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Performance Evaluation of Irrigation Efficiency, Managerial Effectiveness, and Water Economic Productivity in Consolidated Agricultural Lands: A Case Study of the Gündüzler Irrigation Scheme

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ABSTRACT

This study evaluates the performance of the Gündüzler Irrigation Scheme, developed in a fully land-consolidated agricultural area in the Tepebaşı district of Eskişehir Province, with a focus on irrigation efficiency, managerial effectiveness, and the economic productivity of water use. The construction of the piped irrigation system was completed in 2022, and the scheme became operational in 2023 under the institutional management of the Eskişehir Water User Association. Technical and economic data from the 2023 and 2024 irrigation seasons were analyzed to assess the early operational outcomes of the system. The results showed that the irrigation ratio increased from 66% to 92%, while the water supply ratio decreased from 0.55 to 0.40, indicating broader irrigation coverage despite tighter water supply conditions. The irrigated area expanded from 688 to 967 ha, and the Cost Recovery Ratio (CRR) increased from 113% to 298%. Although income per irrigated area declined slightly, income per unit volume of supplied irrigation water improved from 0.41 to 0.53 US$ m^{-3}. Managerial performance was also notable, with nearly 1,000 ha irrigated per staff member in 2024. Although the study does not provide a direct before-and-after comparison of irrigation performance attributable solely to land consolidation, background data indicate substantial improvements in parcel structure, average parcel size, and road accessibility following land consolidation. These improvements created favorable structural conditions for the implementation of a piped irrigation system. Overall, the findings suggest that land consolidation, when completed prior to irrigation infrastructure development, can play an enabling role in supporting efficient water distribution, reducing conveyance losses, and improving system-wide coordination. The Gündüzler case provides a useful reference for future irrigation investments in semi-arid agricultural regions facing water scarcity and operational constraints.

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Introduction

Agricultural irrigation remains the largest consumer of freshwater globally, accounting for nearly 70% of total water withdrawals a ratio similarly high in Türkiye (FAO, 2020). Ensuring the efficient, economical, and sustainable use of water in agriculture has become increasingly critical in the face of rising population, climate change, and growing water scarcity (Berbel et al., 2019). In this context, not only the technical adequacy but also the managerial performance of irrigation systems plays a decisive role in the overall efficiency of agricultural production.

In Türkiye, irrigation development and operation are primarily carried out by the State Hydraulic Works (DSI), with increasing involvement of Water User Associations (WUAs) for the operation and maintenance (O&M) of facilities. Performance evaluation indicators such as irrigation efficiency, cost recovery, and water distribution equity have gained prominence in recent studies (Arslan et al., 2023; Tanışıklı & Çakmak, 2023; Harman & Çakmak, 2023; Çetin et al., 2024).

Land consolidation projects (LCP), on the other hand, have long been recognized as a strategic intervention to reduce land fragmentation and improve both infrastructural and managerial efficiency in rural areas. By rectifying irregular and dispersed land parcels, LCP facilitates the design and implementation of technically sound and cost-effective irrigation infrastructure (Uçar & Kara, 2006; Kırmıkıl & Arıcı, 2013; Fayrap et al., 2018; Eğilmez & Kaman, 2022). Recent studies have also demonstrated the broader contributions of LCP to the economic sustainability of irrigation projects and to environmental performance under climate variability (Fader et al., 2016; Frey et al., 2024).

Several studies have shown that consolidated areas enable more streamlined irrigation layouts, reduced expropriation costs, and better alignment between field geometry and on-farm irrigation systems (Peker & Dağdelen, 2016). For instance, Küsek (2014) emphasized that LCP prior to project implementation leads to significant reductions in overall investment costs and hydraulic complexity.

While previous research has mainly focused on the cost-saving effects of LCP in the design stage of piped irrigation systems such as reduced pipeline lengths, minimized elevation differences, and optimized hydraulic layouts as demonstrated by Arslan et al. (2024) in their national case study and by other scholars (Ertunç, 2020; Akdeniz et al., 2023), few studies have evaluated the actual operational performance of newly implemented irrigation schemes in post-consolidation areas.

This study aims to fill this gap by presenting a comprehensive performance evaluation of the Gündüzler Irrigation Scheme, a recently commissioned piped irrigation system constructed entirely within a consolidated agricultural area in Tepebaşı District, Eskişehir. Unlike comparative cost simulations based on pre- and post-consolidation layouts, this study focuses on real-world indicators such as irrigation water use efficiency (WUE), management effectiveness, and water economic productivity (WEP) during the 2023–2024 irrigation seasons.

The site-specific context of this project also reflects DSI's recent strategic shift toward a "consolidation-first, infrastructure-later" approach, where land consolidation is completed before irrigation infrastructure is built. While the study does not compare consolidated versus non-consolidated areas directly (due to the absence of a previous irrigation scheme in the region), it evaluates the outcomes of this integrated planning model by benchmarking performance indicators with other irrigation schemes in the region.

In this context, the present study examines the Gündüzler Irrigation Scheme, established in a land-consolidated agricultural area, with respect to technical, managerial, and economic performance indicators. Based on data from the 2023 and 2024 irrigation seasons, the study focuses on irrigation efficiency, water supply conditions, managerial cost structure, and economic productivity of water use. The study thereby provides an empirical assessment of irrigation performance in a newly commissioned piped system operating under land-consolidated conditions in semi-arid Türkiye.

Materials and Methods

Description of the Study Area

This study was conducted in the Gündüzler Irrigation Scheme, located within the administrative boundaries of Tepebaşı District in Eskişehir Province, Central Anatolia Region of Türkiye (Figure 1). The total irrigation area of the scheme is 1,050 hectares. The scheme was designed and constructed under the responsibility of the 3rd Regional Directorate of the State Hydraulic Works (DSI) and officially started operation in the 2023 irrigation season.

