenges and reduce the risks of crop failure and drought, Ethiopia is actively working to expand irrigation development by leveraging its available water resources (Awulachew and Merrey, 2007; Zemarku et al., 2022; Ashine et al., 2025).

Irrigation scheme sustainability and performance assessment comprises a systematic approach for data collection, analysis, interpretation, and documentation. It is indispensable to have a deeper understanding of a scheme's performance and sustainability, identify any constraints, and propose corrective measures to improve the system's performance and sustainability (Berihune and Moges, 2022; Chala et al., 2026). The performance and sustainability of irrigation schemes are not up to the standard due to technical and management problems (Awulachew and Ayana, 2011; Mekonnen et al., 2022). Some community-managed small-scale irrigation schemes have failed prematurely, before reaching their expected lifespan, as a result of complex problems of spanning technical, institutional, socio-economic, and environmental aspects (Embaye et al., 2020; Berhe et al., 2022). According to Dessalegn et al. (2021), 80% of the proposed irrigation development in Ethiopia falls within the small-scale irrigation category. In a study by Awulachew and Ayana (2011), indicated that less than 50% of the irrigation users have benefited from the developed irrigation schemes. Among the challenges, the sustainability of the scheme and the water management practices are the most important (Awulachew, 2019). The major irrigation scheme performance and sustainability challenges include limited market availability and extension services, failure of infrastructure, poor management organization, lack of access to financial services, low level of technology usage and adoption, and water availability and quality (Yihune et al., 2022; Wubetu et al., 2022). However, despite unsatisfactory results, there has been little concern for improving the performance and management of existing irrigation schemes (Abera et al., 2019).

The performance and sustainability of the irrigation scheme are ensured through good management, periodic operation, and maintenance of the physical structures of the scheme (Shanono et al., 2022). It can be measured by using indicators that can provide information for decision-making in water resource management. An indicator is a number or qualitative value that describes the level of actual sustainability of an irrigation scheme with respect to one of its objectives of irrigation, namely to benefit the community over the long run (Moges, 2022; Nuru et al., 2024). Even though irrigation infrastructure expansion in the country is promising, little effort is being made towards the sustainability of the constructed schemes (Ali, 2011). Moreover, some of the constructed schemes have totally failed, while others are performing below their capacity (Lambisso, 2008).

Irrigation projects have been implemented in Ethiopia for a long period with assistance from the government, non-governmental organizations (NGOs), farmer groups, and individual farmers. Significant resources have been allocated to advancing and advocating for smallholder irrigation throughout the country. Based on the foregoing, the objective of the study was to examine the factors that affect the sustainability of the Amba Garno irrigation scheme, Upper Blue Nile Basin of Ethiopia. Specifically, it was intended to: 1) identify the scheme management issues that are detrimental to sustainability; 2) evaluate the causes of conflicts and irrigation water users' dispute resolution techniques; and 3) evaluate the scheme's sustainability through the use of a selected set of indicators.

Materials and Methods

Description of the study area

The study area is found in Gondar Zuria district (Figure 1), one of the extensively cultivated areas in the Upper Blue Nile Basin of Ethiopia. It is part of the Central Gondar Zone, which covers a total area of 1,286.76 ha. The district includes 37 administrative kebeles and has 10 perennial rivers. It is bordered by south Gondar Zone on the south, Lake Tana on the southwest, Dembiya district to the west, Lay Armachiho district and Gondar town on the north, and Wegera district on the northeast.

