Analyzing Performance and Agricultural Impacts of the Mahakali Irrigation System, Phase-I

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Abstract

Irrigation infrastructure plays a pivotal role in ensuring food security and sustaining livelihoods. The Mahakali Irrigation System, Phase-I (MIS-I), a national pride project of Nepal, was developed to irrigate over 3,400 hectares in Kanchanpur district. This study evaluates the structural performance, water management efficiency, agricultural impacts, and governance mechanisms of MIS-I to determine its effectiveness and sustainability. A mixed-methods approach was adopted, combining field inspections, structured household survey (No. of Households, n=108) across upstream, midstream, and downstream distributaries. Performance indicators were drawn from four dimensions: structural integrity, water availability and management, institutional governance. The results indicate that although MIS-I has enhanced agricultural productivity, with 65% of farmers reporting moderate yield improvements and 66% observing crop diversification, substantial challenges persist. Around 40% of farmers indicated facing water scarcity during the critical crop sowing months of May and June, while 24% cited poor maintenance causing blockages, sedimentation, and vegetation growth. Tail-end farmers (n=17) experience greater inequities in water distribution compared to head-reach users. Awareness of Water User Associations (WUAs) was found moderate (n=56), with mixed perceptions of their performances (n=40 out of 108 rating “Good”). The study concludes that MIS-I contributes significantly to food security and livelihoods but requires targeted interventions, including systematic maintenance, equitable allocation, WUA capacity-building, and technological upgrades. Strengthening these aspects is essential for enhancing resilience, optimizing water use, and advancing sustainable agricultural development.

Keywords: *Agricultural productivity, Mahakali Irrigation System Phase-I, Water management, Crop diversification, Water User Associations*

Introduction

Agriculture continues to be the cornerstone of rural economies in South Asia, with irrigation infrastructure serving as a lifeline for food security and sustainable livelihoods (Jambo et al., 2021). Globally, irrigated agriculture contributes approximately 40% of the total food production on only 20% of cultivated land (Ingrao et al., 2023). In water-stressed regions, where rainfall is seasonal and erratic, irrigation systems provide stability against climatic uncertainties while enabling crop intensification and diversification (Paria et al., 2021). Nepal, with its agrarian economy, has historically invested in large-scale irrigation projects to boost agricultural productivity and reduce dependence on monsoon rainfall. Among these, the Mahakali Irrigation Project (MIP) occupies a critical place, both due to its transboundary water-sharing context under the Mahakali Treaty of 1996 and its designation as one of Nepal’s National Pride Projects (Tiwari et al., 2025).

The Mahakali Irrigation System, Stage I (MIS-I), draws water from the Sharada Barrage on the Mahakali River, which forms part of the Nepal-India border. Initiated in the mid-1970s with World Bank support, MIS-I was designed to irrigate a command area of approximately 3,400 hectares, later expanded to serve over 11,600 hectares across Kanchanpur district, benefiting nearly 13,000 households (World Bank, 1980).The system’s infrastructure comprises a main canal, distributaries, minors, and a network of appurtenant structures including regulators, cross-drainage works, field channels, and gravel service roads. The project’s structural backbone is thus central to ensuring equitable, timely, and reliable water distribution, minimizing conveyance losses, and safeguarding long-term functionality.

The performance assessment of an irrigation system is carried out by evaluating its structural integrity and agricultural impacts, with a focus on water management efficiency to ensure reliability, crop productivity, and sustainable utilization of resources (Mishra et al., n.d.). From a structural perspective, the system’s efficiency depends on the durability and maintenance of canals, distributaries, and regulating structures. Studies indicate that unlined canals, seepage losses, and poor embankment stability contribute to declining conveyance efficiency (Khan & Akhtar, 2024). Silting, scouring, and vegetation growth also generate impedance on hydraulic performance, necessitating routine dredging and rehabilitation (Zakir-Hassan et al., 2023).

Reliable irrigation enables multi-cropping cycles, shifting farmers from subsistence cereals to high-value crops such as vegetables and cash crops (Holmelin, 2021; Wahaet al., 2020). The MIS-I project has contributed to enhanced food security, higher household incomes, and poverty reduction in the Mahakali region (The World Bank, n.d.). However, seasonal water scarcity, particularly during the dry months when river flow diminishes to 4.25 m^3/s, continues to constrain productivity.

Contemporary assessment of irrigation network performance embraces three key dimensions: stakeholder perceptions, policy frameworks, and technological innovations. Evaluating farmers' satisfaction not only reflects their level of acceptance but also provides valuable insights for the sustainable adoption of irrigation systems. Studies have consistently shown that participatory development approaches enhance the relevance, effectiveness, and uptake of new irrigation technologies (Meinzen-Dick et al., 2014). Technological advances now facilitate performance analysis using tools like remote sensing, IoT sensors, machine learning, and Data Envelopment Analysis, enabling measurements of efficiency, water-use dynamics, and operational sustainability across scales (Abdelmoneim et al., 2025; Neupane & Sawada, 2023). National policies also play a pivotal role: regular water audits in India demonstrate how policy-driven benchmarking can guide improvements in conveyance and irrigation efficiency (Singh, 2024). Our study engages consumers (the irrigators in MIS, Phase-I) in both perception surveys and feedback collection, thereby ensuring the evaluation is participatory, context-aware, and in step with policy assessment paradigms.

Recognizing that farmer participation is central to irrigation sustainability, the Government of Nepal, in collaboration with the World Bank, promoted Water User Associations (WUAs) as grassroots' institutions to manage irrigation distribution, Operation and Maintenance, and conflict resolution. The MIS-I Water User Association was established in 2011 under the Irrigation and Water Resources Management Project (IWRMP). The objectives of WUAs include ensuring equitable water distribution, mobilizing farmers for canal cleaning, promoting awareness of efficient irrigation practices, and serving as a liaison between the Department of Irrigation and water users (Howarth et al., n.d.; Kirmikil, 2025). The underperformance of WUAs reflect broader institutional challenges in participatory irrigation management (PIM), where capacity gaps, politicization, and limited financial autonomy constrain WUA effectiveness (Hussain et al., 2021). The WUA organogram for the Mahakali Irrigation System Phase I consists of a Central Committee (21 members), Regional Committee (17 members), Block Committees (13 each), and Tertiary Committees (4–5) with Outlet Leaders.

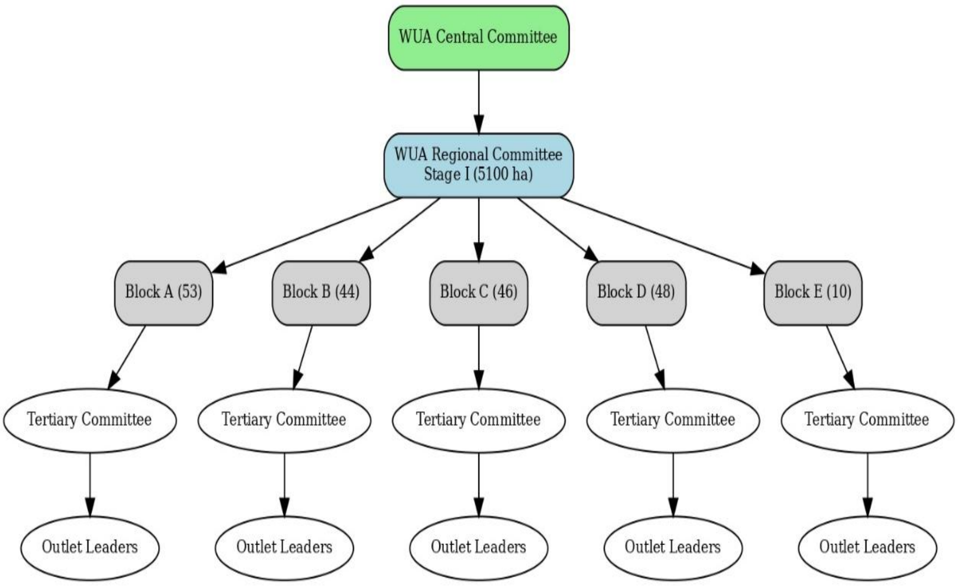

Figure 1: WUA Organogram of MIS-I

The Mahakali Irrigation System, Phase-I, embodies both the potential and pitfalls of large-scale irrigation in Nepal. While it has advanced agricultural livelihoods in Kanchanpur, its sustainability hinges on addressing structural inefficiencies, strengthening WUA capacities, and adapting to hydrological variability. This article thus seeks to provide a comprehensive performance evaluation of MIS-I, examining its agricultural impacts, structural performance, and institutional dynamics. The study evaluates water accessibility, reliability, and structural integrity of the Mahakali Irrigation System Phase-I. It further examines the system's impact on crop yield, agricultural productivity, and the sustainability of resource management practices.

