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Efficient Operation of Minipe Left Bank Canal Irrigation Scheme to Satisfy Irrigation Demands

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Abstract: In Sri Lanka, agriculture depends heavily on irrigation, particularly during dry seasons. Despite its importance, the country faces persistent water deficit challenges due to population growth and operational inefficiencies. Water scarcity is especially severe for farmers located at the tail end of irrigation schemes such as the Minipe Left Bank Canal. Despite efforts under the Minipe Left Bank Canal Rehabilitation Project to increase upstream water storage, operational inefficiencies and mismanagement hinder effective water distribution, resulting in continued shortages for tail-end farmers. This study aims to improve water distribution within the Minipe Left Bank Canal irrigation system through reforms in water rotational scheduling and crop diversification. A scenario-based simulation modelling approach using the Water Evaluation and Planning (WEAP) software was employed to optimize water allocation by balancing supply and demand priorities. The research process involved detailed data collection and the estimation of crop irrigation requirements using the CROPWAT 8.0. By simulating the irrigation system's operation, a water balance framework was applied to develop sustainable water management strategies. The study introduces an efficient operational pattern designed to meet crop water requirements during the Yala and Maha seasons. The findings can contribute to equitable water distribution and sustainable water management in Minipe Left Bank Canal irrigation scheme, thereby increasing the agricultural productivity in Sri Lanka.

Keywords: CROPWAT, Crop Diversification, Water Rotation Schedule, WEAP

1. Introduction

Irrigation plays a vital role in sustaining agriculture, particularly during dry seasons when rainfall alone cannot adequately supply the water needed for cultivation. In Sri Lanka, where agriculture is a cornerstone of economic growth, irrigation schemes have long been essential for ensuring reliable water availability. Paddy cultivation alone accounts for over 70% of the total irrigation water usage [1]. However, water scarcity remains a significant challenge, worsened by population growth, limited water resources, and inefficiencies in water management [2]. Sri Lanka's irrigation schemes frequently face challenges in distributing water evenly, with tail end farmers often experiencing shortages compared to those closer to the canal head.

The farmers at the tail end often experience severe water shortages due to increasing inequality in distribution along the length of the canal [3]. This challenge is evident in the Minipe Left Bank (LB) irrigation scheme, where inefficient water allocation has adversely impacted tail-end farmers [4,5]. To mitigate these issues, initiatives such as the Minipe Left Bank Canal Rehabilitation Project (MLBCRP) have been implemented, including raising the Minipe anicut by 3.5 meters to increase upstream water storage. Despite these efforts, effective water distribution remains a concern and head tail disparity still exists [6,7].

To develop an effective water distribution system, it is essential to consider both water availability from the catchment and the crop water demand. In the Minipe LB Canal irrigation scheme, paddy is the dominant crop.

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Although crop diversification has been introduced as a strategy to reduce unmet water demand, the potential of implementing alternative cropping pattern remains underexplored [8]. Identifying ideal cropping patterns could further enhance water-use efficiency. Additionally, revising water rotation schedules offers another opportunity to improve water distribution and reduce unmet demand [9]. However, these aspects have not yet been systematically evaluated in the Minipe LB Canal irrigation scheme. Investigating how modified cropping patterns and water rotation scheduling can contribute to more equitable and efficient water use is critical for enhancing the operational performance of the scheme. Therefore, it is vital to develop a strategic operational plan for the Minipe LB Canal irrigation system that ensures efficient water allocation based on crop water requirements (CWR) in the Yala and Maha seasons.

To estimate irrigation demands in the command area, CROPWAT software is recommended for its efficiency in calculating CWR with minimal data input [10]. Additionally, the Water Evaluation and Planning (WEAP) system is employed to simulate operational patterns, considering CWR and canal inflows. WEAP, a water allocation and balancing tool, optimizes water distribution under scarcity, that integrates user-defined demand priorities and supply preferences [11]. By implementing a refined operational strategy, this study aims to minimize unmet irrigation demands within the Minipe LB command area, ultimately enhancing cultivation and ensuring equitable water distribution, particularly for tail-end farmers.