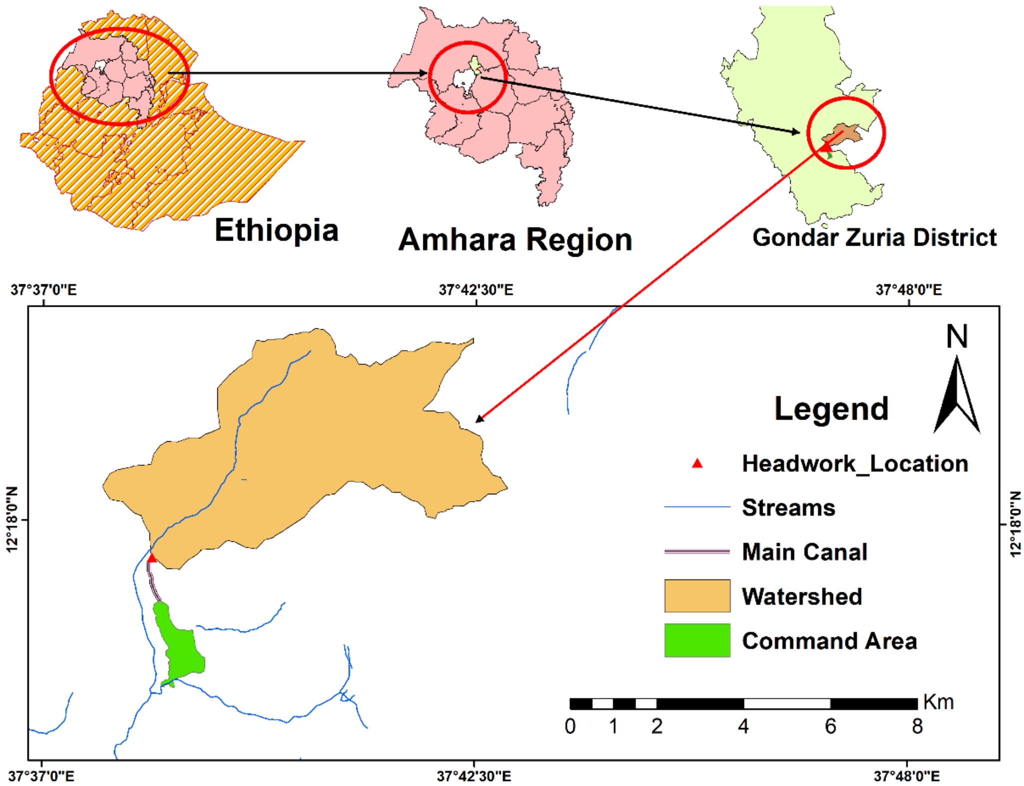

Figure 1. Location map of the study area.

Amiba Garno is a community-managed small-scale irrigation scheme located in the Debisan Tikara kebele of the district. It is located 56 km south of Gondar city and 18 km from Makisegnit (the capital town of the district). The head work site is located at 12° 17' 26" E and 37° 38' 20" N, with an elevation of 2016 m a.s.l. The altitude of the command area is in the range of 1995-2804 m a.s.l., which means that it is in the Tropical Humid agro-ecological zone. The project was designed and constructed to irrigate an area of 82 hectares, comprising a 1.8 km long main canal, of which 1.2 km is lined. The irrigation system conveyance structure consists of flumes, road crossing culverts, vertical drops, turnouts, division boxes, and tertiary canals to irrigate the command area.

The area receives a unimodal pattern of rainfall. The main rainy season extends from June to September and is largely characterized by high rainfall variability, rendering it highly vulnerable amongst small-scale farmers who mostly rely on rain-fed agriculture. The average annual rainfall ranges from 1,030 to 1,223 mm, with a mean annual value of 1,100 mm. The temperature ranges between 14 and 20°C, with a mean annual temperature of 17.9°C.

The major forms of land use in the district include cultivated land (36.02%), shrub and fallow lands (8.66%), grass land (54.38%), and forest land (0.94%). Eutric Leptosols is the dominant soil type (51.73% of the district), and Eutric Fluvisols has a minimum coverage (2.68%). Based on texture, the majority of the district soil is classified as clay loam, with the remaining part being covered with clay. About 39% of the district is cultivated, 45% is grassland, 13% shrub and bush, 1.50% built up, 0.70% forest land, and 0.63% water body. The major crops grown in the study area are wheat, teff, onions, garlic, and peas. Barley and sunflower are the two minor crops grown in the area.