Study Area

The present study was conducted in the cultivable command area of the Mahakali Irrigation System, Phase-I, located in Kanchanpur district. The system comprises a network of 11 sub secondary canal that came out from main canal originating from the Mahakali River. For the purpose of this research, three representative distributaries (sub secondary canal) were selected: Bhujela, Ultakham, and Daijee. The Bhujela Distributary, situated near the head reach of the main canal, covers a command area of 926 ha with a design discharge of 1550 lps, and represents the upstream condition where water availability is relatively higher. The Ultakham Distributary, located in the mid-reach, commands 1064 ha with a design discharge of 1943 lps, reflecting intermediate distributional dynamics. The Daijee Branch, positioned at the farthest downstream end, commands 300 ha with a design discharge of 320 lps, representing the tail-end conditions. These three distributaries collectively provide a comprehensive basis to assess spatial variations in irrigation performance and water management efficiency across the system.

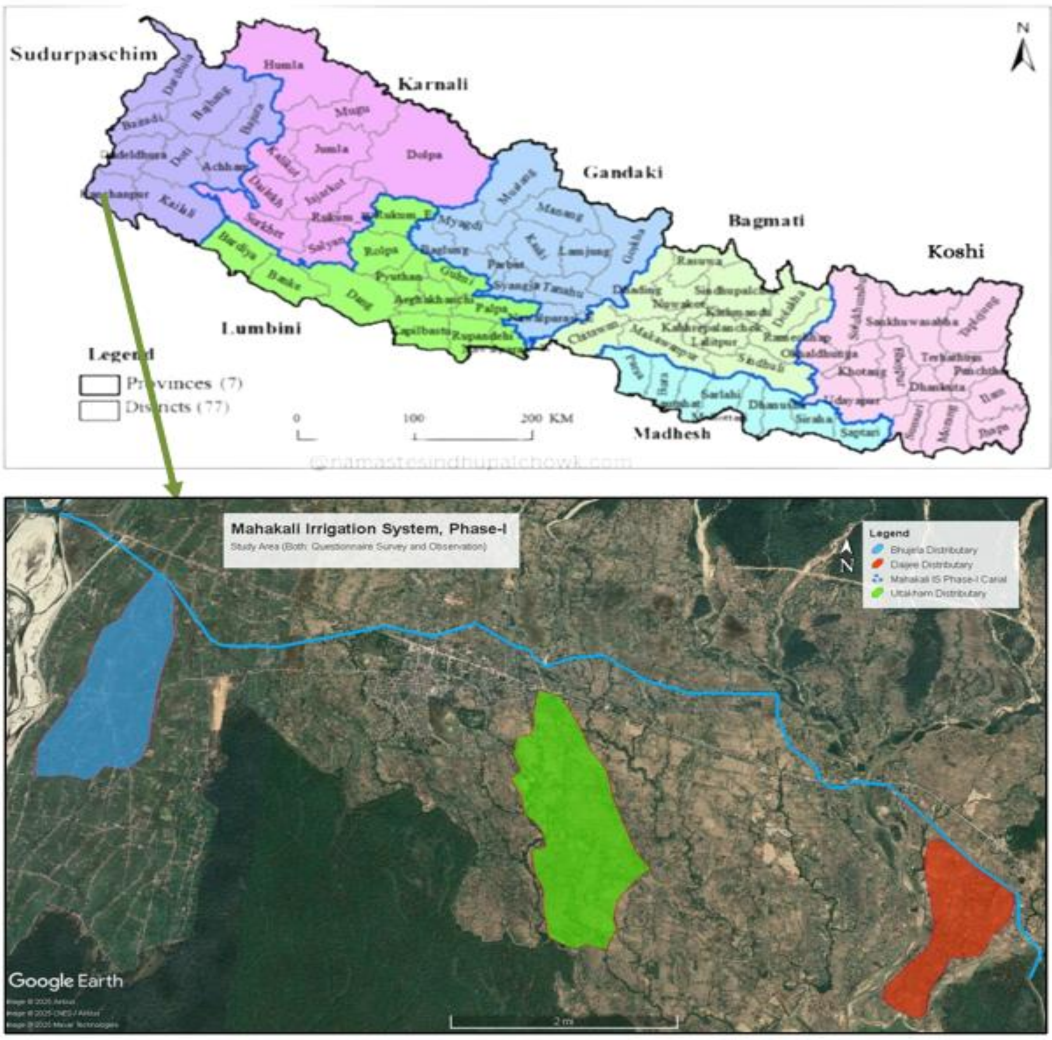

Figure 2: Study Area

Methodology

This study employed a comprehensive and systematic methodology to evaluate the performance of the Mahakali Irrigation System Phase I (MIS-I) from an agricultural perspective. A literature review was undertaken focusing on prior studies of irrigation performance. After selecting the three distributaries chosen to represent upstream, midstream, and downstream conditions: Bhujela Distributary (head reach), Ultakham Distributary (mid-reach), and Daijee Branch (tail end), purposive sampling was employed to select farmer households at the head, middle, and tail sections of each canal within these distributaries. In total, 108 farmers were surveyed: 48 from Bhujela, 43 from Ultakham, and 17 from Daijee.

Data collection relied on multiple tools. A field inspection survey was carried out to examine the physical condition of canal structures, water flows, and maintenance practices, with observations systematically recorded. A structured questionnaire survey of sampled households gathered data on water availability, irrigation reliability, cropping patterns, and overall satisfaction. Secondary data were collected from the Mahakali Irrigation Office and other government records. The data from surveys and field inspections were analyzed to identify system strengths, limitations, and opportunities for improvement.

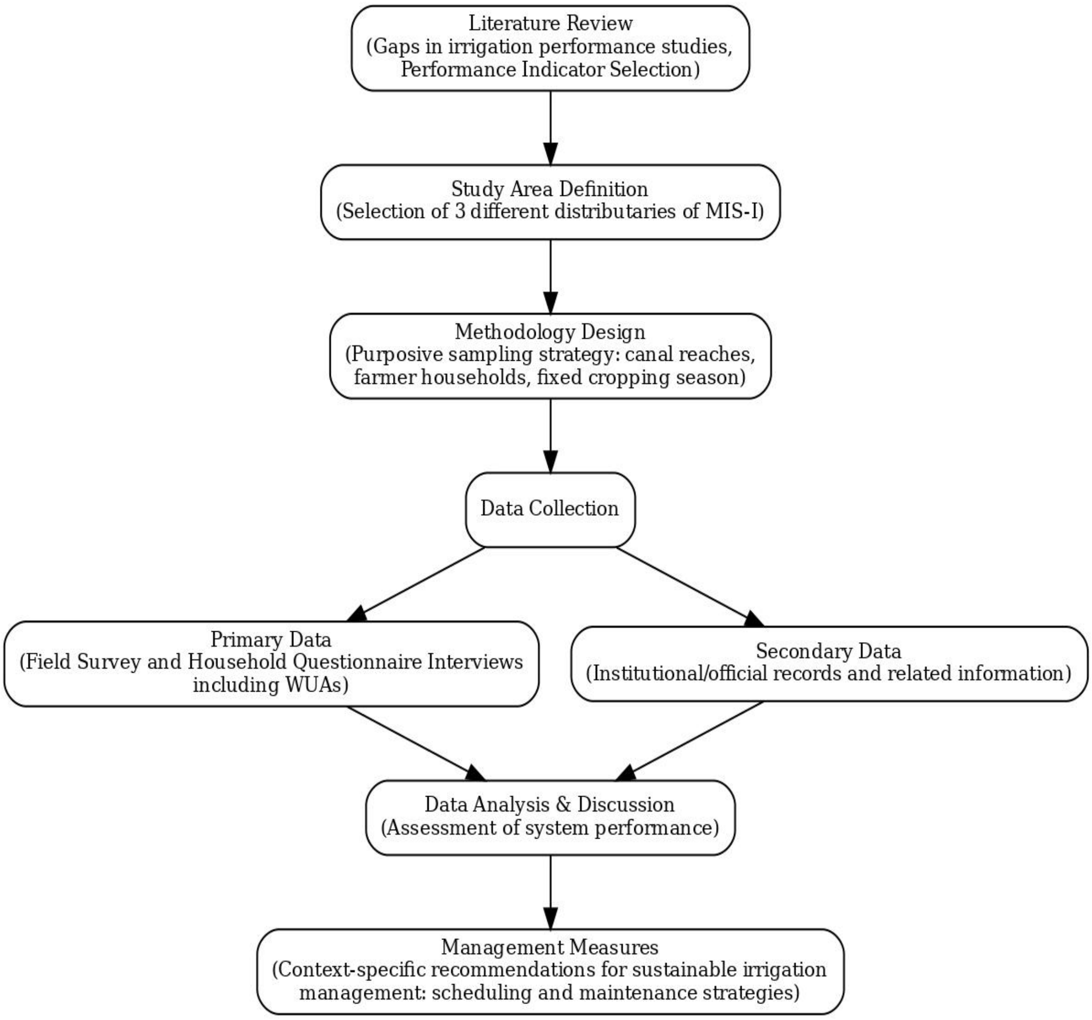

Figure 3: Research Methodology

Performance Indicators

This study conducted questionnaire survey among Mahakali Irrigation System Phase-I users to identify key challenges (such as irregular water supply, inequitable access, and infrastructure maintenance) and to gauge farmers' perceptions of agricultural productivity and their satisfaction with the functioning of the irrigation network and the Water Users Association. In addition, field observations of the canal network were carried out to evaluate its structural condition and maintenance needs. To identify irrigation and agriculture performance indicators, we first selected indicators that reveal availability of facilities as per requirements and impacts produced by irrigation system based on literature from (Nepal et al., 2024; Parra et al., 2020; Şener et al., 2007). The broad themes that emerged were structural indicators, agricultural water management indicators, governance indicators and socio-economic and benefits indicator.