2. Minipe Scheme

The Minipe scheme is a key component of the Mahaweli Development Programme, functioning as an important diversion point that channels irrigation water through both its left and right bank canals. Central to this system is the Minipe Anicut, a concrete gravity structure measuring 225 meters in length, with a maximum height of 13 meters and a crest level situated at 114 meters above sea level. This structure serves as the main control point for directing water into the LB and Right Bank (RB) canals, which are designed to carry flows of 22 m^3/s and 64 m^3/s, respectively.

Located upstream, the Rantambe reservoir supports the water supply to the Minipe anicut by releasing water twice each day to meet peak electricity demand through hydropower generation. The Minipe LB Canal, which extends for about 74 kilometres, is an unlined canal constructed along the natural contour of the land. It provides irrigation to a command area measuring 7,020 hectares. To enhance administrative management, this area is divided into four stages, and each stage is further separated into two sections. These are identified as Stage 1.1, Stage 1.2, and so on. Table 1 presents the details of the various stages within the command area.

Table 1 - Stages of Minipe Left Bank Canal Irrigation Scheme

Stage	Section	Location (km)	Command Area (ha)
1	1	0 - 17	901
	2	17 - 31	1229
2	1	31 - 42	1007
	2	42 - 50	1076
3	1	50 - 58	832
	2	58 - 64	802
4		64 -74	1083

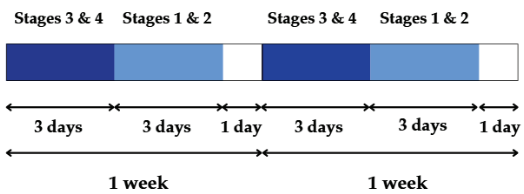


Figure 1 - Current Water Rotation Schedule

Paddy cultivation in the Minipe LB irrigation scheme is confined to the Maha season. Although the Yala season is also intended to focus on paddy, the planned integration of upland crops during the Yala season has not been effectively implemented, as reflected in seasonal summary reports.

3. Methodology

Figure 2 presents the primary methodology employed in the study, beginning with the data collection phase. A stage-wise analysis was adopted to simulate the operation of the irrigation system considering all the stages of the Minipe LB canal. All the data required for the study were acquired as the first step for the considered period of 2015 to 2019. The software CROPWAT 8.0 was utilized to calculate CWR [12]. Subsequently, the operation of the irrigation system was simulated using WEAP, a water balance-based modelling tool, incorporating the estimated irrigation water demands, inflows, and outflows from the Anicut [13].

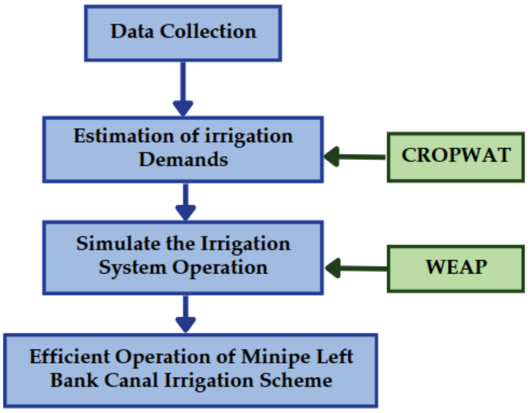


Figure 2 - Outline of the Methodology

3.1 Data Collection

Daily rainfall data were obtained from rainfall gauging stations at Mapakadawewa and Girandurukotte. The study's dataset also included discharges from the Minipe Anicut, command areas, cropping periods, sowing dates, and daily meteorological data from Girandurukotte. Figure 3 shows the location of the two rain gauge stations used while also illustrating the relevant command areas allocated for each Stage and Section.

The inflows coming into the Minipe LB canal were identified based on authors' previous study [8]. Furthermore, the Minipe anicut releases to the LB canal were gathered from 2015 to 2019.