Data collection

Primary data collection

The primary data collection mainly focused on household interviews with developed questioners, focus group discussions, key informant interviews, discharge measurement at selected canal locations, as discussed below:

Household (HH) survey: closed and open-ended questionnaires were used to collect data on the socio-economic, organizational, and institutional situation of the irrigation users, HH assets, activities, income, and demographic information from the sample households using structured interview questionnaires. The interview questionnaires were pre-tested among non-sample respondents of similar characteristics, and, depending on the pre-test results, some modifications were made based on hints received. The household survey, particularly for demographic data collection, was conducted in December 2023 among the selected sample households.

Sample size and sampling procedure: it is difficult to collect data from the entire study area population due to time constraints and limited budgets. Due to this, it is critical to determine the sample size and identify sampling techniques. Probability and non-probability sampling methods were used in this study. To select sample HH respondents for interview from the targeted population, systematic sampling was used, as described by Yamane (1967) and shown in Equation 1. Moreover, stratifying sampling was used to select HH heads from the three equal places depending on the distance of the user's village from the headwork.

$$n = \frac{N}{1 + N(e)^2} \tag{1}$$

Where: n – sample size required; N – number of populations in the five micro-watersheds; e – allowable error between 5 and 10% (5% in this case). For this study, the required sample size (n) was 70 households.

Focus group discussion (FGD): the stratified method of sampling was utilized to select participants from the water user association (WUA), development agents (DAs), and female-headed irrigation water users of the scheme. Users are also selected to have farm plots at the head, middle, and tail of the command area. This was done to get all the information about management activities. Discussion with the group was held on irrigation water sustainability, water diversion mechanism, irrigation schedule, water distribution, and challenges faced in all irrigation activities, starting with water diversion from the main source to the field plot and agricultural seed plants.

Key informant interview (KII): it was conducted with development agents, relevant district irrigation experts, WUC, and role model farmers. A discussion was conducted based on all activities of irrigation management, including the water conveyance system, the sustainability of the irrigation scheme, the major problems faced, and the improvement opportunities of the irrigation scheme.

Discharge measurement: discharge measurement helps to know the conveyance efficiency, and it was done at the main canal using the area-velocity method.

Observation: a transect walk was done to analyze the situation by observing the functionality of irrigation scheme structures, including actual canal carrying capacity, damage to structures, condition of distribution structures, problems of flooding, erosion, siltation, and weed growth in the canal, water logging, salinization, irrigation practices, type of crop grown, and other relevant data.

Secondary data collection

These data were collected from different sources, including institutions involved in the development of the scheme, such as the Bureau of Water Resources Development, the Bureau of Agriculture, the Regional Meteorological Agency, the District Office of Agriculture, the Kebele Administration Office, and rural development workers. Literature, both published and unpublished, was also used to collect the required data. The collected secondary data were: the type of cultivated crops, designed command area, designed features of the scheme, water management structures, and by-laws of the water user association.

Data analysis

A descriptive method of analysis, such as frequency, percentage, and mean, was used to describe the different socio-economic, institutional, environmental, and technical aspects of scheme sustainability. The principal questioners were assessed using a standard questionnaire, requiring a ‘YES’ or ‘NO’ response. This is used to see the presence or absence of a defect and analyze socio-economic, institutional, environmental, and physical structure aspects. Qualitative analysis was employed for the data gathered from key informant interviews, focus group discussions, and observations. At the same time, open-ended questionnaires and discussions with different stakeholders were conducted, and individual responses were summarized. Data from different sources was triangulated to get reliable information. The Statistical Package for Social Sciences (SPSS) software was used for quantitative data analysis (IBM Corporation, 2017).

The socio-economic and environmental categories were selected to reflect the conditions of the scheme that are thought to promote the sustainability of the scheme system. Five categories for the sustainability analysis were selected, including: technical performance indicators, scheme productivity, maintenance indicators, institutional structure and management systems, and environmental protection indicators of the system. The sustainability analysis was done after elaborating the categories using 22 different indicators, where each of them was supposed to reflect the sustainability of one major part of the irrigation systems.