Table 1: Selected Performance Indicators

Category	Indicators	Definition / Relevance
Physical & Structural	Insufficiency of water at fields	Problem of irrigation water not reaching fields
	Leakages from canals	Problem of water leaking/seepage in canals
	Water logging	Excessive water flow/flooding problems
	Mud and sedimentation	Silting in fields and canals
	Maintenance of irrigation canal/system	Lack of maintenance causing blockages, canal condition rating
Agricultural & Water Management	Water availability (seasonal)	Reliability of water supply in winter/monsoon/spring
	Crop yield improvement	Impact on productivity
	Use of alternative irrigation methods	Supplementary systems
Governance (WUA/Knowledge)	Knowledge of irrigation system	Farmers' knowledge ratings
	Information about WUA	Awareness & perceived role of WUA
	Water disputes	Conflicts among users
	Fair irrigation practices/system	Rotation vs continuous irrigation

Results and Discussion

Water Access and Utilization

A considerable proportion of households' access water directly from the canal. However, many farmers reported dependence on alternative means, such as pumping or diverting water from non-operational canal sections. Bhujela distributary recorded higher levels of direct canal access compared to Daiji Minor and Ultakham distributaries. Using water from non-opening section of canal reduces performance of entire canal system.

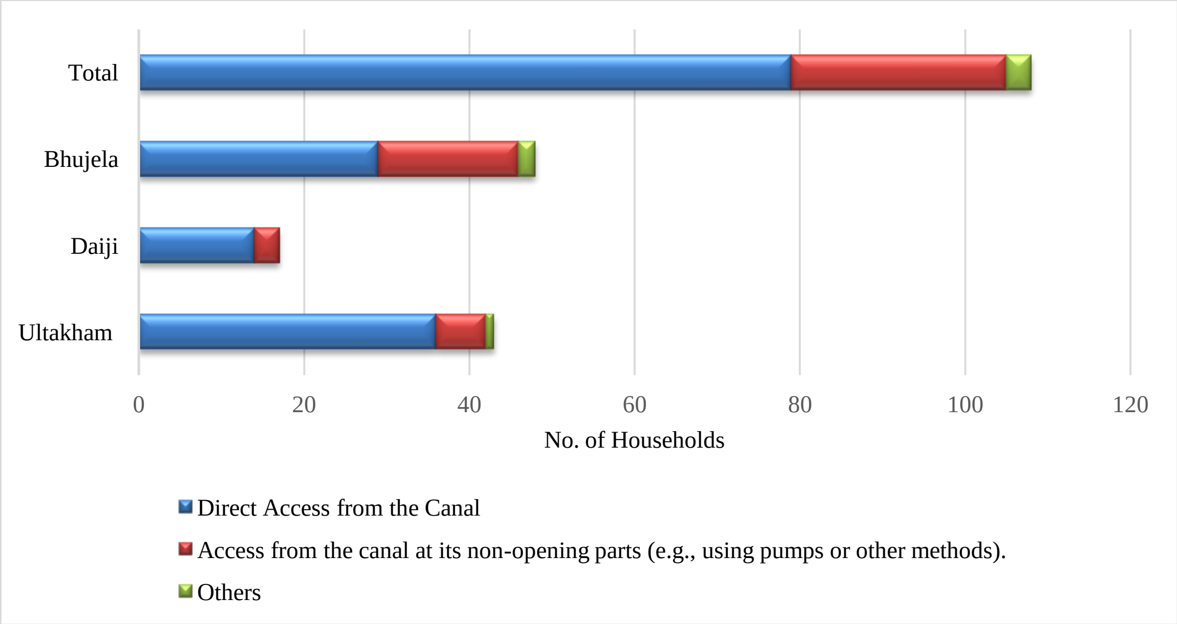

Figure 4: Water Access from Canal to the Field

The frequency of water utilization indicates that the majority of households irrigate their fields only occasionally, while very few reported daily or weekly use. Ultakham distributary, in particular, showed reduced utilization frequency, pointing towards irregular supply and insufficient discharge at the tail reaches.

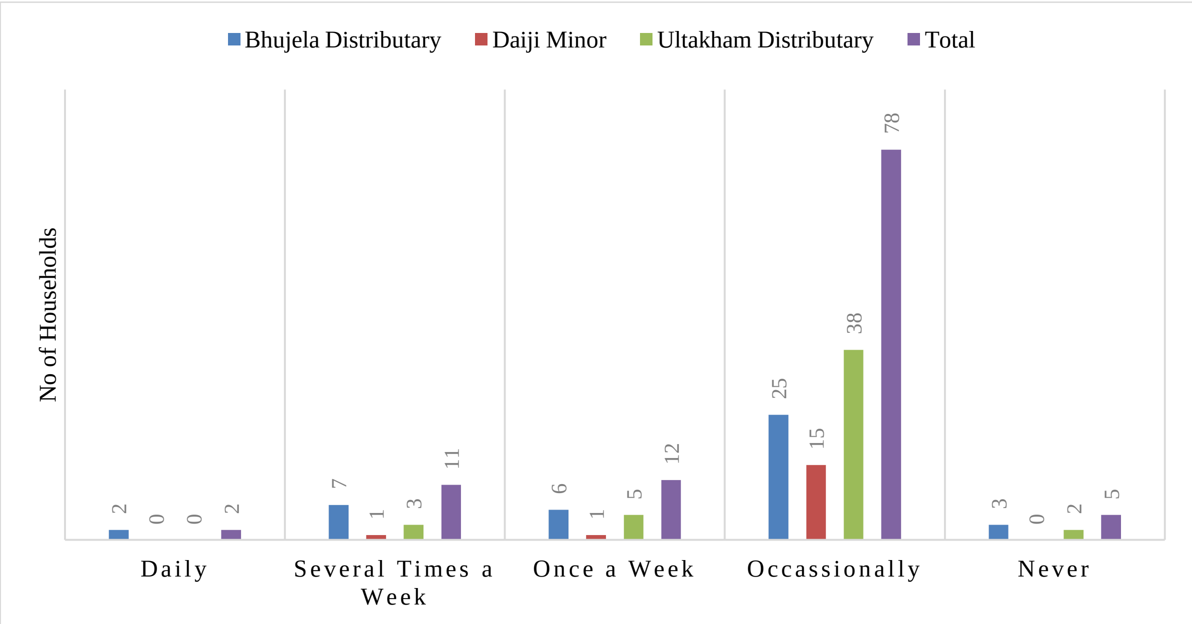

Figure 5: Water Utilization Frequency

Survey data demonstrate that most households rely on continuous flow rather than rotation systems. The predominance of continuous supply practices suggests weak enforcement of rotational schedules, causing inequities in availability between head and tail farmers.