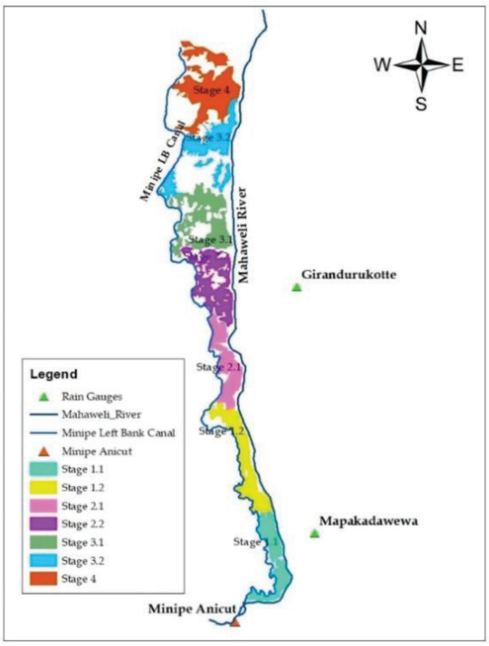


Figure 3 - Rainfall Gauging Stations

3.2 Estimation of Irrigation Demands

The CWR for the Minipe LB canal command area was estimated using CROPWAT 8.0, employing the Penman-Monteith method. Daily climate data from Girandurukotte, spanning 2015 to 2019, were used to estimate the reference evapotranspiration (ETo). The needed climatic variables included relative humidity, maximum and minimum temperatures, sunshine hours and wind speeds. Radiation (MJ/m^2/day) and Eto (mm/day) were obtained as outputs by feeding the climatic data. The Penman Monteith method was selected to determine Eto in CROPWAT 8.0 software.

Daily rainfall data from 2015 to 2019 was used to calculate effective rainfall. Rainfall data from Mapakadawewa were used to estimate CWR for Stages 1 and 2, while data from Girandurukotte were used for Stages 3 and 4. USDA soil conservation service method was selected to calculate the effective rainfall. Mostly, paddy is cultivated in the command area of Minipe LB canal in the Yala and Maha seasons. Therefore, only paddy crops were considered when estimating the CWR for the Business-As-Usual (BAU) Scenario in both the seasons. Accordingly, crop data of Paddy was fed into the system. The actual evapotranspiration was obtained by multiplying Eto by crop coefficients.

The Minipe LB canal operational pattern was improved by reducing unmet demands. Since the rainfall in Yala season is less in comparison with Maha season, it was selected to introduce a crop diversification to the Yala season. Crop diversification was advantageous for lands that did not receive adequate irrigation for paddy cultivation [5]. For this purpose, less water-intensive crops like Millet, Maize, and Soya Bean were suggested [14].

Irrigation schemes were developed to CWR for the Yala season by giving crop patterns. As shown in Figure 4, two cropping patterns were considered for the Yala season. In Cropping Pattern 1, 70% of the land was allocated to paddy and 30% to other field crops (OFCs) comprising 10% maize, 10% green gram, and 10% soyabean. In Cropping Pattern 2, 50% of the land was allocated to paddy and 50% to OFCs, consisting of 20% maize, 20% green gram, and 10% soyabean. These cropping patterns were chosen to represent realistic levels of crop diversification that can be implemented, as farmers are generally reluctant to shift extensively from paddy to OFCs in the area [5]. Therefore, diversification beyond 50% was not considered. The sowing date for the Maha season was set as April 25th, and for the Yala season as November 25th. These dates were determined based on the water release schedules from the Minipe Anicut and by reviewing Seasonal Summary Reports (SSR) from multiple years [15,16]. Water application efficiency to the crops of the irrigation scheme was assumed as 60%, consistent with commonly used values for irrigation systems [17].