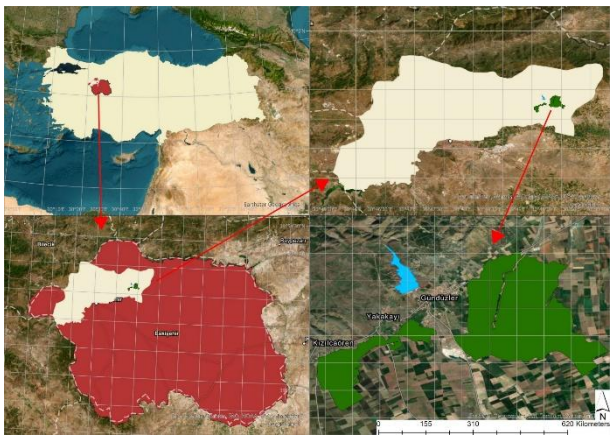

Figure 1. Location of the Gündüzler Irrigation Scheme in Tepebaşı District, Eskişehir Province, Türkiye
Green areas: irrigated lands; Blue area: reservoir catchment of the dam

The irrigation system was established entirely within an area where LCP had been completed prior to construction. The consolidated status of the region allowed for a planned and systematic infrastructure design, including optimized parcel geometry, improved road and well-organized field arrangements. As a result, the scheme facilitates efficient water distribution and infrastructure-based modernization of the area.

Water is supplied to the irrigation network from the Gündüzler Dam, which has a maximum usable storage capacity of 7.8 hm³. The dam is fed exclusively by rainfall and lacks a continuous base flow throughout the year, resulting in a seasonal reservoir recharge pattern that directly affects water availability during the irrigation season. All water deliveries are conducted by gravity flow, meaning that no energy or pumping systems are required to distribute water within the main network. Consequently, the system is better classified as a piped irrigation system rather than a pressurized system in the conventional sense.

Although sprinkler and drip irrigation methods are used in on-farm applications, these are implemented without the need for pressure pumps due to the network's topography and gravity-fed design. Surface irrigation methods are not used in this scheme.

The irrigation system is operated and maintained by the Eskişehir Water User Association (WUA), which is also responsible for fee collection and system supervision. The WUA applies a prepaid volumetric pricing system: water users are required to pre-load credits into smart meters before irrigation, and the system automatically deducts the volume used. This approach strengthens financial discipline, enables better water use monitoring, and prevents unauthorized irrigation.

Due to these characteristics, the Gündüzler scheme serves as a representative pilot area for evaluating post-consolidation infrastructure, digital monitoring systems, modern water delivery methods, and data-based irrigation management.

Land Consolidation Features

The Gündüzler Irrigation Scheme was developed entirely within an area where land consolidation was completed prior to the construction of irrigation infrastructure. The land consolidation project, conducted by the General Directorate of Agricultural Reform, was finalized in 2017 and covered the entire Gündüzler village.

Before consolidation, the area suffered from fragmented and irregular plots with limited road access, complicating both agricultural operations and infrastructure development. After consolidation, significant improvements were made in parcel size, shape, and layout, as well as in road accessibility. These changes laid the groundwork for a systematically planned piped irrigation system, enabling efficient water distribution and modern on-farm irrigation practices.

The performance outcomes of land consolidation are further evaluated in the findings section. Figures 2 illustrate the parcel layout before and after land consolidation, respectively.

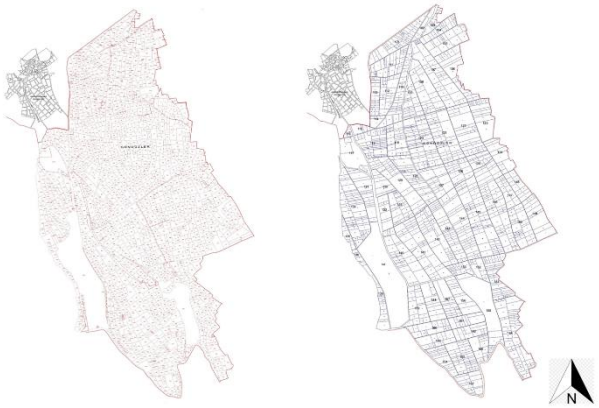

Figure 2. Parcel Layout Before (Left) and After (Right) Land Consolidation

Data and Sources

This study evaluated the technical, managerial, and economic performance indicators of the Gündüzler Irrigation Scheme for the years 2023 and 2024. Data were obtained from the official records of the 3rd Regional Directorate of State Hydraulic Works (DSI) and the Eskişehir Provincial Directorate of Agriculture and Forestry (DSI, 2025; E-ITOM, 2025).

The data used in the analysis are grouped into three main categories:

Technical Data:

The crop patterns and irrigation water requirements for the irrigated area were compiled for both years. Irrigation was applied to a total of 688 ha in 2023 and 967 ha in 2024. The major crops cultivated were wheat and maize, with wheat showing a significant increase in 2024.

The irrigation water requirement data used in this study were obtained directly from the official records of the 3rd Regional Directorate of the State Hydraulic Works (DSI). These values were not recalculated from year-specific real-time climatic observations for 2023 and 2024. Instead, they represent the irrigation water requirement values used in the original project design and in official operational reports prepared by the General Directorate of State Hydraulic Works. In order to remain consistent with the design and operational framework of the scheme and to ensure comparability in performance assessment, the analysis was based on the long-term climatic averages officially adopted by DSI, derived from approximately 50 years of climatic observations prior to 2011. These values were originally calculated using the Blaney–Criddle (USDA-SCS) approach, which has long been used by DSI in irrigation project planning and operation reports. Therefore, the required water values used in this study reflect the institutional planning basis applied in practice, rather than a new crop water requirement dataset recalculated specifically for this research.

This approach was preferred because the main objective of the study was to evaluate scheme performance under the actual institutional and managerial conditions used by DSI in project design and operation.

Table 1 summarizes the cultivated area and corresponding irrigation water requirements.

The irrigation water requirement data used in this study are expressed as u – r (mm), where u denotes the crop water requirement and r denotes effective rainfall. Accordingly, u – r represents the total irrigation water requirement after accounting for effective rainfall.