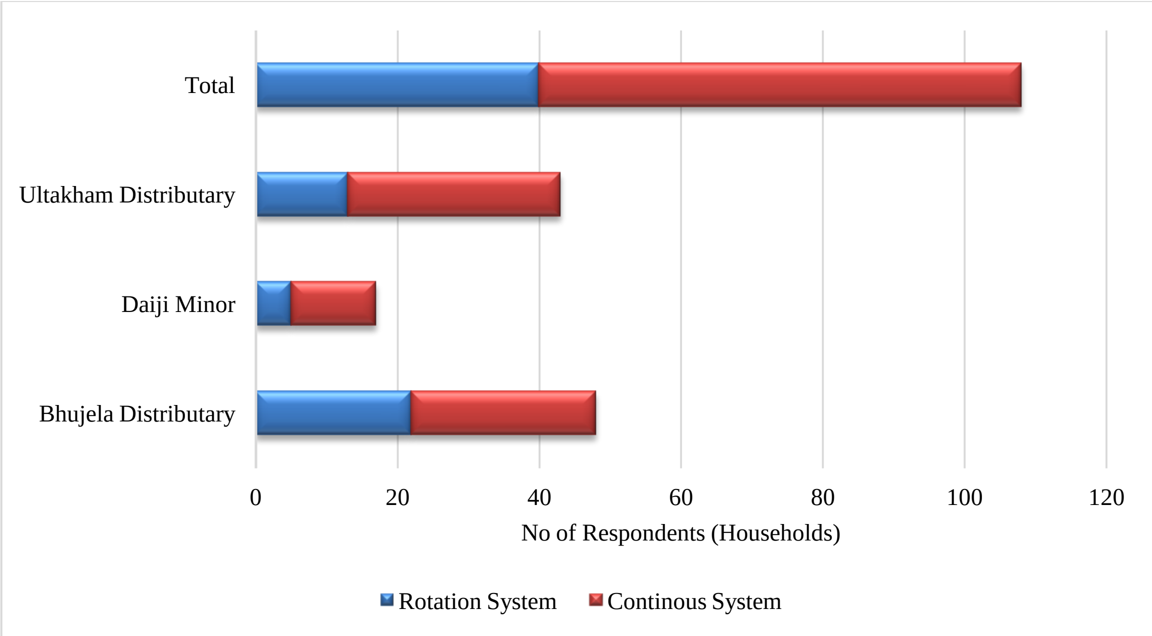

Figure 6: Water Application System

The reliability assessment shows that most respondents perceive MIS-I as reliable. A smaller share rated the system as unreliable or very unreliable, with neutral responses also significant. Farmers' moderate trust in supply reliability underscores the urgent need for improved operation and maintenance, stricter regulation of water distribution, and participatory management mechanisms.

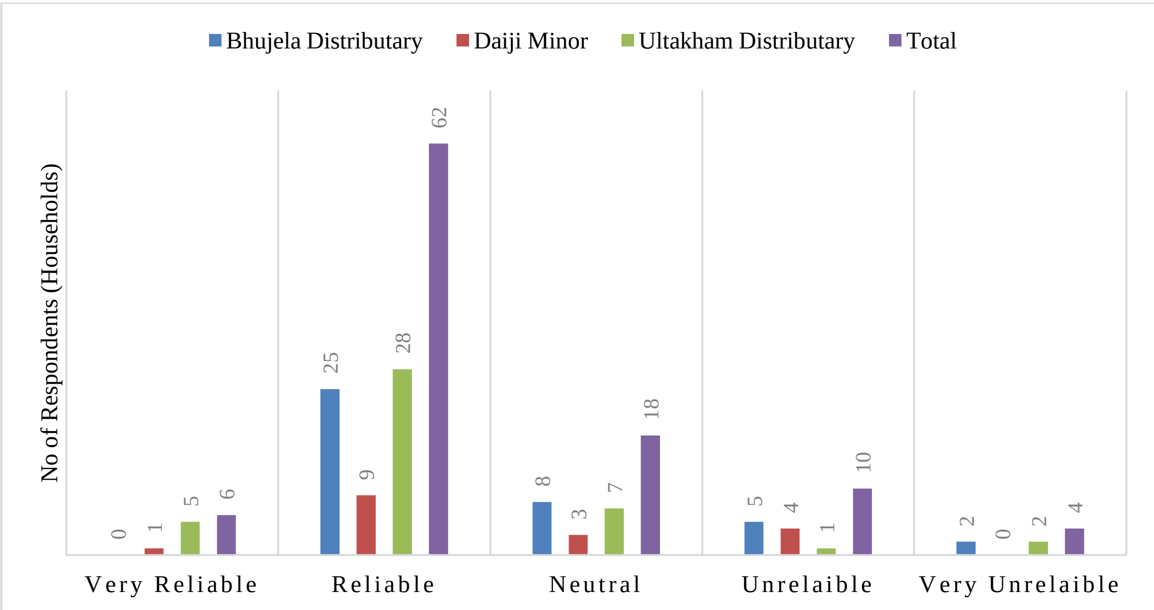

Figure 7: Water Supply Reliability of MIS-I Canal System

Impacts on Crop Yields

Survey results indicate that the majority of farmers reported positive impacts of the Mahakali Irrigation System Phase I (MIS-I) on crop performance. About 65% of respondents observed moderate improvement in crop yield, while 16% noted significant improvement and 15% reported slight improvement. Only a small fraction (4%) stated no improvement. These results suggest that irrigation availability has enhanced agricultural productivity, although gains are not uniform across households.

The introduction of reliable irrigation facilities has also influenced crop pattern dynamics. Approximately 66% of respondents reported changes in cropping patterns, shifting towards more water-intensive and higher-value crops, while 34% indicated no change in crop pattern. This demonstrates the system's role in enabling diversification, although a sizeable proportion of farmers remain dependent on traditional practices.

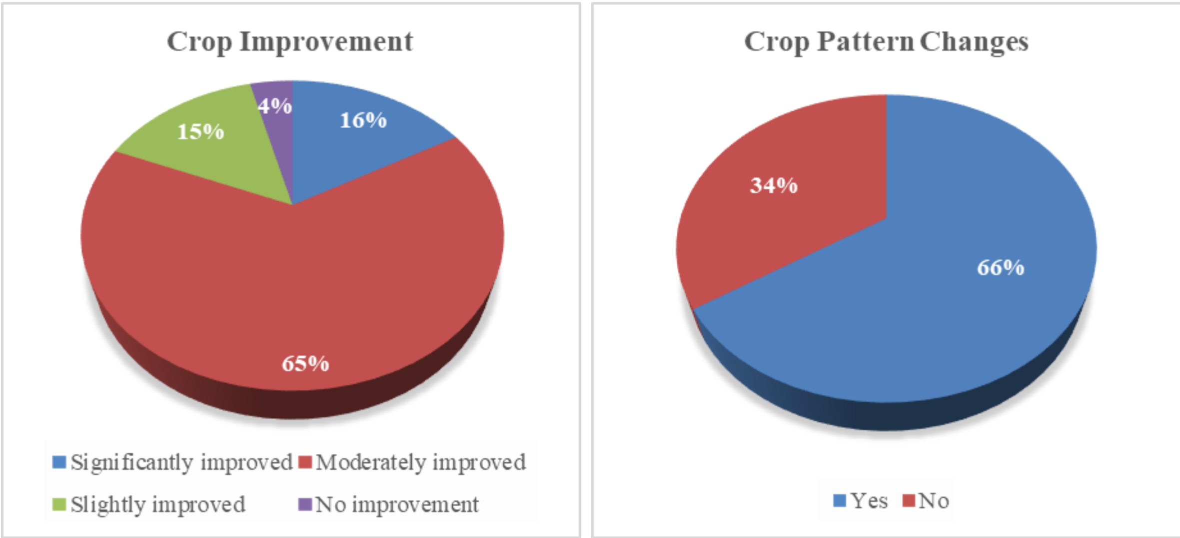

Figure 8: Crop Improvements and Pattern Changes

Regarding the major crops yielded by farmers, Paddy and wheat remain the dominant crops with over 100 households reporting their cultivation. In contrast, maize, pulses, mustard, and vegetables are cultivated at much smaller scales. The predominance of paddy, in particular, underscores the irrigation system's role in supporting staple crop production.

