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Water source, irrigation management and performance in irrigation cooperatives: a comparative analysis in Central Anatolia, Türkiye

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Abstract

This study evaluates irrigation cooperatives operating in the Central Anatolia Region of Türkiye in terms of water source, irrigation infrastructure, water management practices, and irrigation performance. The study is based on field survey data collected from 50 irrigation cooperatives representing groundwater-based, surface water-based, and mixed irrigation systems. Survey findings were cross-checked with official records obtained from the State Hydraulic Works (DSİ) and the General Directorate of Agricultural Reform (TRGM). The results indicate that groundwater-based systems dominate the region, accounting for 72% of the sampled cooperatives. Irrigation performance varies according to water source characteristics, with groundwater-based cooperatives exhibiting the highest irrigation ratio (82.14%), followed by surface water systems (71.79%) and mixed systems (67.82%). Pressurized irrigation methods are widely adopted, particularly sprinkler irrigation (64.40%) and drip irrigation (34.88%). The findings further reveal that water measurement infrastructure and volumetric pricing systems remain insufficiently developed. Although approximately half of the cooperatives employ water measurement, time-based pricing systems (70%) remain dominant, while volumetric pricing is rarely utilized. High energy costs constitute the most critical problem in groundwater-based systems, whereas water scarcity and infrastructure deficiencies are more prominent in surface water systems. Overall, the study demonstrates that water source significantly shapes irrigation infrastructure, management practices, irrigation performance, and sustainability conditions in irrigation cooperatives. The findings highlight the importance of improving monitoring systems, water measurement infrastructure, efficient pricing mechanisms, and sustainable groundwater management under increasing drought and water scarcity conditions.

Introduction

Increasing population growth, climate change, and increasing pressure on water resources have made the efficient and sustainable use of water in agriculture a strategic necessity worldwide. Globally, approximately 70% of freshwater resources are consumed by the agricultural sector (FAO, 2017), highlighting that irrigation management is not only a technical issue but also a critical component of water governance and agricultural policy. This challenge is particularly severe in semi-arid regions, where water availability is limited, climatic variability is high, and drought risks are increasing.

Türkiye is among the countries experiencing increasing water stress, with nearly 77% of total water use allocated to agricultural irrigation (DSİ, 2025). Of the approximately 8.5 million hectares of economically irrigable land, about 7.2 million hectares have been developed for irrigation, largely through public investments. In parallel with irrigation management transfer policies, irrigation systems have increasingly been operated by water user organizations, including irrigation cooperatives, irrigation associations, and local administrations. As a result, the role of these organizations in water distribution, operation, maintenance, and sustainable water management has become increasingly important.

Among these organizations, irrigation cooperatives play a particularly important role in the operation of small- and medium-scale irrigation schemes, especially in regions where irrigation largely depends on groundwater and pumping systems. These cooperatives are responsible for water supply, distribution, pricing, operation, maintenance, and irrigation scheduling. However, irrigation cooperatives in Türkiye exhibit substantial heterogeneity in terms of water source, irrigation infrastructure, institutional capacity, technical personnel, and management practices.

Water source characteristics directly affect irrigation infrastructure, operational costs, irrigation methods, and water management practices. Groundwater-based systems generally provide relatively reliable water supply and facilitate the use of pressurized irrigation systems; however, they are also associated with high energy costs, groundwater depletion risks, and sustainability concerns. In contrast, surface water systems are more vulnerable to climatic variability, seasonal water shortages, conveyance losses, and infrastructure maintenance problems. Therefore, irrigation performance should be evaluated not only in terms of physical infrastructure, but also considering water measurement systems, pricing mechanisms, cropping patterns, institutional capacity, and management practices.