Table 1. Irrigation Water Requirement after Effective Rainfall, u – r (mm)

Crop Type	2023 (ha)	2024 (ha)	Total Irrigation Water Requirement (u-r, mm)
Wheat	79	525	364.8
Dry Bean	–	3	588.7
Melon	11	1	316.3
Sugar Beet	30	14	899.1
Sunflower	177	90	515.1
Maize	254	256	674.0
Apple	1	7	628.4
Tomato	35	15	792.8
Potato	34	6	629.0
Onion	61	45	693.8
Alfalfa	6	5	777.4
Total	688	967	–

Technical and Managerial Performance Data:

The technical and managerial data cover irrigated area, delivered and required water volumes, irrigation methods, and personnel (Table 2). No surface irrigation methods were used; only sprinkler and drip irrigation systems were applied across the scheme.

The entire system is operated via a gravity-fed piped irrigation network sourced from Gündüzler Dam, which eliminates the need for energy-intensive pressurization. Water delivery and monitoring are managed through smart prepaid meters, where users must pre-load water credit, allowing volumetric tracking and cost-effective water use control.

Economic Performance Data:

Economic data included (Table 3):

- Labor costs,
- Maintenance, operation, and management (MOM) costs,
- Irrigation fee collection and accrual,
- Total annual crop production value.

These values were used to compute several economic performance indicators such as Cost Recovery Ratio, Maintenance Cost to Revenue Ratio (MCIR), and water economic productivity indicators.

Table 2. Data Used for Technical and Managerial Performance Analysis

Year	Irrigation Area (ha)	Irrigated Area (ha)	Delivered Water (m^3)	Required Water (m^3)	Personnel (person)	Sprinkler Irrigation (ha)	Drip Irrigation (ha)
2023	1050	688	2,340,000	4,220,000	1	529.8	158.2
2024	1050	967	1,980,000	4,890,000	1	782.4	184.6

Table 3. Data Used for Managerial and Economic Performance Analysis

Year	Labor Cost (US$)	Collected Water Fee (US$)	MOM Cost (US$)	Maintenance Cost (US$)	Accrued Water Fee (US$)	Annual Production Value (US$)
2023	15,038	19,799	17,565	299	19,799	961,099
2024	36,850	136,277	45,685	2,407	136,277	1,053,058

All economic data were reported in US dollars (US$) using the official exchange rate of the Central Bank of the Republic of Türkiye (CBRT) on the first business day of July for each year. July was selected as the reference month for exchange rate conversion because this study assesses annual irrigation scheme performance at the system level rather than crop-specific post-harvest returns. Input costs are incurred progressively throughout the production season, not exclusively during harvest months. Moreover, harvest periods differ among crops; for example, wheat is harvested in July, whereas other crops are harvested later in the season. July was thus adopted as a standardized reference month within the active irrigation season.

Performance Indicators and Analysis Method

The performance of the Gündüzler Irrigation Scheme for the 2023 and 2024 irrigation seasons was evaluated using a comparative annual analysis approach. Technical, managerial, and economic indicators were analyzed separately within a multi-criteria framework (Burton et al., 2000; Malano & Burton, 2001; Harman & Çakmak, 2025; Harman, 2026).

Definition of Indicators:

The indicators used in this study were grouped into four categories: technical, managerial, economic, and land-consolidation-related indicators. Their definitions and formulas are presented below.

Irrigation Water Use Efficiency Indicators:

Water Delivered per Controlled Area (WDCA, m^3 ha^{-1}):

$$WDCA = \frac{Total\ irrigation\ water\ delivered\ (m^3)}{Total\ controlled\ area\ (ha)} \quad (1)$$

Water Delivered per Irrigated Area (WDIA, m^3 ha^{-1}):

$$WDIA = \frac{Total\ irrigation\ water\ delivered\ (m^3)}{Total\ irrigated\ area\ (ha)} \quad (2)$$

Water Supply Ratio (WSR):

$$WSR = \frac{Total\ irrigation\ water\ delivered\ (m^3)}{Total\ water\ requirement\ (m^3)} \quad (3)$$

Irrigation Ratio (IR, %):

$$IR = \frac{Irrigated\ area\ (ha)}{Irrigation\ area\ (ha)}\ x\ 100 \quad (4)$$

Managerial Efficiency Indicators:

Cost Recovery Ratio (CRR, %):

$$CRR = \frac{Total\ water\ fee\ collected\ (US\$)}{TOMMC}\ x\ 100 \quad (5)$$

TOMMC: Total operation maintenance and management costs (US$)

Maintenance Cost to Revenue Ratio (MCIR, %):

$$MCIR = \frac{Total\ maintenance\ costs\ (US\$)}{Total\ water\ fee\ collected\ (US\$)}\ x\ 100 \quad (6)$$

Total Management, Operation and Maintenance (MOM) cost per irrigated Area (MOMI, US$ ha^{-1}):

$$MOMI = \frac{TMOMC}{Irrigated\ area\ (ha)}\ x\ 100 \quad (7)$$

TMOMC: Total management, operation and maintenance cost (US$)

Revenue Collection performance (PWF, %):

$$PWF = \frac{Total\ water\ fee\ collected\ (US\$)}{Total\ water\ fee\ invoiced\ (US\$)}\ x\ 100 \quad (8)$$

Labor Cost per Irrigated Area (LCIA, US$ ha^{-1}):

$$LCIA = \frac{Total\ labor\ cost\ (US\$)}{Irrigated\ area\ (ha)}\ x\ 100 \quad (9)$$

Irrigated Area per Labor (IAL, ha $person^{-1}$):

$$IAL = \frac{Irrigated\ area\ (ha)}{Number\ of\ personnel\ (person)}\ x\ 100 \quad (10)$$

Water Economic Productivity Indicators:

Output per Command Area (IUA, US$ ha^{-1}):

$$IUA = \frac{Annual\ production\ value\ (US\$)}{Irrigation\ area\ (ha)} \quad (11)$$

Income per Irrigated Area (IUIA, US$ ha^{-1}):

$$IUIA = \frac{Annual\ production\ value\ (US\$)}{Irrigated\ area\ (ha)} \quad (12)$$