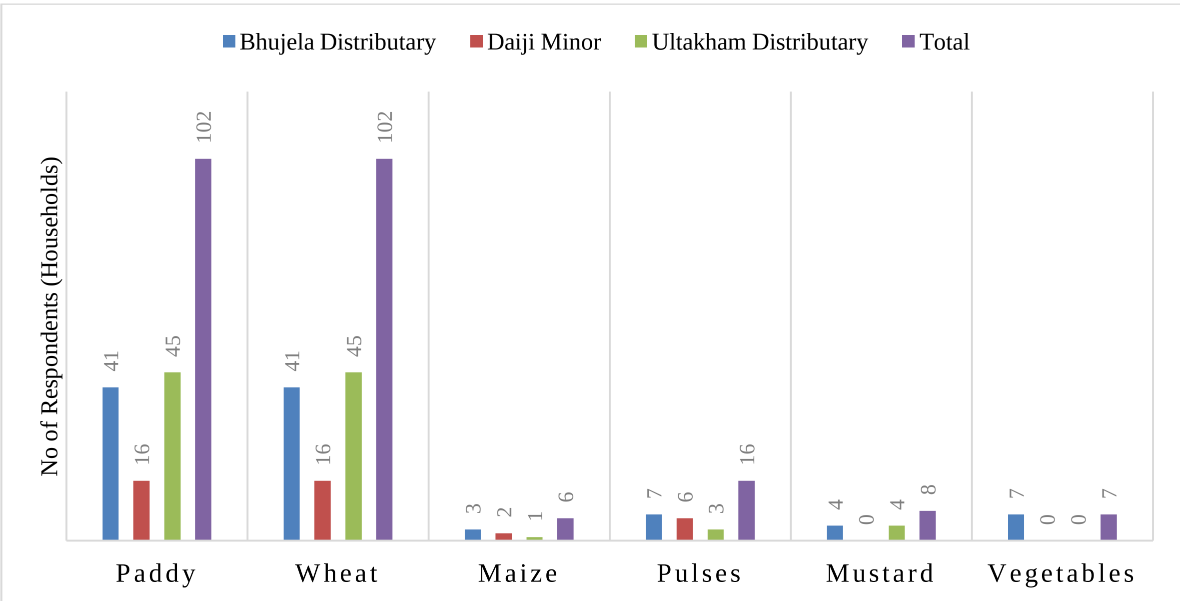

Figure 9: Major Crop Yielded by Farmers

Analysis of irrigated land size reveals that most households cultivate between 10 to 20 kathas under irrigation, with fewer respondents reporting areas larger than 20 kathas. The distribution across distributaries shows relatively higher irrigated landholdings in Bhujela compared to Daiji Minor and Ultakham, where landholdings are smaller and less consistently irrigated.

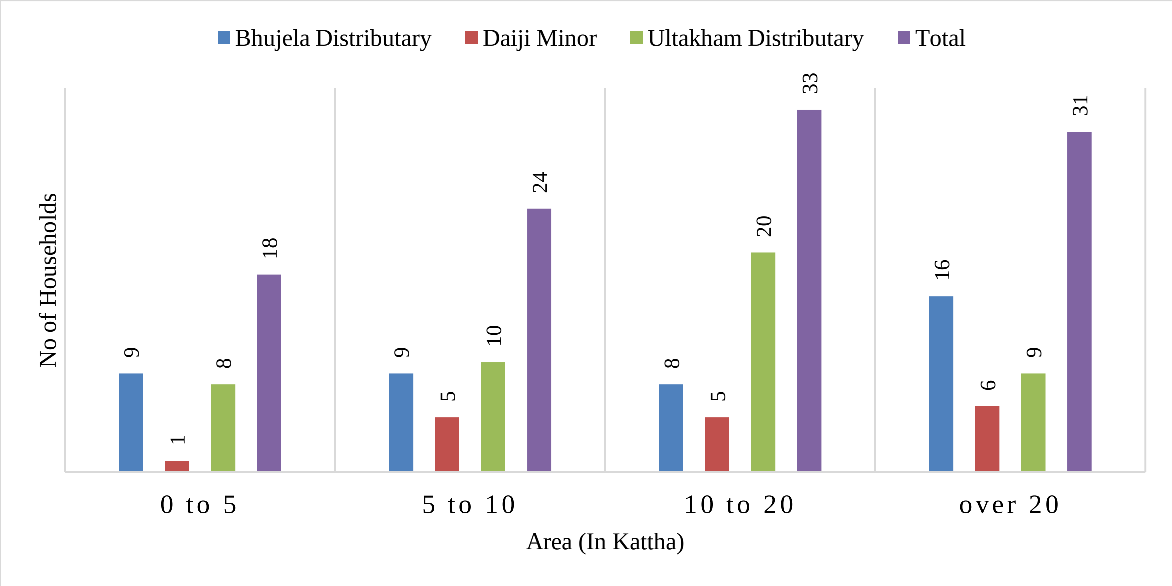

Figure 10: Irrigating Land Area per Households

Critical Challenges

The study also highlighted several critical challenges faced by farming households in the command area. Household responses reveal that the major concern is water scarcity during peak agricultural seasons, reported by 40% of respondents. This indicates that despite the existence of a large-scale surface irrigation system, reliable water availability remains inadequate when crops require it most. Such scarcity directly affects crop yields and compels farmers to adopt coping mechanisms, such as supplementary irrigation systems.

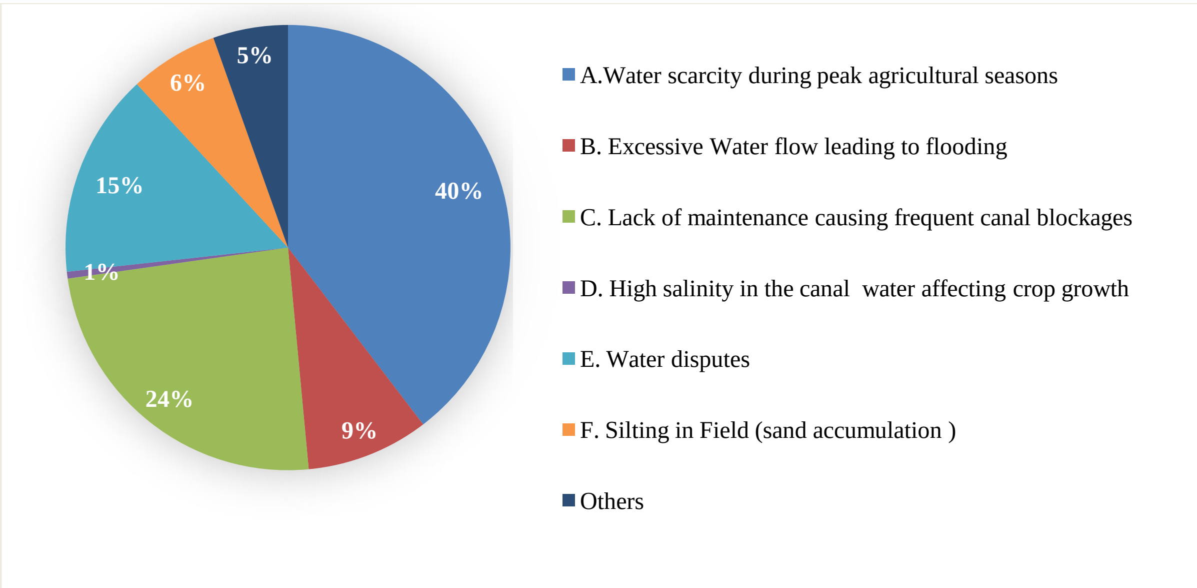

Figure 11: Key Challenges Faced by Farmers

The second major issue, reported by 24% of households, is the lack of maintenance causing frequent canal blockages. Additionally, high salinity in canal water was reported by 15% of households, which poses a significant risk to soil fertility and long-term agricultural productivity. Other issues included excessive water flow leading to flooding (9%), silting in fields due to sand accumulation (6%), water disputes (1%), and other miscellaneous problems (5%). These results underscore the need for better canal operation and maintenance strategies.

To cope with the recurring problem of water scarcity, some households have adopted supplementary irrigation systems such as tube-well borings. However, adoption remains limited: only 7 out of 48 households in Bhujela distributary, 4 out of 17 in Daiji minor, and 14 out of 43 in Ultakham distributary reported using borings. This indicates a dependency on canal water as the primary source of irrigation and highlights constraints such as financial affordability, groundwater availability, and energy costs that limit wider adoption of private irrigation solutions.

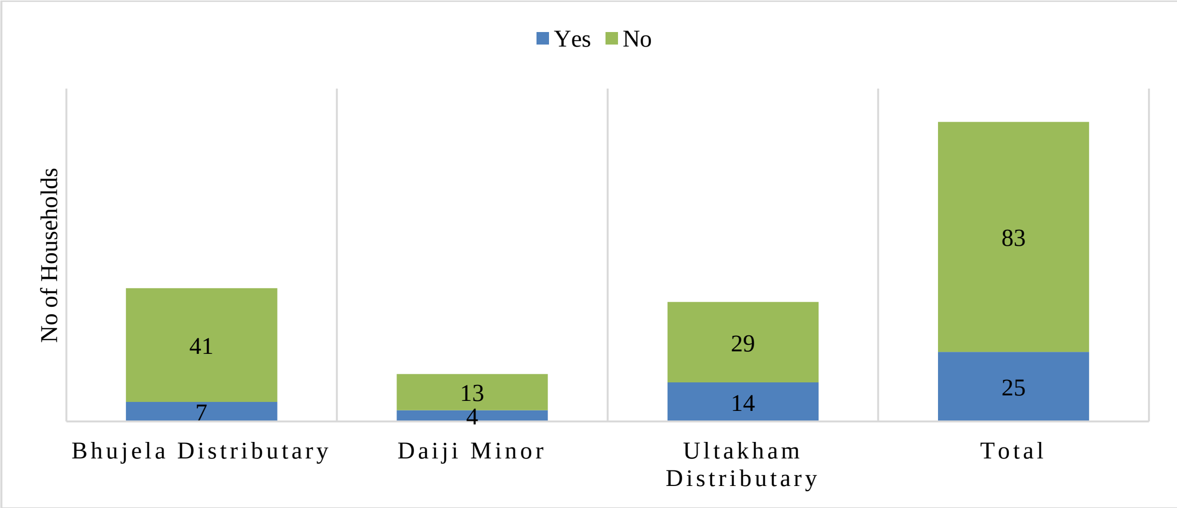

Figure 12: Use of Supplementary Irrigation System

Another significant challenge identified is silting, scouring, and vegetation growth in canals, which reduces conveyance efficiency. The majority of respondents experience this problem occasionally (74 households), followed by rarely (26 households) and frequently (20 households). A very small number of respondents reported that silting and vegetation issues were either never (1 household) or always (3 households) present. This suggests that the recurring nature of canal obstructions continues to affect water distribution reliability.