Previous studies have proposed various indicators for evaluating irrigation performance, including irrigation ratio, water delivery performance, water use efficiency, and economic performance (Bos et al., 2005; Molden et al., 1998). These studies emphasize that irrigation performance is shaped not only by technical infrastructure but also by management practices, institutional capacity, and user behavior (OECD, 2015; Perry, 2007). Although numerous studies have examined irrigation systems and irrigation performance in Türkiye, most of them have focused on limited case areas, specific irrigation schemes, or technical performance indicators. Comparative studies evaluating irrigation cooperatives according to water source characteristics remain relatively limited, particularly at the regional scale.

In addition, the lack of a comprehensive and systematic monitoring and evaluation framework for irrigation cooperatives constitutes a major institutional limitation in Türkiye. Existing studies generally rely on relatively small sample sizes and insufficiently address the structural and managerial differences between groundwater-based, surface water-based, and mixed irrigation systems. Furthermore, limitations in long-term institutional records restrict the calculation of important performance indicators such as irrigation efficiency, water productivity, and financial sustainability indicators. This situation creates significant challenges for evidence-based water governance, sustainable irrigation planning, and climate change adaptation policies.

These issues have become increasingly important in the Central Anatolia Region, where groundwater dependency, drought severity, declining groundwater levels, and sinkhole formations have intensified in recent years. In such water-stressed environments, understanding how irrigation cooperatives manage water resources under different water source conditions is critically important for sustainable agricultural production and long-term water security.

The novelty of this study lies in its water source–based comparative evaluation of irrigation cooperatives using field-based survey data collected from approximately 10% of the active irrigation cooperatives operating in the Central Anatolia Region of Türkiye. Unlike many previous studies based on limited case areas, this study provides a broader regional assessment by comparatively analyzing groundwater, surface water, and mixed irrigation systems in terms of irrigation infrastructure, water management practices, irrigation performance, pricing systems, cropping patterns, and major operational problems. In addition, survey findings were cross-checked with official records obtained from DSİ and TRGM to improve data reliability.

Therefore, this study aims to contribute to the literature in three main ways. First, it provides a regional-scale empirical dataset regarding irrigation cooperatives in one of Türkiye's most water-stressed regions. Second, it offers a comparative framework for evaluating the effects of water source characteristics on irrigation management and performance. Third, it highlights the importance of systematic monitoring and evaluation systems for sustainable irrigation governance under increasing climate change and water scarcity pressures. The findings are expected to provide valuable insights for policymakers, practitioners, and researchers involved in irrigation management and sustainable water governance.

Study Area and Scope

The study was conducted in the Central Anatolia Region of Türkiye, covering the provinces of Aksaray, Ankara, Eskişehir, Karaman, Konya, Niğde, Kayseri, Yozgat, and Nevşehir. The region is characterized by semi-arid climatic conditions, limited surface water resources, recurrent drought conditions, and a high dependence on groundwater for agricultural irrigation. In recent years, increasing groundwater abstraction, declining groundwater levels, and sinkhole formations have become major environmental concerns in several parts of the region.

The study population consisted of irrigation cooperatives actively engaged in irrigation activities within the selected provinces. Only cooperatives currently operating irrigation systems were included to ensure the use of up-to-date and operational data. Cooperatives with incomplete, inconsistent, or inactive records were excluded from the analysis.

The distribution of irrigation cooperatives according to province and water source type is presented in Table 1.

Table 1. Distribution of irrigation cooperatives by province and water source (n)

Province	Total Cooperatives	Active Irrigating Cooperatives	Groundwater Cooperatives (n)	Surface Water Cooperatives (n)	Mixed Cooperatives (n)	Sample (n)
Aksaray	28	21	2	1	0	3
Ankara	57	38	0	3	0	3
Eskişehir	101	99	8	2	0	10
Karaman	36	35	4	0	0	4
Konya	278	192	15	2	3	20
Niğde	57	38	3	1	0	4
Kayseri	46	39	2	1	1	4
Yozgat	17	12	1	0	0	1
Nevşehir	11	8	1	0	0	1
Total	631	482	36	10	4	50

Sampling Method

The sample size was determined using the proportional sampling formula for finite populations proposed by Yamane (1967):

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

Here:

- n = sample size,
- N = population size,
- e = acceptable sampling error.