Output per Unit Irrigation Water Delivered (IUITN, US$ m^{-3}):

$$IUITN = \frac{Annual\ production\ value\ (US\$)}{Total\ irrigation\ water\ delivered\ (m^3)} \quad (13)$$

Income per Unit Net Irrigation Water Requirement (IUIWC, US$ m^{-3}):

$$IUIWC = \frac{Annual\ production\ value\ (US\$)}{TNWR} \quad (14)$$

TNWR: Total net irrigation water requirement (m^3)

Land Consolidation Performance Indicators:

To assess the structural and functional impacts of land consolidation project (LCP) on the irrigation scheme, a comparative analysis was conducted using official records from the General Directorate of Agricultural Reform (TRGM) and project reports obtained from the State Hydraulic Works (DSI). The evaluation focuses on several key indicators related to spatial configuration and infrastructure feasibility before and after the implementation of LCP in the Gündüzler area.

Parcel Reduction Rate (%):

This indicator evaluates the extent of plot amalgamation. It was calculated as:

$$PRR = \left(\frac{(NP_B - NP_A)}{NP_B}\right) \times 100 \quad (15)$$

PRR: Parcel Reduction Rate (%)
NP_B: Number of Parcel$_{Before\ LCP}$
NP_A: Number of Parcel$_{Before\ LCP}$

Average Parcel Size Increase (%):

This reflects the improvement in average landholding size per parcel, using the formula:

$$APS = \left(\frac{(PS_B - PS_A)}{PS_B}\right) \times 100 \quad (16)$$

APS : Average Parcel Size Increase (%)
PS_B : Parcel Size$_{Before\ LCP}$
PS_A : Parcel $_{SizeAfter\ LCP}$

Legal Road Access Ratio (%):

Calculated by dividing the number of parcels with formal road access by the total number of parcels, both before and after LCP.

$$LRAR = \left(\frac{\text{Parcels with Road Access}}{Total\ Parcels}\right) \times 100 \quad (17)$$

LRAR: Legal Road Access Ratio (%)

Data Transformation and Calculation Method:

Technical data were obtained from the annual evaluation reports of DSI (2025), while annual production values were retrieved from the Eskişehir Provincial Directorate of Agriculture and Forestry via official correspondence (E-ITOM, 2025). The total production value was calculated by multiplying the cultivated area for each crop with its unit market value. All values expressed in Turkish Lira (TRY) were converted into US dollars (US$) based on the exchange rate published by the Central Bank of the Republic of Türkiye (CBRT) on the first business day of July in the respective year.

Comparative Yearly Analysis:

All indicators for the years 2023 and 2024 were presented side by side in tabular format and interpreted together with the percentage changes. This allowed a quantitative assessment of the performance development trend between the first operational year (2023) and the subsequent year (2024).

Graphical and Visual Applications:

To enhance the visibility of indicator variations, dual comparative graphs (e.g., combined bar and line charts) were used. Additionally, indicators such as income-to-water usage relationships, area-to-water distribution patterns, and cost recovery trends were supported by visual data representation techniques.

Results

In this section, the performance indicators of the Gündüzler Irrigation Scheme for the years 2023 and 2024 are comparatively evaluated. The results related to technical, managerial, economic indicators and land consolidation situation are summarized under the following sub-sections.

Technical Performance Results

The irrigation water use efficiency of the Gündüzler Irrigation Scheme showed notable changes between 2023 and 2024. Table 4 presents a comparative summary of the four main technical indicators evaluated.

Between 2023 and 2024, WDCA decreased by approximately 15%, indicating that a larger share of the irrigation area was served with a lower volume of delivered water. Similarly, WDIA declined by about 40%, reflecting a lower amount of water delivered per irrigated hectare. However, these decreases should not be interpreted directly as an improvement in irrigation efficiency. The Water Supply Ratio (WSR) also declined from 0.55 to 0.40, indicating that only 40% of the estimated irrigation water requirement was met in 2024 and pointing to increasing water stress within the scheme.

Despite this tighter water supply, the Irrigation Ratio (IR) increased markedly from 66% to 92%, showing that irrigation coverage expanded substantially in 2024. This pattern indicates that the scheme maintained broader operational coverage under constrained water availability. Field observations suggested that farmers responded to anticipated water limitations by shifting toward lower-water-demand crops, particularly wheat, and by relying more on sprinkler and drip irrigation practices. In addition, irrigation scheduling was applied more selectively in order to reduce drought-related losses during critical crop growth stages.

Table 4. Irrigation Water Use Efficiency Indicators*

Years	WDCA (m^3 ha^{-1})	WDIA (m^3 ha^{-1})	WSR	IR (%)
2023	2,229	3,401	0.55	66
2024	1,886	2,048	0.40	92

*(2023–2024)