The sustainability rating scale of the selected indicators was calculated using Equation 2, as proposed by vanLoon et al. (2005). To get the rating scale for each category, the average value of the calculated rating scale of indicators was used. Then, the average of the whole category is calculated to get the sustainability index of the scheme.

$$\text{Sustainability scale} = \frac{\text{Condition index} - \text{minimum goalpost value}}{\text{Maximum goalpost vaue} - \text{minimum goalpost value}} \times 5 \quad (2)$$

The equation was used to find the numerical scale values of sustainability that are rated on a scale of < 1, between 1 and 2, 2 and 3, 3 and 4, and 4 and 5, as indicated in Table 1. Normally, the condition index (CI) is expressed as a ratio between the actual and designed values. Depending on the result of the percentage of the respondent, the 'condition index' that shows the status of the selected indicators' goalposts was determined. In this study, 50 and 100% were taken as the lowest and maximum goalpost values, respectively, even though the values can range from 0 to 100.

Table 1. Condition index (CI), status, and scale of sustainability rating.

CI	Scale of sustainability	Status
81–100	3 to 5	Good, indicating no significant structural deterioration or loss of hydraulic function.
70–80	2 to 3	Fair, indicating partial loss of function and/or some risk to the integrity of the structure. Action is not immediately urgent.
51–69	1 to 2	Poor, indicating a serious loss of function and/or some risk to the structural integrity. Action needs to be taken to prevent.
< 50	< 1	Very poor, indicating effective failure/approach to unsustainable.

Source: vanLoon et al. (2005).

Selection of sustainability indicators

Researchers and scholars have developed many indicators to evaluate the sustainability of irrigation schemes and categorize them into groups (Moges, 2022). For this study, the categories of sustainability indicators were chosen based on their effectiveness, relevance, and ability to clearly and easily measure the central pillars of sustainability of the scheme, i.e., the technical, and management aspects, as well as the economic, socio-cultural, and environmental aspects. The details of the selected indicator categories and their methods of assessment are provided below.

1. Technical performance indicators

For this study, the technical performance indicators were estimated by computing the conveyance efficiency (EC) of the main canal, cropped area ratio (CA), and beneficial target performance (BTP). Conveyance efficiency (EC) was determined by computing water delivered by the conveyance system to total inflow (Equation 3). Conveyance losses (LC), attributable to seepage, leakage, and overtopping, is the difference between the amount of inflow and outflow. The cropped area ratio (CA), calculated using Equation 4, indicated deviations from the designed irrigated area. CA values less than one suggested the need for system rehabilitation. Beneficial target performance (BTP) addressed system shortcomings, planning collective actions to improve outcomes, and learning from successes and failures (Equation 5).

$$E_C = \left(\frac{Q_{out}}{Q_{in}}\right) \times 100 \quad (3)$$

$$CA = \frac{A_C}{A_D} \quad (4)$$

$$BTP = \frac{A_B}{P_B} \quad (5)$$

Where: Q_{out} and Q_{in} – amounts of outflowing and inflowing water from the canal, respectively, in L s^{-1}; A_B – actual number of beneficiaries; P_B – planned number of beneficiaries; A_C – actual total command area, in ha; A_D – designed command area, in ha.

2. Scheme productivity

Stability of the structures, soil fertility, and productivity of the land, water availability, and land scarcity were addressed by questionnaires. Then the stability-rated scale was calculated using Equation 2. Moreover, the productivity of the land (decreasing or increasing), water availability, land scarcity, sufficient income generation of the community for the household using irrigation, improvement of farmers livelihood, intensification of the crop, increasing of annual production after modernization, and availability of farm labour in the area were analyzed using the collected data of the questioners.