According to the proportional sampling formula proposed by Yamane (1967), the calculated sample size for the study population was approximately 83 irrigation cooperatives at a 10% sampling error level. However, due to time, accessibility, and field survey constraints, the study was conducted with 50 irrigation cooperatives, representing approximately 10% of the active irrigation cooperatives in the region. Although the sample size is below the theoretical minimum suggested by the formula, efforts were made to ensure regional representation and inclusion of different water source types through proportional and purposive sampling approaches.

To ensure both statistical representativeness and comparative analytical capacity, a combination of proportional and purposive sampling methods was applied. Approximately 10% of the active irrigation cooperatives in the region were included in the sample, while efforts were made to ensure provincial representation and inclusion of different water source types. In addition, purposive sampling was used to ensure adequate representation of different water source types, including groundwater-based, surface water-based, and mixed irrigation systems. This combined sampling approach enabled both regional representation and comparative evaluation of irrigation management characteristics under different water source conditions.

The final sample consisted of 50 irrigation cooperatives representing different irrigation system characteristics, water management practices, operational scales, and water source conditions within the Central Anatolia Region.

Data Collection

Primary data were collected through structured questionnaires conducted with cooperative managers, board members, or authorized representatives of irrigation cooperatives. Surveys were administered through face-to-face and online interviews between 2024 and 2025.

The questionnaire consisted of multiple-choice, multiple-response, Likert-scale, and open-ended questions. The complete questionnaire used in this study is provided in Supplementary Material 1. https://drive.google.com/file/d/1ev0ceRxmjSM8eq2W7FmPawNips6w1_Zm/view?usp=sharing

The survey covered the following topics:

- institutional and organizational characteristics,
- water source structure,
- irrigation infrastructure and irrigation methods,
- water measurement systems,
- water pricing practices,
- irrigated area and irrigation performance,
- cropping patterns,

- operational and managerial problems,
- drought and water scarcity issues.

To improve data reliability and consistency, control questions were incorporated into the questionnaire. In addition, survey responses were cross-checked with official records obtained from DSİ and TRGM. Variables such as irrigated area, number of cooperative members, number of wells, irrigation system type, and water source characteristics were verified using institutional records wherever possible. Questionnaires containing incomplete, contradictory, or unreliable information were excluded from the final dataset.

Variables and Performance Indicators

The collected data included institutional characteristics, irrigation infrastructure, water management practices, irrigation methods, irrigated area, irrigation ratios, pricing systems, cropping patterns, and major operational problems. Definitions of the variables and performance indicators used in the analysis are presented in Supplementary Material 2. https://drive.google.com/file/d/1jNuTtVqs8QVgwVXTiS8iHyBcxNSbGjHV/view?usp=sharing

Irrigation performance was primarily evaluated using the irrigation ratio indicator. Irrigation ratio (%) was calculated as the ratio of irrigated area to the total irrigation command area multiplied by 100:

$$Irrigation\ Ratio\ (\%) = \frac{Actually\ Irrigated\ Area}{Total\ Irrigation\ Area} \times 100$$

Due to limitations in systematic institutional records, advanced indicators such as irrigation efficiency, water productivity, and financial performance indicators (e.g., collection efficiency and cost recovery ratios) could not be calculated consistently for all cooperatives.

Data Analysis

Descriptive statistics were used to evaluate institutional characteristics, irrigation infrastructure, water management practices, pricing systems, and operational problems of irrigation cooperatives.

The relationships between categorical variables were analyzed using the chi-square (χ^2) test of independence. The following variable pairs were examined:

- water source and irrigation method,
- water source and water measurement practices,
- water source and pricing method.