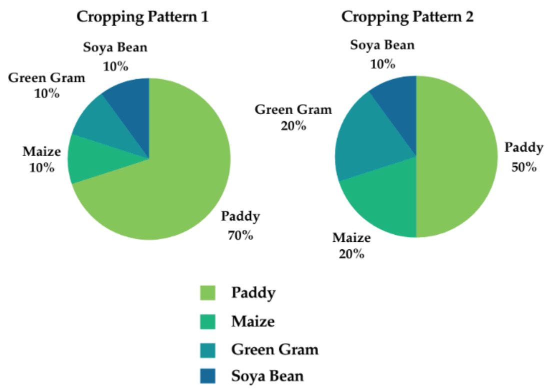


Figure 4 – Cropping Patterns

3.3 Simulation of Irrigation System Operation

A simulation model of the Minipe Left Bank canal irrigation system was developed for the 2015 to 2019 period using the WEAP software. This model utilized the inflow data to the canal along with the CWR within the system. The simulation approach is grounded in maintaining a water balance throughout the system.

As illustrated in Figure 5, the schematic model layout shows how nineteen streams from the Left Bank catchment connect to the canal system. The canal crosses the Heen Ganga using an aqueduct and intersects the Hasalaka Oya at a level crossing.

Activity levels on an annual basis for each demand point, as well as for the overall command area, served as inputs for simulating different stages of the Minipe Left Bank (LB) irrigation system. The model incorporated average daily water usage values, aligned with the canal's current 3-day rotational schedule. To reflect the actual operational cycle of the Minipe LB canal, variations in daily water demands were integrated into the model. Since the CROPWAT outputs were initially provided in 10-day intervals, these values were adjusted and evenly allocated to match the 3-day rotation framework.

Multiple operational scenarios were tested with the goal of enhancing system efficiency. Minimizing unmet water demands emerged as a primary focus for improving performance. Water availability was analyzed for both the Yala and Maha cultivation periods.

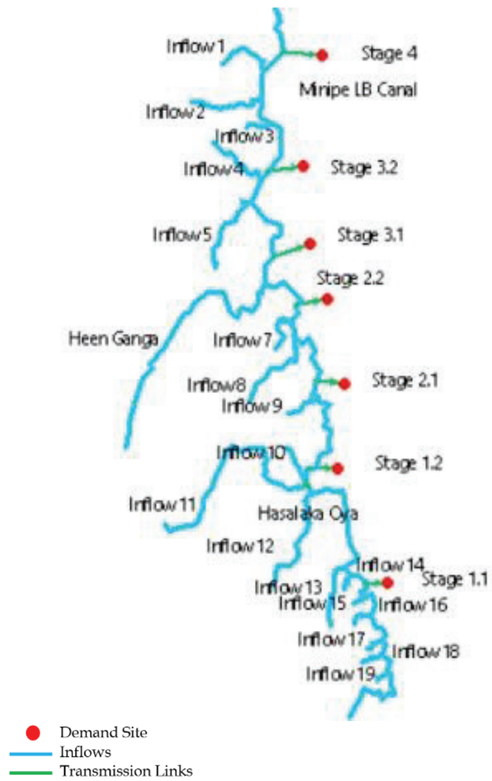


Figure 5 - Schematic Diagram in WEAP

To explore reductions in unmet water demand, different cropping patterns were applied across various stages of the Minipe LB canal under multiple scenarios. In addition, several scenarios explored modifications to the existing water rotational schedule, including continuous water supply to all stages and varying distribution patterns among stages. A separate scenario also considered a 15% increase in discharge from the Minipe Anicut, made possible by raising the anicut structure. Based on performance, the most effective scenarios, those involving changes to cropping patterns, water rotation schedules, and increased anicut discharge were combined and further evaluated to determine which Scenario achieved the greatest reduction in unmet demand.

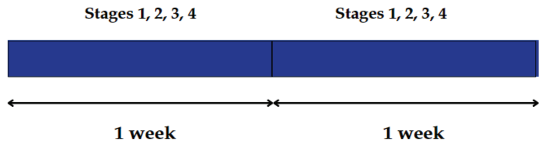
A summary of the scenarios analysed (Table 2) are mentioned below.