3. Institutional structure and management system

The key organizational structure in irrigation systems is the Water Users Association (WUA), formed by the members of the water users. It is a legal body that has full control over irrigation scheme infrastructure (Moges, 2022) and is considered a link between the local community and external actors (Berhe et al., 2022). It plays a major role in successful and sustainable irrigation management by establishing a strong organizational system. Sustainable management of farmer-managed irrigation systems requires well-established rules that assure the interests of all farmers (Berhe et al., 2022; Moges, 2022). Sense of ownership; participation of the beneficiaries; management transfer; establishment of legitimate WUC; capacity to organize and enforce rules; integration of stakeholders; ability of beneficiaries to generate operation and maintenance costs; and construction of new facilities were chosen as indicators under this category.

4. Environmental protection

Traditional irrigation was practiced by users of the area for a long period of time, resulting in increased food production and socio-economic development. However, environmental degradation, socio-economic difference, and social distraction are among the impacts that irrigation has on the environment. To assess the environmental sustainability, data was collected concerning plot fertility, the occurrence of human and animal diseases due to the development of irrigation schemes, the condition of natural disasters, and the scarcity of natural resources, which delay the sustainability of the physical structure facility.

5. Maintenance indicator

In this study, the maintenance indicators were assessed using the relative change of water level (RCWL) and efficiency of infrastructure (EI). The RCWL was used to estimate the impact of sedimentation and erosion on the irrigation canal systems. The measurement of water level at the main canal during the irrigation season was done at the head, middle, and tail reaches using a staff gauge and a measuring tape meter. The measured values were compared with the designed, and the CI value of the RCWL was computed using Equation 6.

$$RCWL = \frac{\text{Change of depth}}{\text{Design or intended depth}} \quad (6)$$

The other maintenance indicator used for this study was the EI, and its evaluation was focused on the physical structures in the irrigation system (Abera et al., 2019). It is computed as the ratio of functional structure to the total number of structures primarily installed, and the result was used to understand the level of maintenance requirements of the system. To determine the structural performance of the irrigation scheme, infrastructures such as the diversion weir, head regulator, drop structures, division boxes, and main canal off-take gates (gates closure) were monitored during field observations, and it was calculated using Equation 7.

$$EI = \frac{\text{Number of functioning structures}}{\text{Total number of structures}} \quad (7)$$

Finally, the results of this study are presented using descriptive statistics and an indicator-based evaluation approach. Quantitative data from surveys and field measurements are summarized using percentages, means, and CI values with corresponding sustainability rating scales. The findings are organized under key sustainability dimensions, while qualitative insights from interviews, discussions, and observations are used to support the analysis.

Results and Discussion

Household characteristics

Population dynamics and anthropogenic activities are believed to be prime causes of environmental degradation (Müller and Zeller, 2002). The impact depends on the conditions of land use and associated human activities; for instance, an increase in population density increases food demand and necessitates more agrarian practices to produce more food (Awulachew and Ayana, 2011; Awulachew, 2019; Berhe et al., 2022). To meet households' food demand and needs, cultivators are forced to plough their land regularly, causing nutrient mining and soil erosion problems, in turn hampering crop productivity (Jamieson et al., 1998).

Age plays a significant role in employment (including agricultural work) and mobility, as the use of child labor on farm activities still prevails in Ethiopia (Jilo et al., 2020). Generally, those under the age of 18 are mostly spending their time in school and can be considered children. However, in most rural parts of Ethiopia, it is common for children above six years old to partly help their parents with different household activities aside from schooling. Similarly, people over 65 years are also believed to be too old to practice agriculture actively. The household survey data showed that under 14 years is the dominant age, representing above 54.3% of the total population (Table 2). The study area was dominated by active laborers who could fully practice agricultural activities, indicating fewer dependents. The average family size of the sample household is six. Their adult son, relatives, or neighbours support crop production in female-headed households.

The household analysis revealed that 35.7% of the respondents indicated that their land holding size is very small (< 0.5 ha), 42.9% small (0.5 to 1.0 ha), and 21.4% sufficient (> 1 ha). This confirms the scarcity of irrigation land in the area.

Sustainability of the scheme

As described previously, the five major categories for the sustainability analysis, detailed by 22 indicators, were used and briefly presented in the following sections.