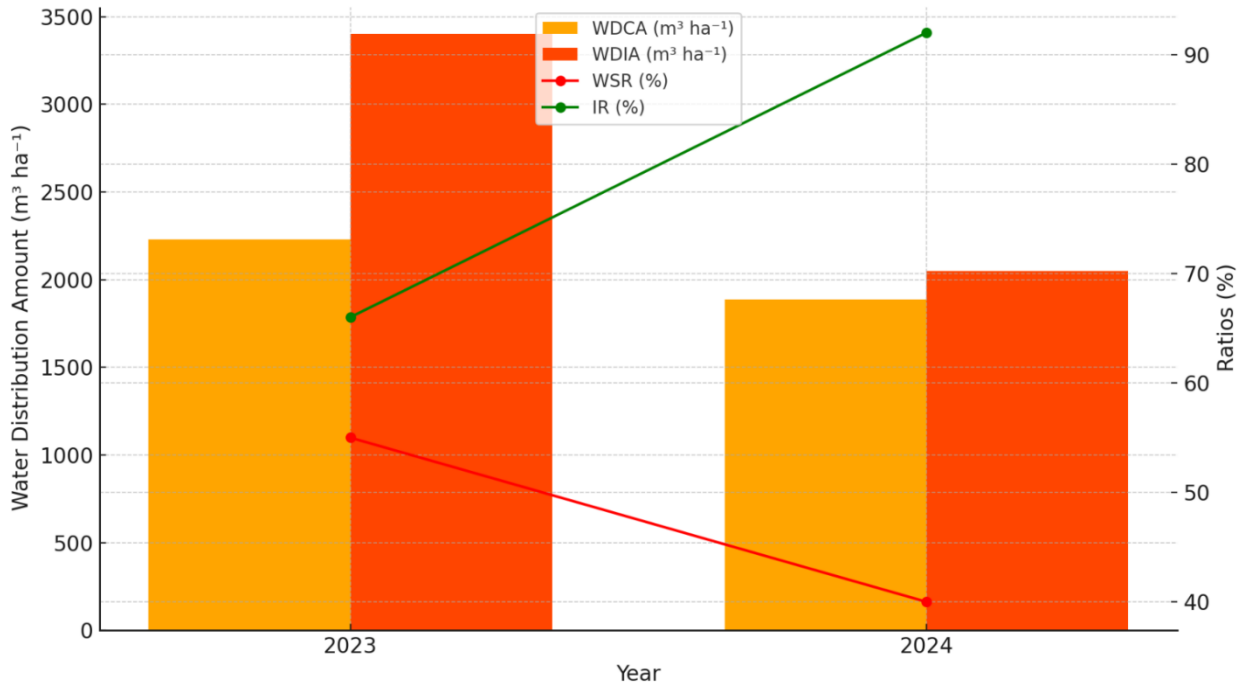

Figure 3. Comparison of Irrigation Water Use Efficiency Indicators for 2023 and 2024

Table 5. Managerial Performance Indicators of the Irrigation Organization (2023–2024)

Years	CRR	MCIR	MOM	PWF	LCIA	IAL
2023	113%	2%	25.53	100%	21.86	688
2024	298%	2%	47.24	100%	38.11	967

CRR: Cost Recovery Ratio (%); MCIR: Maintenance Cost to Revenue Ratio (%); MOM: Total MOM Cost (US$ ha^{-1}); PWF: Collection Performance of Water Fee, PWF (%); LCIA: Labor Cost LCIA (US$ ha^{-1}); IAL: Irrigated Area per Labor IAL (ha person^{-1})

These field-level responses were supported by the piped infrastructure of the scheme and by the structural advantages created through land consolidation, which facilitated the adoption of on-farm piped irrigation systems under more regular parcel geometry and improved road access.

Overall, the results indicate adaptive operational management under water-limited conditions; however, the pronounced decline in WSR clearly shows that the scheme experienced severe water stress in 2024, which may pose risks for long-term agricultural productivity (Figure 3).

Managerial Performance Findings

The indicators related to the managerial efficiency of the irrigation organization are presented in Table 5. These indicators were used to assess the financial sustainability, cost management, and labor efficiency of irrigation services.

Cost Recovery Ratio (CRR) indicator rose sharply from 113% in 2023 to 298% in 2024. This increase reflects a financial situation where revenues collected from water fees significantly exceeded the annual expenditures for operation, maintenance, and management (MOM). The observed rise is mainly attributed to the fact that the irrigation scheme was newly commissioned, and maintenance needs remained minimal during the first two years of operation. Since the infrastructure was not yet subject to major repairs, component replacements, or system inefficiencies, operating costs were naturally low. In this context, the irrigation organization was able to achieve a financial surplus, as water service fees collected from users were more than sufficient to cover MOM expenses. Nevertheless, this favorable balance is likely to change in future years as the infrastructure begins to age and maintenance demands increase. The current high CRR value is thus best interpreted as a short-term indicator of cost-effective operation under optimal starting conditions, rather than a long-term measure of sustainability or profitability.

The Maintenance Cost to Revenue Ratio (MCIR) remained stable at 2% in both years. This indicates that maintenance expenditures accounted for only a small share of the collected irrigation revenue during the study period. However, this result should be interpreted together with the newly commissioned status of the scheme, since maintenance requirements were still limited during the first two years of operation. Therefore, the low MCIR values reflect favorable short-term maintenance cost conditions rather than a definitive indication of long-term financial stability.

In contrast, the Total Management, Operation, and Maintenance Cost per Irrigated Area (MOMI) increased from US$25.53 ha^{-1} to US$47.24 ha^{-1}. This increase was mainly attributable to inflation-driven growth in personnel expenses, which significantly raised overall management and operating costs in 2024.

The Collection Performance of Water Fee (PWF) remained at 100% in both 2023 and 2024; however, this

outcome does not reflect a managerial improvement over time but rather results from the institutional enforcement of a prepaid irrigation fee policy. Within the Gündüzler Irrigation Scheme, farmers are required to pay their entire seasonal water service fees in advance, prior to water delivery. This prepayment system structurally ensures full collection and eliminates the risk of unpaid dues, making the observed 100% rate a direct consequence of the policy design rather than the result of enhanced administrative efforts. Accordingly, the term collection performance is preferred over collection efficiency, as it better captures the fiscal rigidity of the prepaid model and avoids misinterpretation regarding year-to-year operational variation.

The Labor Cost per Irrigated Area (LCIA) increased from US$21.86 ha^{-1} to US$38.11 ha^{-1}, despite the number of personnel remaining constant (one employee). This increase is attributed not to additional staff but to inflation-driven increases in wages and social security obligations in Türkiye during this period.

At the same time, the Irrigated Area per Labor (IAL) rose from 688 ha person^{-1} in 2023 to 967 ha person^{-1} in 2024, indicating a remarkable gain in labor productivity. This is particularly noteworthy given that the irrigation scheme is operated with a single staff member, highlighting the operational simplicity and efficiency made possible through automation, prepaid water meters, and streamlined administrative processes.