- **Scenario 1 -** Business as Usual (BAU) Scenario. 100% Paddy grown in Yala & Maha seasons.
- **Scenario 2 -** Crop pattern changed to 70% paddy and 30% OFCs in Yala season for stages 3 and 4.
- **Scenario 3 -** Crop pattern changed to 70% paddy and 30% OFCs stages in Yala season, for all stages.

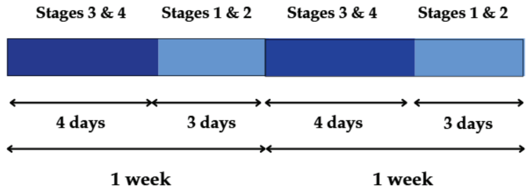
Table 2 - Scenario Summary

Scenario	Cropping Pattern		Stages	Water Rotation Schedule	Anicut Discharge Increase
	Yala	Maha			
1	100% Paddy	100% Paddy	Stages 1, 2, 3, 4	-	-
2	70% Paddy 30% OFC	100% Paddy	Stages 3, 4	-	-
3	70% Paddy 30% OFC	100% Paddy	Stages 1, 2, 3, 4	-	-
4	50% Paddy 50% OFC	100% Paddy	Stages 3, 4	-	-
5	50% Paddy 50% OFC	100% Paddy	Stages 1, 2, 3, 4	-	-
6	100% Paddy	100% Paddy	Stages 1, 2, 3, 4	Continuous	-
7	100% Paddy	100% Paddy	Stages 3,4	4 days	-
			Stages 1,2	3 days	
8	100% Paddy	100% Paddy	Stages 3,4	3 days	-
			Stages 1,2	4 days	
9	50% Paddy 50% OFC	100% Paddy	Stages 3,4	4 days	-
			Stages 1,2	3 days	
10	50% Paddy 50% OFC	100% Paddy	Stages 1, 2, 3, 4	Continuous	-
11	100% Paddy	100% Paddy	Stages 1, 2, 3, 4	-	15%
12	50% Paddy 50% OFC	100% Paddy	Stages 1, 2, 3, 4	Continuous	15%

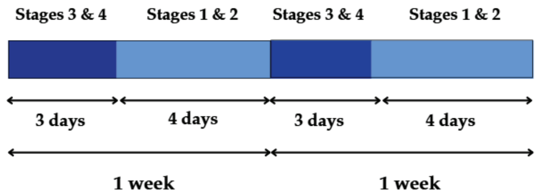
- **Scenario 4 -** Crop pattern changed to 50% paddy and 50% OFCs in Yala season for stages 3 and 4 in Yala season.
- **Scenario 5 -** Crop pattern changed to 50% paddy and 50% OFCs in Yala season for all stages.
- **Scenario 6 -** Existing water rotational schedule changed by continuously supplying water for all the stages.



- **Scenario 7 -** Existing water rotational schedule changed by supplying water to stages 3 & 4 for 4 days and to stages 1 & 2 for 3 days.



- **Scenario 8 -** Existing water rotational schedule changed by supplying water to stages 3 & 4 for 3 days and stages 1 & 2 for 4 days.



- **Scenario 9 -** Scenario 7 and Scenario 5 combined.
- **Scenario 10 -** Scenario 6 and Scenario 5 combined.
- **Scenario 11** - Discharges at the Minipe anicut were increased by 15%, subject to the canal capacity constraint of 22 m^3/s, to ensure operational feasibility.
- **Scenario 12** - Scenario 10 and Scenario 11 combined.

4. Results and Discussion

4.1 LB Catchment Inflows

Figure 6 illustrates the average monthly inflows to the Minipe LB canal [8].