When expected cell frequencies were below acceptable thresholds, categories were merged and Fisher's exact test was applied where necessary. The strength of associations was evaluated using Cramér's V coefficient.

Statistical results are reported using χ^2 values, degrees of freedom (df), sample size (N), p-values, and Cramér's V coefficients.

A significance level of $p < 0.05$ was adopted for all analyses. Statistical analyses were conducted using IBM SPSS Statistics (Version 29).

Limitations

This study is based on survey data obtained from 50 irrigation cooperatives operating in the Central Anatolia Region of Türkiye. Although the sample reflects the general structural and managerial characteristics of irrigation cooperatives in the region, some limitations should be acknowledged.

First, the limited number of mixed irrigation systems requires cautious interpretation of comparisons involving this group. Second, insufficient long-term institutional monitoring systems restricted the availability of consistent data regarding irrigation efficiency, water productivity, financial sustainability, and collection-performance indicators.

Despite these limitations, the study provides valuable field-based empirical evidence regarding irrigation cooperatives operating under increasing drought and water scarcity conditions in Central Anatolia.

Results and Discussion

General and Institutional Characteristics of the Sample

A total of 50 irrigation cooperatives operating in nine provinces of the Central Anatolia Region were included in the analysis. The spatial distribution of the sample indicates a strong concentration in Konya Province, which accounts for a substantial share of the irrigated agricultural area in the region. This reflects the strategic importance of irrigation activities in the Konya Closed Basin, where agricultural production is highly dependent on groundwater resources under semi-arid climatic conditions. The historical establishment periods of the sampled irrigation cooperatives are presented in Figure 1.

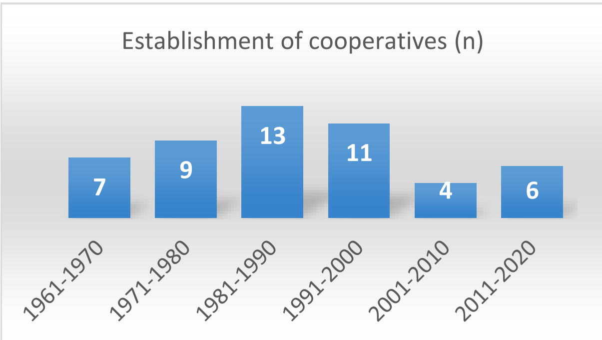

Figure 1. Distribution of irrigation cooperatives by establishment period

The sampled cooperatives collectively irrigate 47,437 ha, with an average irrigated area of 949.3 ha per cooperative. However, considerable variation exists among provinces, indicating a heterogeneous organizational structure in terms of operational scale, irrigation infrastructure, and management capacity. Cooperatives located in Konya and Karaman tend to operate larger irrigation schemes, whereas relatively smaller-scale cooperatives are more common in provinces with fragmented agricultural structures.

A total of 9,685 farmers benefit from irrigation services provided by the sampled cooperatives, corresponding to an average irrigated area of 3.94 ha per farmer. This variation suggests that irrigation cooperatives differ not only in physical infrastructure but also in terms of farmer participation, land fragmentation, and production structure.

Institutional characteristics further demonstrate significant structural differences among cooperatives (Table 2). Approximately 90% of the cooperatives operate irrigation systems developed by multiple institutions, reflecting a fragmented investment and management structure. Such fragmentation may create coordination problems in operation, maintenance, rehabilitation, and infrastructure modernization processes.

Table 2. Institutional characteristics of irrigation cooperatives

Indicator	Category	Cooperatives (n)	Ratio (%)
Investment structure	Multi-institution investment	45	90.00
	Single institution investment	5	10.00
Union membership	Member	28	56.00
	Non-member	22	44.00
Staff availability	Available	34	68.00
	Not available	16	32.00
Technical staff	Yes	28	56.00
	No	22	44.00

In addition, institutional integration remains relatively limited, as only 56% of the cooperatives are affiliated with regional unions. Weak organizational integration may reduce access to technical support, collective decision-making mechanisms, and institutional capacity development opportunities. Similarly, although 68% of cooperatives employ paid staff, only 56% employ technical personnel, indicating that technical and managerial capacity remains insufficient in a substantial proportion of the cooperatives.