Technical performance indicator

The conveyance efficiency (EC) of the scheme was found to be 88% in the lined main canal and 63 in unlined main canals, indicating water loss of 12 and 37%, respectively. These losses are higher than those reported by Abera et al. (2019) for the Bebeks and Shina irrigation schemes, both found in the Lake Tana sub basin. Factors contributing to the low efficiency may be related to sedimentation, seepage, weed growth, and unauthorized water withdrawals (Figure 2). During a field campaign, illegal water abstraction on the main canal was observed, with local residents for domestic purposes such as drinking water, washing clothes, and bathing. Addressing these issues is essential for the sustainably use of the irrigation scheme.

Table 2. Demographic status of the sample households in December 2022.

Demographic characteristics		Number (frequency)	Percent
	≤ 14 years	38	54.3
	From 15 to 32 years	27	38.6
	From 33 to 65 years	4	5.7
Age distribution	> 65 years	1	1.4
Head of the household	Male-headed	60	85.7
	Female-headed	10	14.3
	Married	57	81.4
	Single	3	4.3
	Divorced	1	1.4
Marital status	Widowed	9	12.9
	Christian	61	87.1
Religion	Muslim	9	12.9
Ethnic	Amhara	70	100
	Primary school	16	22.9
	Secondary school	1	1.4
	Special Skill training	2	2.9
	Read and write	19	27.1
Educational status	Illiterates including under school kids	32	45.7
Average family size			6

Figure 2. Consequences of water loss in the main canal (A), growth of grasses and weeds (B), seepage loss (C), and unauthorized water turnout by farmers (D), during the field campaign in December 2023.

As shown in Table 1, the sustainability rate for the main canal is classified as fair, with an average EC value of 75.55%, indicating a partial loss of function and some risk to the structural integrity (vanLoon et al., 2005). In contrast, the unlined portion of the main canal is rated as poor, indicating a significant loss of function and some risk to the structural integrity. The scheme was designed to irrigate 82 ha, but currently, only 64 ha are being irrigated, leaving 18 ha unserved due to poor management. The condition index (CI) value of the cropped area ratio (CA) was 78%, with a sustainability rating scale of 2.8 (Equation 1), indicating a fair technical performance (vanLoon et al., 2005), which does not require immediate action (Table 1).

The planned beneficiary farmers of the Amiba Garno irrigation scheme were 85, but the actual number is 70. This resulted in a BTP condition index (CI) value of 82.4% and a sustainability rating of 3.24, indicating it is at good condition (vanLoon et al., 2005). By averaging the CI values of the CA and BTP, the technical performance indicator stands at 3.02, suggesting that the scheme is in a sustainable condition. However, further strengthening activities are needed to enhance the performance of the scheme.

Scheme productivity

For this study, the natural resources (water and land) were investigated with indicators like soil fertility, productivity of the land, and water availability to ensure the sustainability of the system. The analysis was done mainly based on the household survey results (Table 3).

The analysis showed that the overall scheme stability becomes fair (vanLoon et al., 2005) due to the existence of good and fair land productivity and soil fertility that is affected by poor water availability (Table 4). This indicates that there is a partial loss of function and some risk to the reliability of the structure, and hence immediate remedial measures are required. The farmers in the study area have experience with mulching and traditional ways of improving soil fertility. To analyze the productivity and profitability of the scheme, the household responses from developed questioners were used. These responses include factors such as generating sufficient household income, improving farmer's living standards, increasing the production of dominant crops, boosting annual production following scheme upgrades, and ensuring the accessibility of farm labour.

As shown in Table 4, the average rated sustainability scale of the scheme lies in a good range, indicating no significant structural deterioration or loss of hydraulic function.

Table 3. Scheme stability measured with different indicator variables and corresponding condition index (CI) and sustainability-rated scale values, during the field campaign in December 2023.

Indicator variables	Condition index value (%)	Rated scale	Remark (based on Table 1)
Soil fertility	71.4	2.14	Fair
Land productivity	84.3	3.43	Good)
Water availability	62.8	1.43	Poor
Average rated scale of stability	72.83	2.33	Fair

Table 4. Scheme productivity and profitability measured with different indicator variables and corresponding condition index (CI) and sustainability-rated scale values, during the field campaign in December 2023.