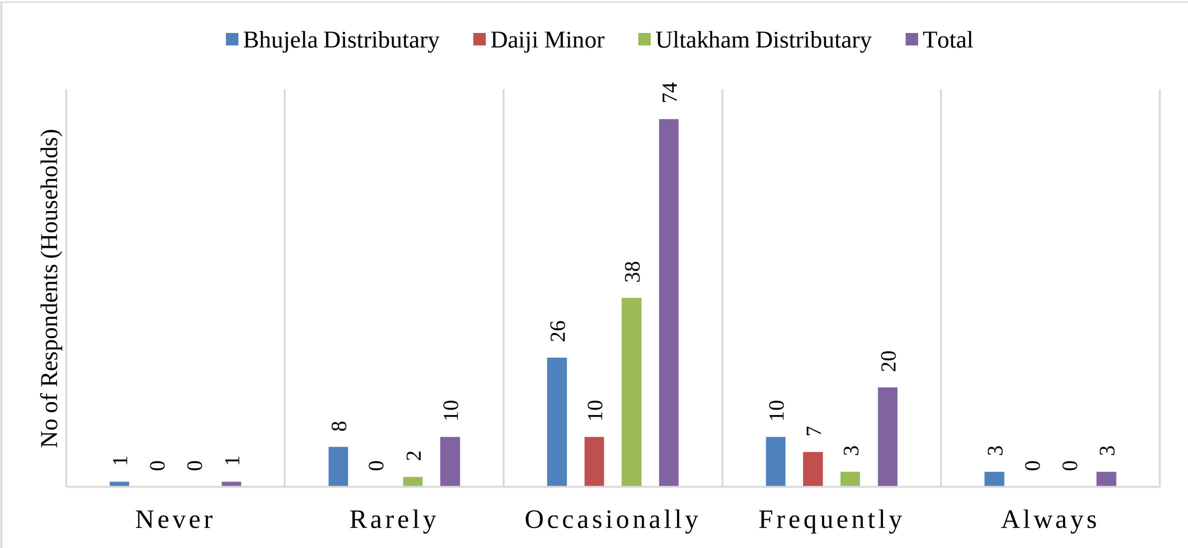

Figure 13: Frequency of Silting, Scouring and Vegetation in the Canal Network

WUA and Its Roles

The survey results indicate that farmer awareness about the Water Users' Association (WUA) in the Mahakali Irrigation System Phase I is moderate. Out of the total respondents, 52% reported being aware of the WUA, while 48% had no awareness. The lack of awareness among a significant proportion of farmers implies that many WUA committees may not be actively engaged in collective decision-making or water management activities, which can weaken participatory irrigation management. Since farmer awareness and involvement are critical to the success of WUAs, as they enhance accountability, equitable distribution, and collective action in system maintenance, the active WUA committees must be reformed.

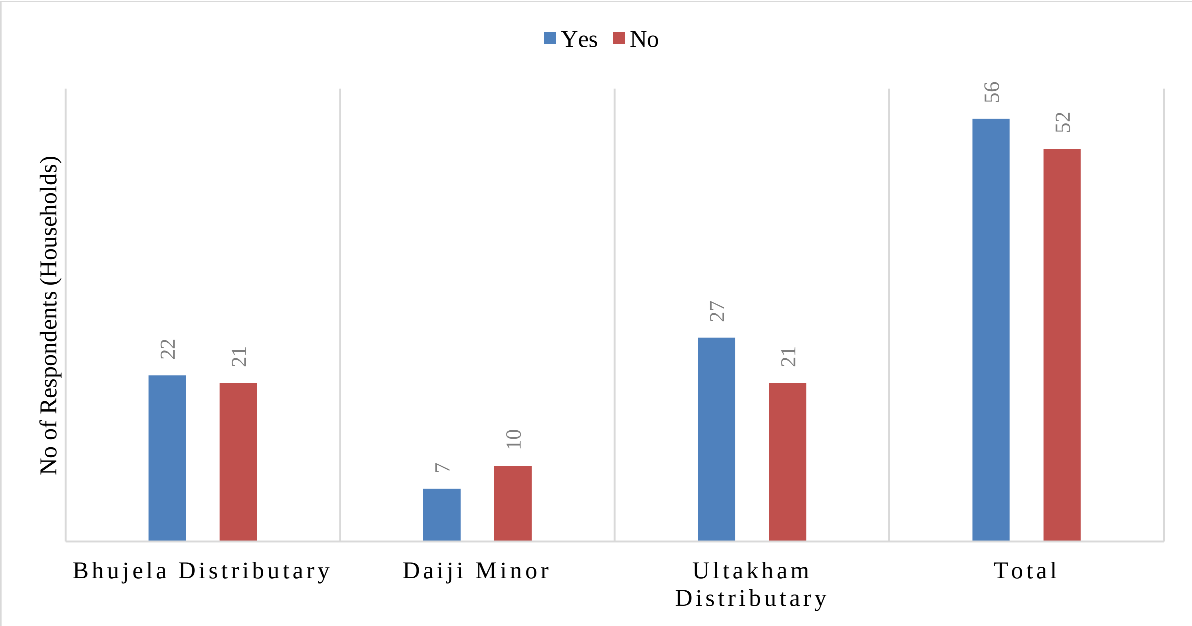

Figure 14: Awareness about WUAs among Farmers

When asked the aware farmers about their satisfaction with the role of the WUAs, household responses showed mixed perceptions. The largest share of respondents rated the WUA's role as "Good", followed by "Poor" and "No Opinion". A smaller number of respondents considered the WUA's role to be "Very Poor" or "Very Good".