Economic Performance Findings

In order to evaluate the economic efficiency of the irrigation scheme, the income generated per irrigated area and per unit of irrigation water used was analyzed (Figure 4). Table 6 presents the economic performance indicators of the Gündüzler Irrigation Scheme for the years 2023 and 2024

In 2023, the Income per Irrigation Area (IUA) was calculated as 915 US$ ha^{-1}, which increased to 1,003 US$ ha^{-1} in 2024. This increase is primarily attributed to the expansion of the cultivated area in 2024. Although the total irrigation area remained the same in both years, a larger portion of this area was actively cultivated in 2024, leading to higher total production income. On the other hand, the Income per Irrigated Area (IUIA) declined from 1,397 US$ ha^{-1} in 2023 to 1,089 US$ ha^{-1} in 2024. Field observations confirm that farmers, aware of the limited irrigation water availability, preferred crops requiring less water particularly wheat. Such crops generally have lower economic returns per hectare compared to high-value alternatives like maize or vegetables. Furthermore, the increased adoption of modern irrigation methods (drip and sprinkler systems), facilitated by geometric field arrangements from land consolidation, enabled wider irrigation coverage despite limited resources. Therefore, the drop in IUIA should not be interpreted solely as a deterioration in scheme performance but rather as an adaptive response to drought risk, balancing irrigation coverage with water scarcity conditions.

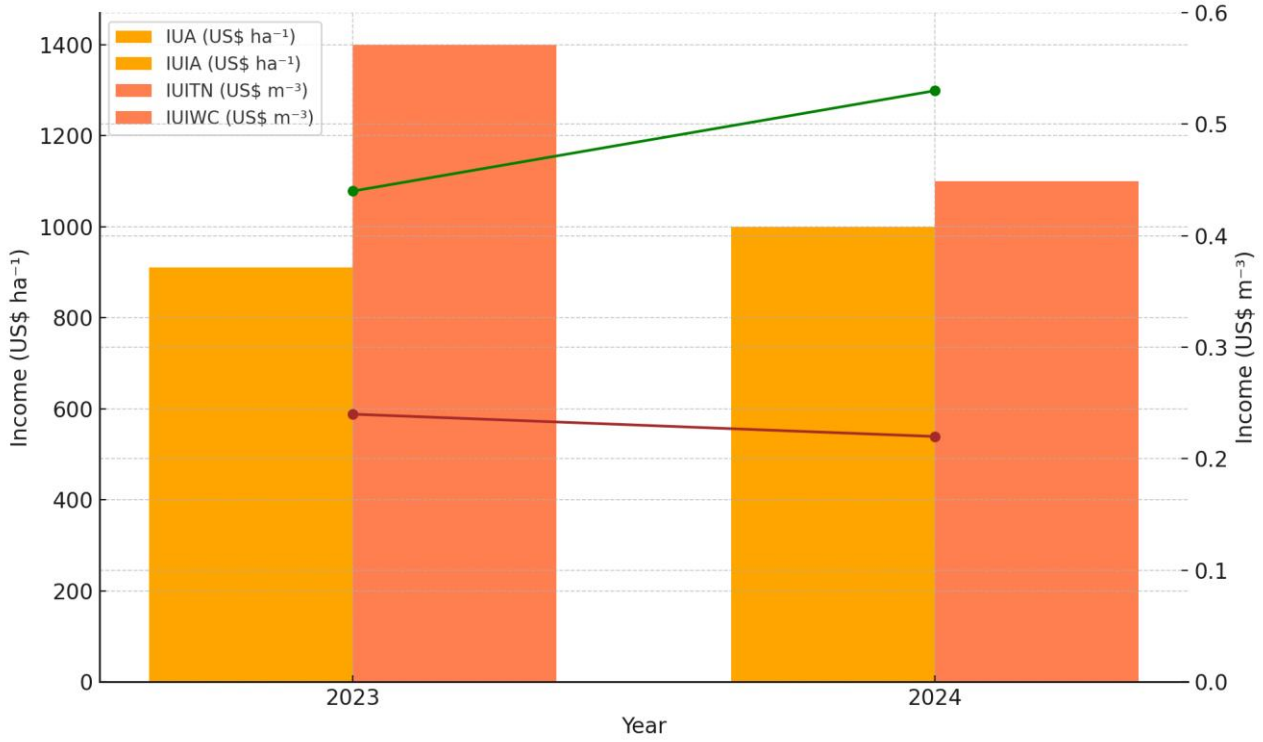

Figure 4. Economic performance indicators in the Gündüzler Irrigation Scheme (2023–2024)

Table 6. Economic Performance Indicators of the Irrigation Scheme (2023–2024)

Year	IUA	IUIA	IUITN	IUIWC
2023	915	1,397	0.41	0.23
2024	1,003	1,089	0.53	0.22

IUA: Income per Irrigation Area (IUA, US$ ha^{-1}); IUIA: Income per Irrigated Area (IUIA, US$ ha^{-1}), IUITN: Income per Volume of Supplied Irrigation Water (IUITN, US$ m^{-3}); IUIWC: Income per Volume of Consumed Irrigation Water (IUIWC, US$ m^{-3})

Table 7. Structural Improvements in the Irrigation Area Following Land Consolidation

Parameter	Before Land Consolidation	After Land Consolidation
Total number of parcels	1,587	1,175
Parcel reduction (%)	–	–25.96%
Average parcel size (m²)	15,084	20,104
Average parcel size increase (%)	–	+33.28%
Parcel shape	Irregular	Machine-friendly geometry
Parcel continuity	Fragmented (multiple scattered plots)	Consolidated (fewer, larger, contiguous plots)
Road access	Only 387 parcels (24.39%) had road access	100% of parcels have legal road access
Irrigation infrastructure feasibility	Low due to irregular shapes and access problems	High due to improved layout and parcel planning
On-farm piped irrigation system suitability	Limited and costly	Economical and efficient

The income per cubic meter of irrigation water supplied to the network (IUITN) increased from 0.41 US$ m^{-3} in 2023 to 0.53 US$ m^{-3} in 2024, indicating a higher economic return per unit of delivered irrigation water.