Productivity and profitability indicators	Condition index value (%)	Rated scale	Remark (based on Table 1)
Produce sufficient income for the households	88.5	3.85	Good
Upgrading of the living standard of the farmers	84.3	3.43	Good
Increase production of dominant crop in the area)	68.5	1.85	Poor
Increasing of annual production after upgrading of the scheme	87.1	3.71	Good
Accessibility of farm labour	82.8	3.28	Good
Average CI and rated scale values	82.2	3.2	Good

Organizational structure and management system

The result of the household survey indicates that 82.8% of the respondents did not know of any water organizations, whereas 17.2% said they knew of the establishment of a water use association. Surprisingly, 90% of the respondents were not members of the water user association (WUA). Some of the reasons they raised include a lack of participatory approach during committee elections, a lack of confidence in its importance, and the unaffordability of paying membership contributions. This indicates that the existing WUA is insignificant and that the kebele administration and the traditional leader play a great role in managing the scheme. The main causes of low scheme performance are due to the low attention given to the social and institutional aspects during scheme development and management (Berhe et al., 2022). This was confirmed as 41.4% of the respondents indicated that there is less post-construction support from concerned bodies, and 85.7% of the users have not received any training regarding irrigation scheme management. Moreover, 90% of the users did not show their willingness to cooperate to maintain the damaged part of the scheme. This indicates the poor performance of the water user's association and its inability to act based on the developed bylaws.

For irrigation scheme sustainability, one of the important steps is farmers' participation in all stages of the project phase (Yami, 2013; Annys et al., 2020; Berhe et al., 2022). However, the government has been making vast investments in irrigation scheme design and construction without the participation of the community. This leads to farmers' dependency on the government, which decreases their sense of ownership and responsibility for operation and management. The sustainability of the scheme regarding organizational structure and management system was summarized in Table 5 below. The negative value of the average organizational structure and management system indicates the worst case for the sustainability of the system

Environmental sustainability of the scheme

As shown in Table 6, selected environmental indicator variables were used to assess the environmental sustainability of the scheme. All the respondents indicated that the existence of local erosion (scour) downstream of the apron (Figure 3) was one of the major natural factors that may affect the sustainability of the scheme. 91.4% of the respondents indicated that soil erosion is the major environmental problem; however, 81.4% of them indicated no existence of a productivity decrease. Most of the respondents in the area did not specify an incidence of human or animal diseases after the implementation of the irrigation schemes. The scheme was in an unsustainable environmental condition, with an average environmental sustainability rating scale value of 1.42.

Table 1. Organizational structure and management system, and environmental sustainability of the scheme.

Indicators	Variables	Condition index (%)	Rated scale	Remark
Organizational structure and management system	Ability and willingness to pay for the construction of new scheme	10	-4	90% not willing to pay
	Participation of the beneficiaries	30	-2	
	Establishment of legitimate WUA/WUC	17.2	-3.28	
	Capacity building of users	14.3	-3.58	
	Post construction support	38.6	-1.14	
	Sense of ownership	85.7	3.57	
	Average	32.63	-1.07	
Environmental protection for sustainability of the scheme	Absence of soil erosion	20	-3	92 % said yes erosion is sever
	Cropping pattern for protection of soil fertility	51.4	0.14	No crop rotation
	Watershed management and environmental impact assessment	0	0	
	Change in environment due to intervention	92.8	4.28	13% agreed
	Average	41.05	1.42	

Source: Household survey, December 2023.

Table 6. List of major installed and functional irrigation infrastructures, during the field campaign in December 2023.

No	Name of structure	Installed	Functional	Non-functional	EI (%)
1	Weir	1	1	0	100
2	Flume	2	2	0	100
3	canal regulator gate	1	1	0	100
4	Turn out gate	5	3	2	60
5	Drop structure	4		4	0
6	Division box	12	8	4	67
7	Road crossing culvert	2	2	0	100
8	Division box gate	26	15	11	58
9	under sluice gate	1		1	0
10	Turn out	10	6	4	60
	Total	64	38	26	59.38

EI – efficiency of infrastructure.