These findings indicate that irrigation cooperatives in Central Anatolia exhibit considerable heterogeneity in terms of organizational structure, technical capacity, and institutional development. Such differences are likely to directly influence irrigation management performance, water allocation practices, infrastructure sustainability, and adaptation capacity under increasing drought and water scarcity conditions.

Water Source and Irrigation Infrastructure

The results demonstrate that irrigation systems in the Central Anatolia Region are predominantly dependent on groundwater resources. Approximately 72% of the sampled cooperatives rely exclusively on groundwater, whereas 20% use surface water and only 8% operate mixed systems (Table 3). This distribution reflects both the limited availability of surface water resources and the increasing dependence on groundwater under semi-arid climatic conditions.

The widespread use of groundwater-based irrigation systems in the region is closely associated with the increasing impacts of drought, irregular precipitation regimes, and insufficient surface water availability. Particularly in the Konya Closed Basin, groundwater has become the primary source for sustaining agricultural production. However, this dependency also creates serious sustainability concerns, including declining groundwater levels, increasing pumping depths, rising energy costs, and sinkhole formations observed in recent years.

The analysis further shows that water source characteristics strongly influence irrigation conveyance infrastructure. Groundwater-based systems are largely associated with pressurized irrigation infrastructure, with approximately 88.60% of groundwater-based cooperatives using closed pressurized systems. This is primarily due to the technical compatibility between pumping systems and sprinkler/drip irrigation methods. In contrast, surface water-based systems exhibit a more diversified structure and continue to rely partially on open canal conveyance systems.

Statistical analysis confirms a significant relationship between water source and irrigation conveyance system (χ^2 (df, N = 50) = 72.50, $p < 0.001$). This result demonstrates that water source is not only a hydrological variable but also a major determinant shaping irrigation infrastructure, operational practices, and water management strategies.

From a management perspective, pressurized irrigation systems provide more controlled water delivery and generally support higher irrigation performance and water use efficiency. However, these systems simultaneously increase dependency on energy inputs and expose irrigation cooperatives to rising operational costs. Conversely, open canal systems reduce energy requirements but are generally associated with higher conveyance losses, lower control capacity, and maintenance problems.

These findings are consistent with previous studies emphasizing that irrigation infrastructure and operational performance are strongly influenced by water source characteristics and system design (Bos et

Table 3. Distribution of water sources and conveyance systems

Water Source	Cooperatives (n)	Ratio (%)	Pressurized (%)	Open canal (%)	Mixed (%)
Groundwater	36	72.00	88.60	2.90	8.50
Surface water	10	20.00	50.00	37.50	12.50
Mixed	4	8.00	20.00	20.00	60.00
Total	50	100.00	86.00	2.00	12.00

al., 2005; Molden et al., 1998). However, unlike many previous studies focusing on limited irrigation schemes, the present study demonstrates these relationships at a broader regional scale using field-based cooperative data.

Similar findings have also been reported in previous studies conducted in Türkiye. Çakmak (2001) and Yazgan and Değirmenci (2002) emphasized that groundwater-based irrigation systems generally improve irrigation reliability and facilitate the adoption of pressurized irrigation methods, particularly in semi-arid regions. However, these studies also highlighted increasing concerns regarding energy costs, groundwater depletion, and long-term sustainability risks associated with intensive groundwater use.

Water Management: Measurement and Pricing

Effective irrigation management depends largely on the ability to accurately measure water use and implement appropriate pricing mechanisms. In this context, water measurement practices and water pricing systems were evaluated together to better understand water governance practices in irrigation cooperatives.