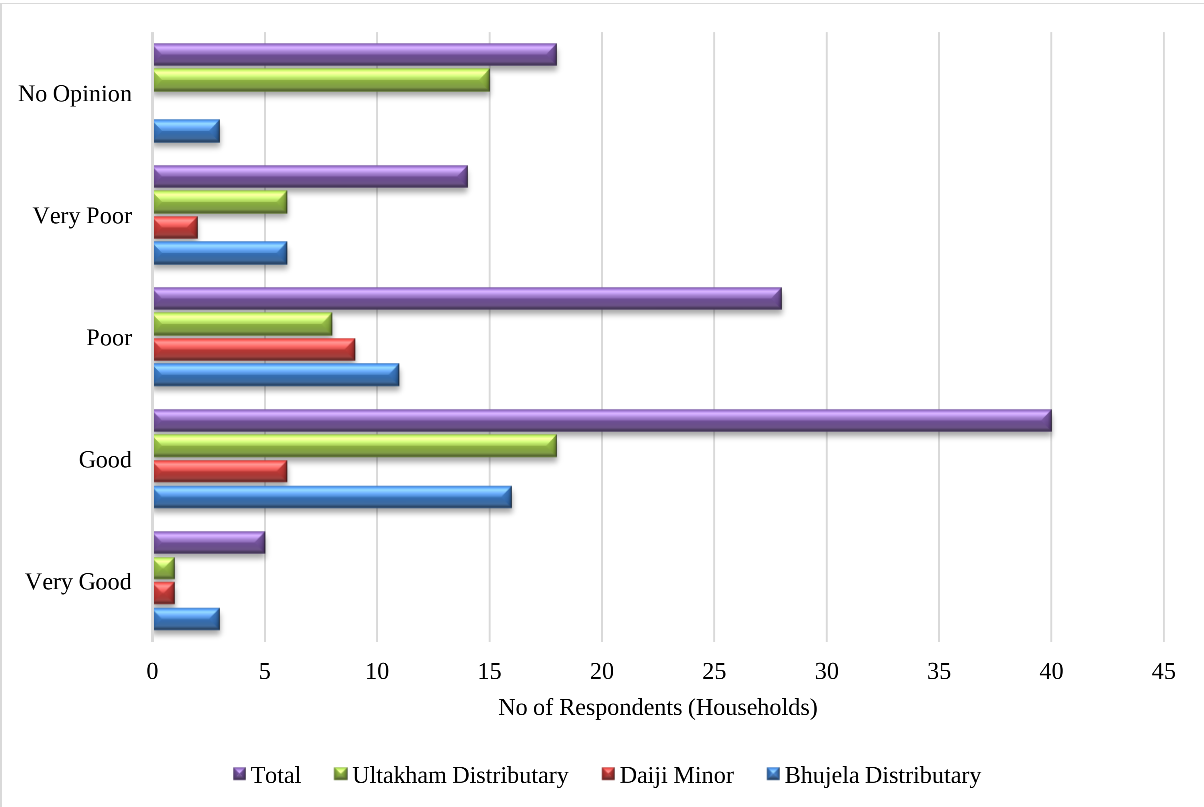

Figure 15: Farmers Satisfaction with the Roles of Current WUAs

Overall System Rating and Farmer Satisfaction

The assessment of the functioning of the Mahakali Irrigation System Phase I (MIS-I) indicates that farmers hold a generally moderate perception of system performance. The majority of respondents (42 households) rated the system functioning at 3 (average) on a 5-point scale. A further 29 households provided a relatively better rating of 4 (good), while only 2 households rated it at the highest score of 5 (very good). On the lower side, 14 households rated the functioning at 2 (poor), and a small number (7 households) gave the lowest score of 1 (very poor). Distributary-level responses show a similar trend with the largest concentration of ratings clustered around the mid-point (3). The moderate ratings reflect concerns about critical challenges identified earlier in the study.

The survey also examined farmer satisfaction with the overall performance of MIS-I, and the results show a predominance of positive but cautious perceptions. The largest group of respondents (57 households) reported being Satisfied, while 10 households expressed being Very Satisfied. On the other hand, 30 households reported a Neutral stance, reflecting uncertainty or mixed experiences. Negative perceptions were less common, with 6 households Unsatisfied and only 5 households Very Unsatisfied. The relatively high proportion of satisfied households suggests that MIS-I continues to play a vital role in supporting agricultural livelihoods, but the presence of dissatisfied and neutral households' points to localized inefficiencies and inequities in service delivery.

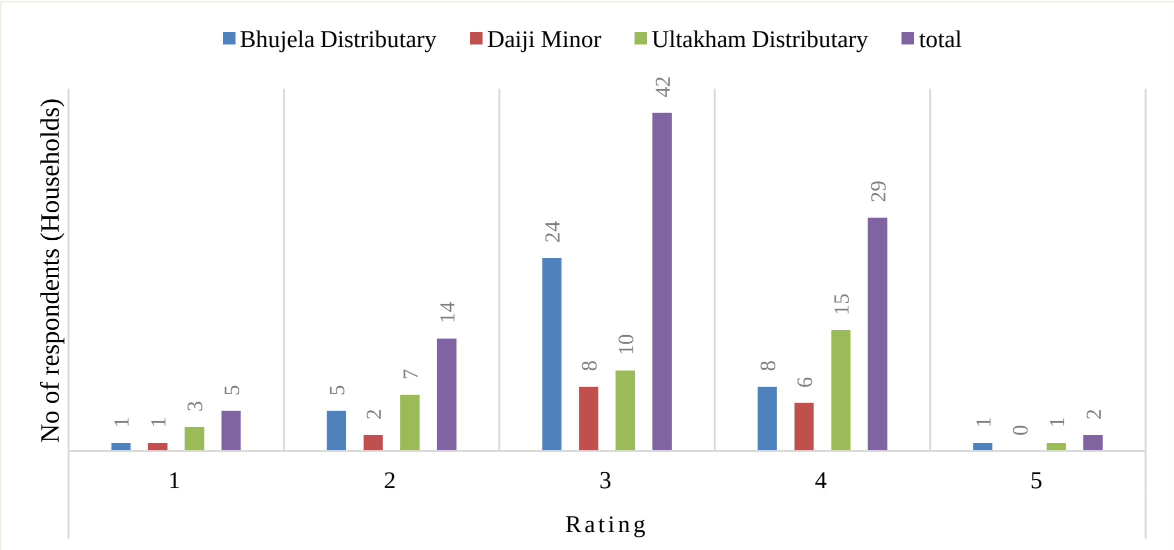

Figure 16: Rating of the Functioning of MIS-I Irrigation System

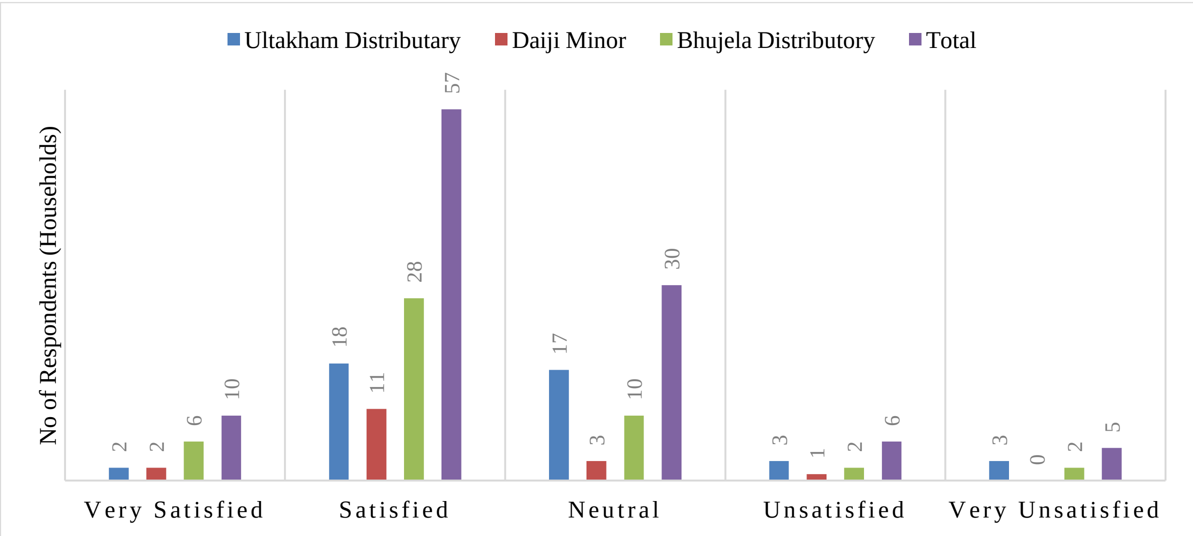

Figure 17: Farmers Satisfaction with Overall Performance of MIS-I irrigation system

Areas of Improvements for Enhancing Performance

The household survey identified key areas for improving the Mahakali Irrigation System Phase I. Most respondents (43%) highlighted the need to enhance maintenance schedules, indicating poor upkeep as a major challenge. Upgrading technology and sensors (17%) and expanding network coverage (15%) were also prioritized, reflecting concerns over efficiency and equitable water distribution. Additionally, 16% emphasized promoting water-saving techniques, while 9% stressed the need for farmer training and updates. Overall, the findings suggest that while infrastructure improvements are viewed as most urgent, integrating capacity-building and sustainable practices will be essential for enhancing system performance and long-term reliability.