The income per cubic meter of net irrigation water consumed in the field (IUIWC) remained relatively stable, with values of 0.23 US$ m^{-3} in 2023 and 0.22 US$ m^{-3} in 2024. This stability indicates that the economic return of water use in crop production did not vary significantly between the years.

Land Consolidation Performance Results

As outlined in the methodology, the impact of land consolidation on parcel structure and infrastructure feasibility was assessed through comparative analysis of pre- and post-consolidation indicators. The results presented in Table 7 reveal substantial improvements in spatial organization and system readiness, which played a crucial role in enabling the efficient implementation of the piped irrigation network and subsequent operational success of the Gündüzler Irrigation Scheme.

The results of the structural evaluation indicate that land consolidation brought significant improvements to the physical and operational infrastructure of the Gündüzler Irrigation Scheme. As shown in Table 7, the total number of parcels was reduced by 25.96%, while the average parcel size increased by 33.28%. In addition, road access improved from just 24.39% of parcels to full accessibility for all land units. These changes reflect a fundamental shift in the spatial structure, transforming a fragmented and irregular land pattern into a more consolidated, accessible, and geometrically efficient layout.

These structural improvements were critical for the successful implementation of a fully piped, gravity-fed irrigation network. The alignment of parcels, roads, and canal networks enabled hydraulically optimized planning, which significantly reduced system complexity. As noted by Akkaya et al. (2017), land consolidation facilitates the cost-effective deployment of modern irrigation systems such as sprinkler and drip by improving parcel geometry and reducing installation costs. The Gündüzler scheme mirrored these findings, where consolidated and contiguous plots with road access enabled the widespread adoption of on-farm piped irrigation.

Moreover, the improved physical conditions led the Water User Association to prohibit traditional surface irrigation methods, steering all users toward piped and water-saving systems. This policy shift, enabled by the spatial reconfiguration from land consolidation, resulted in enhanced field-level irrigation efficiency and water productivity.

At the system level, land consolidation allowed for equitable and technically sound water distribution. At the farm level, it promoted user-driven adoption of efficient irrigation practices. This integrated approach is consistent with the technical planning framework outlined by Arslan et al. (2024), who emphasized that land consolidation supports the development of hydraulically optimized and spatially consistent piped irrigation systems, thereby improving the economic feasibility of implementation through more uniform plot geometries and reduced network complexity.

The findings suggest that land consolidation functioned as an important structural enabler of infrastructure efficiency and irrigation performance in the Gündüzler Irrigation Scheme.

Discussion

The positive impacts of land consolidation on irrigation performance have been demonstrated in many studies. For instance, in their analysis of the Bafra Plain, Arslan and Tunca (2013) reported that the irrigation ratio increased from 27% to 95.84% after land consolidation, while the number of parcels decreased from 1,315 to 616. Similarly, Fayrap et al. (2018) observed that the irrigation ratio reached 62% in the Daphan Irrigation Project following land consolidation, and the level of infrastructure utilization increased significantly. These findings are consistent with the 92% irrigation ratio achieved in the Gündüzler Irrigation Scheme in 2024, confirming the technical success of the system's operation.

In another study conducted on the Isparta-Atabey irrigation network, Uçar and Kara (2006) reported a water conveyance loss of 6.75% in areas with land consolidation, compared to 7.62% in areas without it. Although land consolidation appears to have facilitated more effective water conveyance and distribution structures, as also noted by Uçar and Kara (2006), the decline in the Water Supply Ratio (WSR) in the Gündüzler scheme cannot be attributed

to deficiencies in field-level distribution efficiency alone. Rather, the lower WSR in 2024 was mainly associated with insufficient inflow to the reservoir basin, while the cropping pattern also increased total irrigation water demand. Consequently, the available water supply remained below the required irrigation water level.

In a study conducted in the Aydın region, Peker and Dağdelen (2016) reported a significant increase in average parcel size, irrigable parcel share, and irrigation ratio, which reached 94.68% after land consolidation. Similarly, in the Gündüzler Irrigation Scheme, although a direct before-and-after performance comparison was not the primary objective of the present study, background data indicate that the number of parcels decreased from 1,587 to 1,175, the average parcel size increased by 33.3%, and legal road access improved from 24.4% to 100% following land consolidation. These structural improvements created favorable conditions for the establishment of a piped irrigation system and were associated with the high irrigation ratio (92%) and notable managerial capacity observed in 2024, when a single staff member managed irrigation over 967 hectares. Taken together, these findings suggest that land consolidation can provide an important structural basis for the operational performance of post-construction irrigation systems.

In a comparable case study conducted in Beyazaltın village of Eskişehir, Sönmezyıldız and Çakmak (2013) evaluated the performance of an irrigation system developed after land consolidation. The study reported a 25.19% reduction in total parcel numbers, with a significant increase in rectangular-shaped plots from 6.82% to 89.50%. Additionally, 100% of the parcels were connected to the road network after consolidation. These improvements led to a full irrigation rate (100%) and efficient water delivery, with an annual irrigation water supply of 4,311.02 m^3 ha^{-1}. The economic analysis revealed a high investment return rate (530%) and a relatively low maintenance cost-to-income ratio (8%). Furthermore, the study noted positive socio-economic outcomes, including improved living conditions and income increases in all beneficiary farms. These findings align with the results of the Gündüzler Irrigation Scheme, where land consolidation significantly enhanced infrastructural and operational conditions, enabling high irrigation efficiency and widespread adoption of modern irrigation practices. The similarities between the two cases further underscore the importance of implementing land consolidation prior to irrigation development, particularly in semi-arid regions where resource optimization is critical.

Eğilmez and Kaman (2022), in their evaluation of a project in Meram-Konya, emphasized that land consolidation projects lead to significant improvements in agricultural infrastructure, including roads, irrigation, and drainage systems. Similarly, in the Gündüzler case, the widespread adoption of piped irrigation methods (sprinkler and drip systems) and the control of overall management, operation, and maintenance (MOM) costs are facilitated by the improved infrastructure.