The findings indicate that water measurement practices vary significantly depending on water source characteristics. Measurement systems are more common in groundwater-based cooperatives, mainly because pumping systems facilitate the monitoring of water abstraction and irrigation duration. In contrast, measurement infrastructure remains limited in surface water systems, where open canal conveyance structures complicate accurate water measurement and monitoring processes (Figure 2).

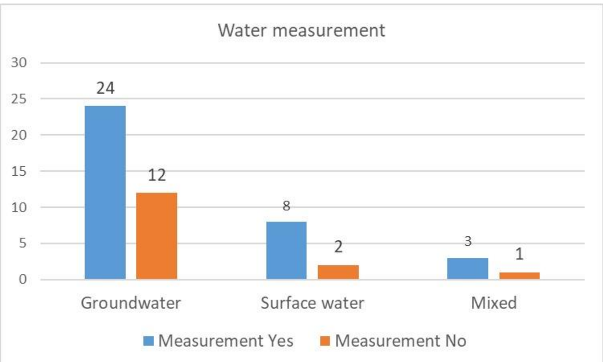

Figure 2. Distribution of irrigation cooperatives using water measurement by water source (n)

The analysis also demonstrates a strong relationship between water measurement infrastructure and pricing methods. Cooperatives with water measurement systems are more likely to implement volumetric pricing methods (per m³), allowing a closer relationship between water consumption and irrigation cost. However, in systems lacking measurement infrastructure, water pricing is generally based on irrigation duration (TL h^{-1}) or irrigated area (TL ha^{-1}), which weakens incentives for efficient water use (Table 4).

Time-based pricing remains the dominant pricing method in the region (70%), particularly in groundwater-based systems where energy consumption is directly linked to pumping duration. Volumetric pricing remains very limited (6%), despite its potential contribution to water-saving behavior and sustainable water management.

Table 4. Water pricing methods used in irrigation cooperatives

Pricing Methods	Cooperatives (n)	Ratio (%)
Time-based (TL h^{-1})	35	70.00
Area-based (TL ha^{-1})	6	12.00
Volumetric (TL m^{-3})	3	6.00
Mixed systems	6	12.00
Total	50	100.0

The limited adoption of measurement-based pricing systems reflects broader institutional and infrastructural deficiencies in irrigation management. Similar findings have been reported in previous studies indicating that inadequate measurement infrastructure limits the implementation of efficient water allocation and pricing mechanisms (OECD, 2015; Perry, 2007).

These findings are particularly important under increasing drought and water scarcity conditions. Without reliable water measurement systems, improving irrigation efficiency, implementing water-based production planning, and promoting sustainable groundwater management become considerably more difficult. Similar problems related to insufficient water measurement infrastructure and the limited use of volumetric pricing systems have also been emphasized in irrigation management studies conducted in Türkiye (Değirmenci, 2001; Elicabuk, 2017). These studies reported that the dominance of traditional time-based pricing methods reduces incentives for efficient water use and complicates sustainable water management practices.

Irrigation Performance and Irrigation Methods

Irrigation performance was evaluated using irrigated area, actual irrigated area, and irrigation ratio indicators. The results indicate that irrigation performance varies considerably according to water source characteristics (Table 5).

Groundwater-based cooperatives exhibit the highest irrigation ratio (82.14%), followed by surface water systems (71.79%) and mixed systems (67.82%). Higher irrigation performance in groundwater systems can largely be attributed to the relatively reliable and controllable nature of pumped water supply, which facilitates more flexible irrigation scheduling and supports the widespread adoption of pressurized irrigation systems.

However, although groundwater-based systems demonstrate higher irrigation performance, these results should not be interpreted solely as an indicator of sustainability. The intensive use of groundwater resources may improve short-term irrigation reliability while simultaneously increasing long-term risks related to groundwater depletion, energy dependency, and environmental sustainability.