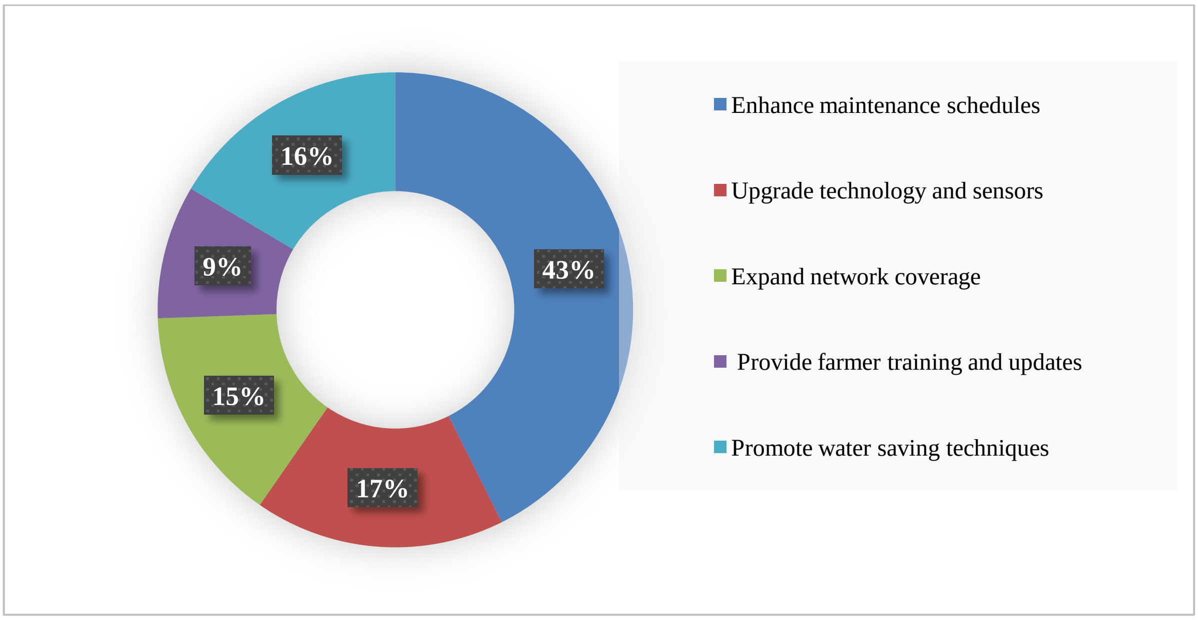

Figure 18: Areas of Improvements for Enhancing Performance

Field Observation

Field inspections of the canal network revealed multiple structural and operational deficiencies. Vegetation growth within tertiary canals (Fig. a) obstructs water flow, reducing conveyance efficiency and contributing to unequal distribution. At Bhujela, excessive water accumulation (Fig. b) suggests poor regulation and lack of timely discharge management, which can result in localized flooding and wastage. Conversely, areas such as Ultakham experience water scarcity (Fig. c), underscoring spatial inequity in water availability caused by ineffective allocation and conveyance losses. Structural degradation was evident, with several regulating structures damaged (Fig. d). These impairments disrupt controlled water release and compromise irrigation scheduling, directly affecting agricultural productivity. Farmers have increasingly resorted to alternative irrigation methods (Figs. e and f), which reflect declining trust in the canal system's reliability.

The observed problems collectively point to inadequate maintenance and weak institutional regulation. Sediment removal, vegetation clearance, and periodic repair of control structures appear neglected, resulting in inefficiencies across the distribution network. Without systematic upkeep and stronger regulation, the canal's role in ensuring equitable and efficient irrigation delivery will remain compromised.

Figure 19: Areas Photographs of Field Observations Representing Existing Problems

Addressing SDGs

The Mahakali Irrigation System, Phase-I project plays a crucial role in advancing Sustainable Development Goals (SDGs) by enhancing agricultural productivity, promoting efficient water management, and building climate resilience. Through improved irrigation systems, the project directly contributes to SDG 2 (Zero Hunger) by boosting crop yields, supporting smallholder farmers, and ensuring sustainable food production practices. In alignment with SDG 6 (Clean Water and Sanitation), it fosters efficient water use and integrated management to balance agricultural and regional needs. The project also supports SDG 12 (Responsible Consumption and Production) by encouraging the sustainable use of resources and reducing food loss linked to water scarcity. Moreover, by strengthening adaptation to droughts and climate variability, it contributes to SDG 13 (Climate Action). Additionally, efficient irrigation protects soil health and ecosystems, addressing SDG 15 (Life on Land). Overall, evaluating this project underscores its broader role in sustainable agriculture, resource conservation, and climate adaptation as highlighted in the figure below.

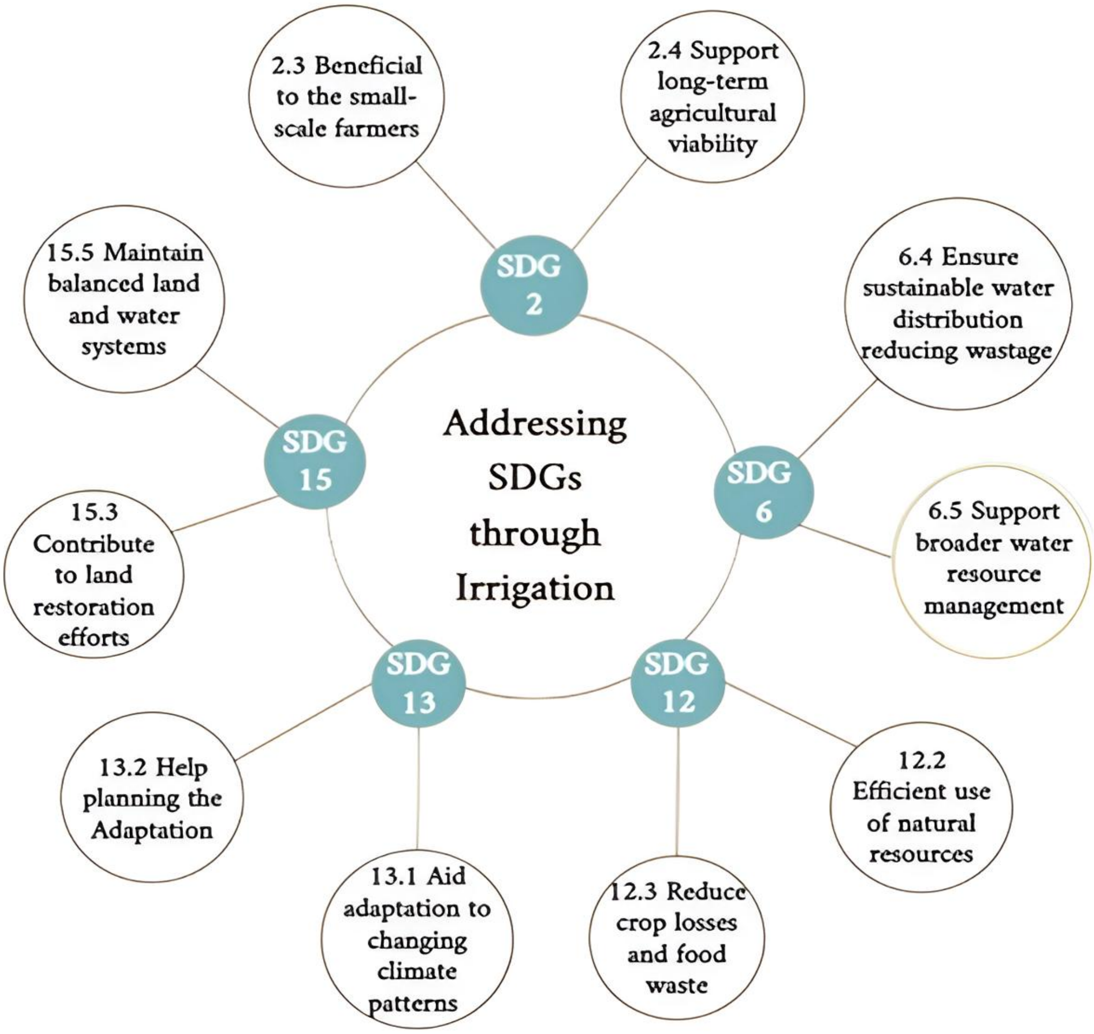

Figure 20: Relevance of the Study with SDGs

Conclusion

The performance evaluation of the Mahakali Irrigation System Phase I (MIS-I) reveals that several operational and institutional challenges continue to limit its overall effectiveness though the project has made substantial contributions to agricultural productivity, household income, and food security in Kanchanpur. The system has facilitated improved crop yields, with most households reporting moderate to significant gains, and enabled diversification of crops. However, the benefits are not equitably distributed across the command area, with tail-end farmers experiencing greater water scarcity and reduced reliability compared to those at the head reach.

Survey findings highlight that 40% of farmers experience water shortages during critical agricultural periods, underscoring the need for improved seasonal regulation and equitable allocation. Maintenance deficits, reported by 24% of households, further reduce system efficiency due to blockages, sedimentation, and vegetation growth. Field inspections verified these findings, revealing canal degradation, damaged control structures, and inadequate vegetation clearance. Although Water User Associations (WUAs) were established to address these issues, nearly half of farmers remain unaware of their role, and satisfaction levels with WUA performance remain mixed.

In terms of improvement priorities, farmers emphasized enhancing maintenance schedules (43%) as the most urgent intervention, followed by upgrading monitoring technology (17%), expanding network coverage (15%), promoting water-saving practices (16%), and providing farmer training

(9%). These responses demonstrate that physical and structural interventions remain the foremost need, but must be complemented by farmer capacity-building and institutional strengthening.

Based on the study findings, several actionable strategies are recommended to enhance the reliability, efficiency, and farmer-centered performance of the irrigation system. These include establishing a dedicated maintenance fund, enforcing rotational water distribution, rehabilitating critical structures, managing sedimentation and vegetation, and strengthening Water Users' Association (WUA) operations.

Acknowledgement

The authors gratefully acknowledge Asst. Prof. Toran Prasad Bhatta and Asst. Prof. Janardan Joshi, School of Engineering, Far Western University, for their valuable guidance and support during the course of this study. Authors would also like to thank all the respondents who helped during data collection.

Conflicts of Interest

The authors declare no conflict of interest.

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