The economic performance indicators of the Gündüzler Irrigation Scheme provide a useful basis for evaluating the economic productivity of delivered irrigation water during the initial operational period. In 2024, the income per irrigation area (IUA) was calculated as 1,003 US$ ha^{-1}, while the income per unit of irrigation water delivered (IUITN) reached 0.53 US$ m^{-3}. These results suggest that, despite constrained water supply conditions, the scheme was able to generate a measurable economic return per unit of supplied water.

Comparable evidence has also been reported in previous irrigation performance studies from Türkiye. Harman and Çakmak (2025), in their evaluation of the Eskişehir Water User Association, reported IUA values ranging from 2,782 to 5,192 US$ ha^{-1} and IUITN values between 0.48 and 2.37 US$ m^{-3} over the 2016–2022 period. Likewise, Torun and Çakmak (2024), in their assessment of irrigation associations in the Konya Closed Basin, reported IUITN values generally ranging between 0.18 and 0.81 US$ m^{-3}, depending on year and irrigation association. Within this context, the IUITN value obtained in Gündüzler falls within a plausible range for operational irrigation systems under water-limited conditions, although the IUA value remained comparatively lower.

In addition, the Cost Recovery Ratio (CRR) reached 298% in 2024, indicating that the collected water fees substantially exceeded the annual operation, maintenance, and management costs during the first two years of operation. This result reflects favorable short-term cost recovery conditions under a newly commissioned irrigation system, rather than a full recovery of capital investment costs.

Recent studies further highlight the broader economic and environmental impacts of irrigation modernization projects integrated with land consolidation. For example, Borrego-Marín and Berbel (2019) demonstrated that in the Guadalquivir Basin, the cost-effectiveness of modernization depends not only on technological upgrades but also on spatial restructuring through land consolidation, which enhances water productivity and reduces system-wide inefficiencies. Similarly, Fader et al. (2016) emphasized that sustainable irrigation in the Mediterranean requires systemic efficiency gains under increasing climate stress, underscoring the value of low-loss, gravity-fed systems like the one implemented in Gündüzler. In line with these findings, Frey et al. (2024) showed that land consolidation projects in Spain contributed significantly to the long-term sustainability of irrigation schemes by improving water delivery infrastructure, reducing energy inputs, and maintaining environmental coherence. The Gündüzler Irrigation Scheme reflects several of these integrated benefits by combining spatial, technical, and managerial improvements into a cohesive system characterized by gravity-fed operation and low operational costs. Despite the severe water limitation observed in 2024, when the Water Supply Ratio (WSR) declined to 0.40 due to insufficient inflow to the reservoir basin and increasing irrigation water demand, the scheme showed notable managerial efficiency and infrastructure functionality during the study period, illustrating the enabling role of land consolidation and modern irrigation design under resource-limited conditions.

Similar results were reported by Moradinejad and Eslampour (2018), who found that integrated land consolidation and drip irrigation projects in Iran increased irrigation efficiency by 85% and crop income by nearly 4-fold, while reducing water consumption and labor costs.

Although the Gündüzler Irrigation Scheme does not provide direct evidence for reduced labor costs, it does demonstrate comparable improvements in technical and economic performance especially through high water productivity (0.53 US$ m^{-3} in 2024) and the ability to manage extensive irrigated areas with minimal personnel. These findings reinforce the value of combining land consolidation with modern irrigation infrastructure to achieve sustainability in water-limited regions.

Furthermore, a mathematical optimization model developed by Shirdeli and Dastvar (2014) showed that integrated management of cropping patterns and land use could increase farmers' income by up to 250% and improve water productivity to over 77%. In the Gündüzler Irrigation Scheme, the cropping pattern is determined by individual farmer preferences rather than a centralized directive. However, the distribution of irrigation water is managed institutionally by the water user association, ensuring systematic and efficient operation of the system.

Overall, the findings suggest that irrigation projects implemented in land-consolidated areas may achieve favorable outcomes not only in technical performance, but also in managerial effectiveness and economic productivity, particularly when supported by piped infrastructure and coordinated institutional management. In this respect, the Gündüzler Irrigation Scheme provides a useful case for understanding the potential contribution of land consolidation to irrigation performance under semi-arid conditions.

Conclusions and Recommendations

This study evaluated the Gündüzler Irrigation Scheme in terms of technical, managerial, and economic performance during its first two years of operation. The results indicate that land consolidation created favorable structural conditions for the implementation of a piped irrigation system and supported coordinated water management at scheme level.

Although the scheme operated under constrained water supply conditions in 2024, it maintained broad irrigation coverage and demonstrated effective managerial performance. The findings also suggest that the system provided measurable economic returns per unit of delivered water under its initial operational conditions.

Based on these findings, the following recommendations are proposed:

- *Integrated planning and land consolidation:* Land consolidation should be considered an integral component of new irrigation projects, as it provides an important structural basis for the technical and economic functionality of modern irrigation systems.
- *Institutional water management:* Centralized water distribution supported by prepaid smart meters and piped infrastructure can improve equitable allocation, reduce losses, and strengthen irrigation coordination under limited water supply conditions.
- *Performance monitoring:* Regular monitoring of key indicators such as irrigation water use efficiency, water economic productivity and managerial efficiency should be institutionalized to support adaptive and evidence-based management.
- *Modern irrigation technologies:* The wider adoption of on-farm piped irrigation systems should be encouraged through technical support and policy incentives in order to improve operational efficiency and economic water productivity.

Declarations

Ethical Approval Certificate

This study does not involve human participants, animal subjects, clinical trials, or personal data. The data used in the study were obtained from official institutional records of the State Hydraulic Works (DSI) and the Eskişehir Water User Association. Therefore, ethical approval was not required for this research.

Author Contribution Statement

Conceptualization, Eray Harman; methodology, Eray Harman; validation, Eray Harman; formal analysis, Eray Harman; investigation, Eray Harman; resources, Eray Harman; data curation, Eray Harman; writing original draft preparation, Eray Harman; writing review and editing, Eray Harman; visualization, Eray Harman; supervision, Belgin Çakmak All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

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