The distribution of irrigation methods further supports these findings. Sprinkler irrigation (64.40%) and drip irrigation (34.88%) dominate the region, while surface irrigation remains extremely limited (0.73%). This indicates a significant transition toward pressurized irrigation technologies, particularly in groundwater-dependent systems.

Table 5. Irrigation performance and methods by water source

Water Source	Irrigated Area (ha)	Actual Irrigated (ha)	Irrigation Ratio (%)	Flood irrigation (%)	Sprinkler irrigation (%)	Drip irrigation (%)
Groundwater	40,235.0	33,055.5	82.14	0.00	62.89	37.11
Surface water	5,492.1	3,942.5	71.79	2.54	73.94	23.53
Mixed	1,740.0	1,180.0	67.82	12.71	69.49	17.80
Total	47,467.1	38,178.0	80.43	0.73	64.40	34.88

Nevertheless, the persistence of surface irrigation practices in some surface water and mixed systems indicates that infrastructure modernization remains incomplete. In such systems, open canal conveyance structures, insufficient measurement infrastructure, and limited control capacity may reduce water use efficiency and increase conveyance losses.

Although mixed systems exhibited certain structural differences, these findings should be interpreted cautiously due to the limited sample size of this group.

Overall, the results demonstrate that irrigation performance is strongly shaped by water source characteristics, infrastructure conditions, and irrigation management practices. Similar relationships between pressurized irrigation systems and improved irrigation performance have been emphasized in previous studies (Bos et al., 2005; Burt & Styles, 2001).

Similar results were also reported in studies conducted in Türkiye, where groundwater-based pressurized irrigation systems were found to improve irrigation performance and irrigation reliability under semi-arid climatic conditions (Çakmak, 2001; Şener, 2011). However, these studies similarly emphasized that higher irrigation performance in groundwater-dependent systems may increase long-term sustainability risks due to excessive groundwater abstraction and rising energy costs.

Major Problems of Irrigation Cooperatives

The analysis of major operational problems reveals that irrigation cooperatives face multiple technical, financial, and managerial constraints, many of which differ according to water source type (Table 6).

Table 6. Major problems faced by irrigation cooperatives

Problem	Groundwater (%)	Surface water (%)	Mixed (%)
High energy cost	95.00	70.00	80.00
Water scarcity	80.00	85.00	75.00
Maintenance issues	45.00	35.00	40.00
Rehabilitation need	35.00	50.00	30.00
Infrastructure problems	30.00	55.00	35.00
Equipment shortage	35.00	40.00	30.00
Pre-harvest payment	40.00	30.00	45.00
Low farmer participation	25.00	15.00	35.00

Note: Percentages may exceed 100% as multiple responses were allowed

High energy costs emerge as the most critical problem, particularly in groundwater-based cooperatives, where approximately 95% of respondents identified energy expenditures as a major constraint. This finding reflects the strong dependency of groundwater irrigation systems on pumping technologies and highlights the growing vulnerability of irrigation cooperatives to increasing energy prices.

Water scarcity represents another major challenge, especially in surface water-based systems, where seasonal fluctuations, insufficient storage capacity, and drought-related reductions in water availability directly affect irrigation reliability. Although groundwater systems provide relatively more stable water supply, long-term over-abstraction may create significant sustainability risks.

Infrastructure-related problems, including rehabilitation needs and maintenance deficiencies, are more prominent in surface water systems due to the aging of open canal infrastructure and insufficient modernization investments. These findings indicate that irrigation infrastructure modernization remains an important policy priority in the region.

In addition to technical problems, several institutional and managerial challenges were identified. Limited farmer participation, insufficient technical capacity, and financial constraints negatively affect the operational sustainability of irrigation cooperatives. These findings also demonstrate that irrigation management problems cannot be explained solely by hydrological conditions but must also be evaluated within broader institutional and governance frameworks.