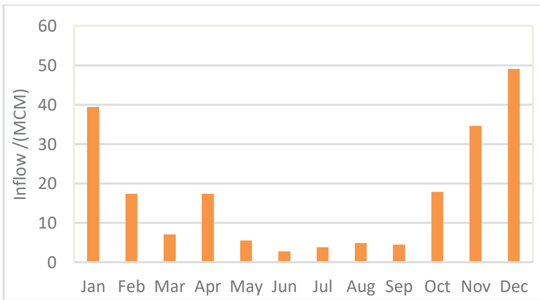


Figure 6 - Average Monthly Inflows

4.2 CROPWAT Results

The calculated CWR for the Maha season, based on data from the Mapakadawewa (Mapa) and Girandurukotte (Gira) rain gauge stations, was used as in the authors' previous study, since different cropping patterns were introduced only during the Yala season [8].

Figures 7 and 8 represent the calculated CWR for the Yala season, considering the three cropping patterns.

- 100% paddy
- 70% paddy and 30% OFCs
- 50% paddy and 50% OFCs

While it is observed that both rain gauge stations have a similar pattern for the variation of the CWR, it is also noted that the CWR reduces as the OFC percentage increases.

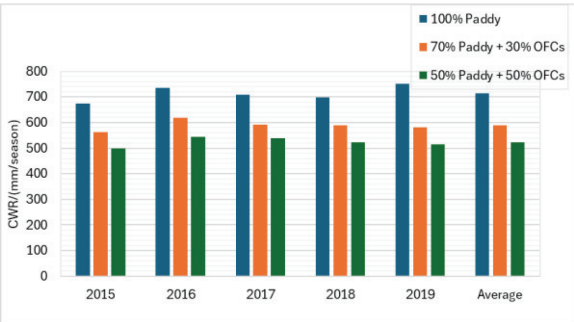


Figure 7 - CWR in Mapakadawewa for Yala Season for Different Cropping Patterns

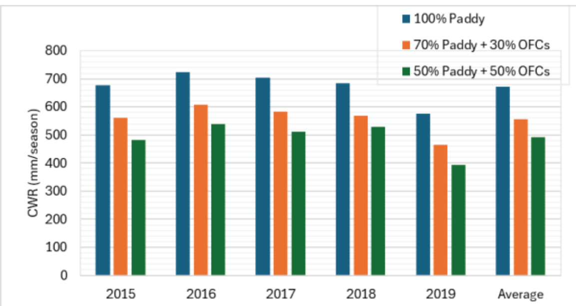


Figure 8 - CWR in Girandurukotte for Yala Season for Different Cropping Patterns

The average seasonal CWR reductions are 18 % and 17% by introducing the crop pattern of 70% Paddy and 30% OFCs considering rainfall of Mapakadawewa and Girandurukotte, respectively. The average seasonal CWR reductions are 26 % and 24% by providing the crop pattern of 50% Paddy and 50% OFCs considering rainfall of Mapakadawewa and Girandurukotte, respectively.

4.3 Simulation Results

BAU Scenario

Figure 9 illustrates the calculated annual average monthly variation in CWR, water supply delivered, and unmet demand across the entire command area from 2015 to 2019. The highest unmet demand was recorded in April. On average, the unmet demand during the Maha season was 6.8 MCM, while for the Yala season, it was 13.4 MCM.

A stage-wise analysis was conducted under BAU scenario to gain a more detailed understanding of the Minipe LB canal irrigation system. To improve accuracy and provide clearer insights, unmet water demands were calculated per square kilometre. Figure 10 presents the section-wise unmet demands for the Yala and Maha seasons. Stage 4 recorded the highest unmet demand in both seasons.