Figure 3. Scour at the downstream of the weir and abrasion of launching apron.

Maintenance indicators

The infrastructure effectiveness (EI), reflecting the need of maintenance, is found to be 59.38%, with only 38 out of the 64 constructed structures are functional (Table 6). As suggested by Mekonnen et al. (2022), the analysis indicates that repair or rehabilitation of the physical structures is necessary as the EI value exceeds the 5% threshold.

Challenges and level of scheme sustainability

Identifying the major challenges in irrigation management is crucial for developing solutions to protect irrigation schemes. The primary issue is the lack of a well-organized institutional structure, particularly the ineffective establishment of Water User Committees (WUC), leading to poor maintenance performance. Strengthening or re-establishing the WUC is seen as a key step in addressing many of the users' concerns. Additional problems include poor stakeholder integration, overlapping responsibilities among sector offices, and institutional instability. In irrigation scheme development, emphasis has been placed on constructing physical infrastructure while neglecting operation, maintenance, and regular monitoring. Farmers and key informants prioritized challenges affecting irrigation sustainability, ranging from small landholdings and outdated technology to inadequate market information and insufficient training. Other significant issues include maintenance difficulties, water scarcity, poor infrastructure (such as roads), limited access to credit, and a lack of support and extension services.

For this study, the overall sustainability of the irrigation scheme was computed by averaging all indicators, and its value was 1.528, indicating that it was on the verge of becoming unsustainable. The result indicated that it is useful to organize an impact study on the irrigation systems that cause unsustainability. Similarly, the very low value of the environmental protective average rating scale indicates a lack of protective means to overcome any threat against the distraction of the conveyance system and the natural resources of this project. The survey result revealed that irrigation water use is the major source of conflicts due to its scarcity, followed by unequal maintenance fee contributions. These were aggravated by water theft and poor water management.

Conclusions

The aim of this study was to study the sustainability of a community-managed Amiba Garno small-scale irrigation scheme using selected indicators considering environmental, institutional, technical, and socioeconomic aspects. The analysis was done combining qualitative and quantitative data based on primary and secondary data collected from different sources. Questionnaires were used to collect household data. Focus group discussion was conducted with water user leaders, water committee members, women, and youth. Field observations, measurements and key informant interviews were also used to collect data. In addition, secondary data were collected from design documents, literature, and published books. The scheme was planned to provide service for 20 years, and the project provided service for six years.

It was observed that the overall sustainability of the irrigation scheme was 1.528, indicating that it is about to become unsustainable. The analysis revealed that the good productivity of the scheme was counteracted by the poor technical performance and institutional structure. The major unsustainability factor was the absence of a well-organized institutional structure, which results mainly from the low value of the establishment of legitimate Water Users Association (WUA), that resulted in water shortage at the tail. Hence, the WUA of the scheme has to be strengthened, and efforts also have to be made to bring all beneficiaries of the irrigation scheme under the water user association. Other factors include the low environmental protection actions combined with the lack of protective means to overcome any threat to the distraction of the conveyance system and the natural resources of the project.

It is essential that farmers are involved in the planning, implementation, and evaluation phases of irrigation projects, and the approach should follow a bottom-up approach, treating farmers as owners rather than beneficiaries. Training in water management, marketing, and general crop production for farmers and extension workers, institutional support, and regular monitoring and evaluation of irrigation schemes are necessary to provide feedback and information important for the future planning of the management of new schemes and the maintenance of old schemes. Sustaining the already constructed irrigation schemes should receive the same attention as implementing new irrigation facilities.

It is increasingly appreciated that irrigation sustainability will occur within the nexus of water, costs and knowledge. Improved knowledge is associated with better and more informed management. It is also highly dependent on the continued understanding of the basic processes associated with soils, water and plants and on continued innovation of irrigation practice.

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