The findings further suggest that irrigation cooperatives in Türkiye continue to operate under limited monitoring and evaluation capacity. The inability to systematically calculate advanced performance indicators such as irrigation efficiency, water productivity, and financial sustainability indicators reflects broader institutional deficiencies in data collection and monitoring systems. This institutional gap represents an important obstacle for evidence-based irrigation management and sustainable water governance.

Overall, the results indicate that irrigation cooperatives require not only technical infrastructure improvements but also stronger institutional support, monitoring systems, energy management policies, and water governance strategies under increasing drought and climate change pressures.

These findings are consistent with previous studies emphasizing that groundwater dependency, rising energy costs, and water scarcity are among the most critical constraints affecting irrigation sustainability in semi-arid regions (Turral et al., 2010; World Bank, 2006).

Similar institutional and operational problems have also been identified in irrigation management studies conducted in Türkiye. Previous studies emphasized that high energy costs, inadequate infrastructure modernization, insufficient monitoring systems, and limited technical capacity negatively affect the operational sustainability of irrigation organizations, particularly in groundwater-dependent irrigation systems (Çetin, 2021; Tanrıverdi, 2011). These findings indicate that sustainable irrigation management requires not only physical infrastructure investments but also stronger institutional capacity and monitoring systems.

Conclusion and Policy Implications

This study provides a regional-scale evaluation of irrigation cooperatives operating in the Central Anatolia Region of Türkiye by comparatively examining the relationships between water source, irrigation infrastructure, water management practices, irrigation performance, and major operational problems.

The findings demonstrate that water source is one of the main factors shaping both the technical and institutional characteristics of irrigation systems. Groundwater-based cooperatives generally exhibit higher irrigation performance due to relatively reliable water supply conditions and the widespread use of pressurized irrigation systems. However, these systems also face increasing energy dependency, rising operational costs, and long-term sustainability risks associated with groundwater depletion. In contrast, surface water-based cooperatives are more vulnerable to climatic variability, infrastructure deficiencies, and seasonal water shortages, resulting in relatively lower irrigation performance.

The study further reveals that water measurement infrastructure and volumetric pricing systems remain insufficiently developed in the region. The dominance of traditional time-based pricing systems limits incentives for efficient water use and reduces the effectiveness of sustainable irrigation management strategies. In addition, the continued cultivation of water-intensive crops further increases pressure on limited water resources, particularly under increasing drought conditions in Central Anatolia.

Another important finding is the considerable institutional heterogeneity among irrigation cooperatives in terms of technical capacity, infrastructure conditions, and management practices. Limited institutional integration, insufficient technical personnel, fragmented infrastructure investments, and weak monitoring systems negatively affect the operational sustainability of irrigation cooperatives.

One of the major contributions of this study is highlighting the lack of systematic monitoring and evaluation systems for irrigation cooperatives in Türkiye. The absence of consistent institutional records restricts the calculation of important performance indicators such as irrigation efficiency, water productivity, and financial sustainability measures. This institutional data gap represents a significant limitation for evidence-based irrigation governance, sustainable water management, and climate change adaptation policies.

In this context, improving water measurement infrastructure, expanding volumetric pricing systems, modernizing irrigation networks, promoting energy-efficient irrigation technologies, and strengthening technical and institutional capacity should be considered priority areas for sustainable irrigation management. Particularly in groundwater-dependent regions, sustainable groundwater management should become an integral component of agricultural and water governance policies under increasing climate change and water scarcity pressures.

Overall, the findings of this study provide valuable empirical evidence for policymakers, irrigation managers, and researchers seeking to improve irrigation sustainability and water governance in semi-arid regions.

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Authorship Contribution

M.T.: Conceptualization of the study, methodology development, coordination of field experiments, data validation, investigation, manuscript review, and editing. **S.N.T.A.:** Conceptualization of the study, methodology development, data analysis, data curation, interpretation of the results, preparation of the original manuscript draft, manuscript revision, and final editing.

Conflict of Interest

No potential conflict of interest was reported by the authors

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