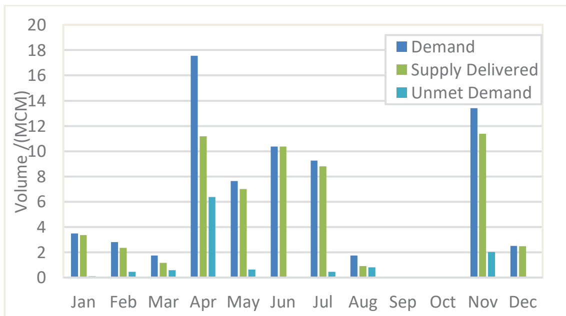


Figure 9 - Demands, Supply, and Unmet Demands for BAU Scenario

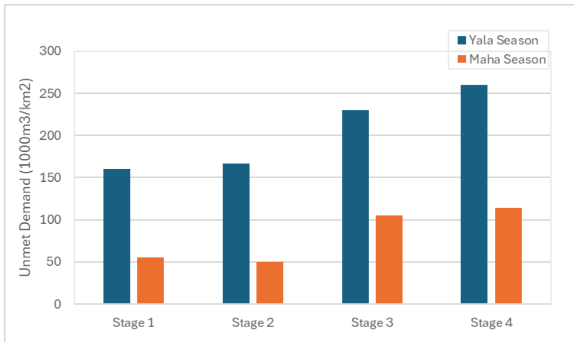


Figure 10 - Stage-wise Analysis for Unmet Demands in Yala and Maha Seasons

Unfulfilled irrigation needs during the Maha season were comparatively less than those in the Yala season, due to the increased rainfall received during that time. While in the Yala season, the unmet demands in Stage 1 and Stage 2 were in the range of 150,000 m^3/km^2 for Stage 3 and Stage 4, the unmet demands were within a range of 250,000 m^3/km^2. For the Maha season, by comparing with Stages 1 and 2, Stages 3 and 4 have doubled the unmet demands.

Figures 11 and 12 present the estimated unmet demands for the Yala and Maha seasons from 2015 - 2019, respectively.

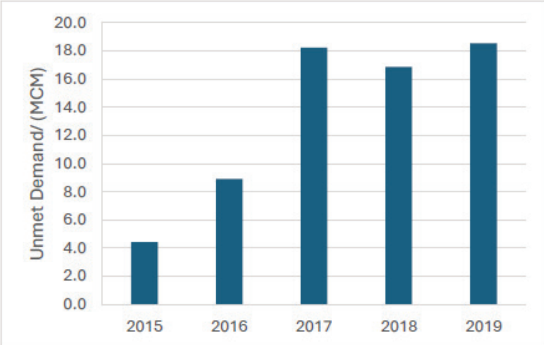


Figure 11 - Estimated Unmet Demands for the Yala Seasons

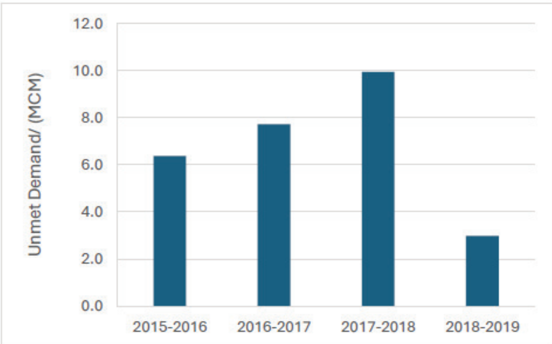


Figure 12 - Estimated Unmet Demands for the Maha Seasons

The average unmet demand for the Maha season is 6.8 MCM and 13.4 MCM for the Yala season. The highest value of unmet demand for the period from 2015 – 2019 is observed in the Yala season of 2019 as 18.5 MCM and the lowest value of unmet demand is observed in the Maha season of 2019 -2020 as 3.0 MCM.

Other Scenarios

Twelve scenarios were considered to find the optimum operation pattern to the Minipe LB canal irrigation scheme. The unmet demands of all the scenarios were compared with the BAU scenario.

Crop patterns were altered only during the Yala season since the unmet demands are significantly higher during the Yala season compared to the Maha season. Therefore, Scenarios 2, 3, 4 and 5 were only considered in the Yala Season.

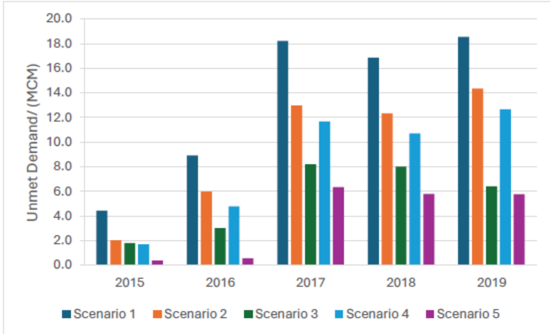


Figure 13 - Estimated Unmet Demands for Scenarios 2, 3, 4 and 5 in Yala Season

According to the results depicted in Figure 13, the most significant improvement is observed in Scenario 5, where 50% of paddy and 50% of OFCs are considered for the entire command area of the canal. In this scenario, the average seasonal unmet demand is reduced by 71.9% compared to the BAU scenario, with the average CWR in the Yala season decreased to 3.8 MCM. Thus, it is evident that Scenario 5 provides the most enhanced operational pattern for the Minipe LB canal among the considered scenarios, showcasing substantial reductions in unmet demand and CWR.

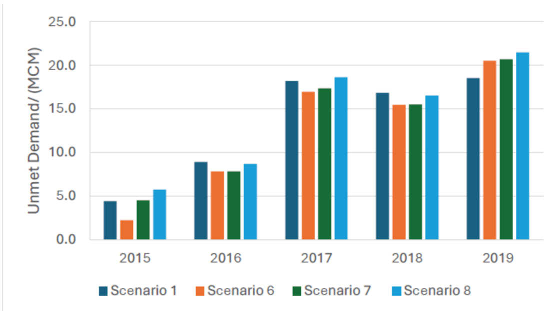


Figure 14 - Estimated Unmet Demands for Scenarios 6, 7 and 8 in Yala Season

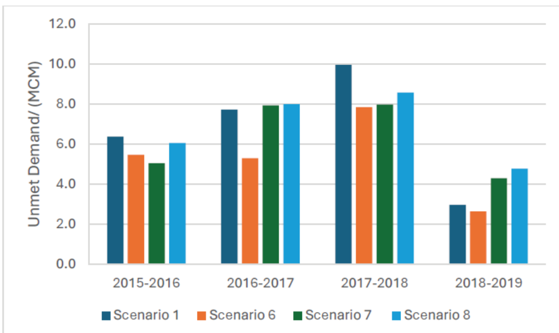


Figure 15 - Estimated Unmet Demands for Scenarios 6, 7 and 8 in Maha Season

Upon evaluation of the results presented in Figures 14 and 15, it is evident that Scenario 6, which continuously supplies water for all the stages, offers the most favourable operational pattern for the Minipe LB canal among Scenarios 6, 7, 8, with modest reductions in unmet demand and CWR for both Yala and Maha seasons. As in Scenario 6, continuous water supply is practical to implement, as water availability is sufficient and the canal capacity is adequate to support continuous flows.

For Scenarios 9 and 10 also, only Yala season was considered as presented in Figure 16.

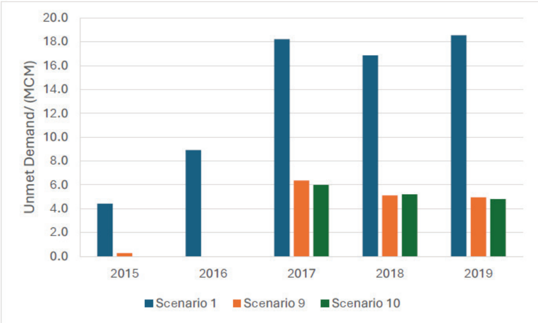


Figure 16 - Estimated Unmet Demands for Scenarios 9 and 10 in Yala Season

It could be observed that Scenario 10, where Scenarios 5 & 6 are combined, provides the most suitable operational pattern for the Minipe LB canal out of the two Scenarios.

Figures 17 and 18 represent the estimated unmet demands for Scenarios 11 and 12 in Yala season and Maha season, respectively.

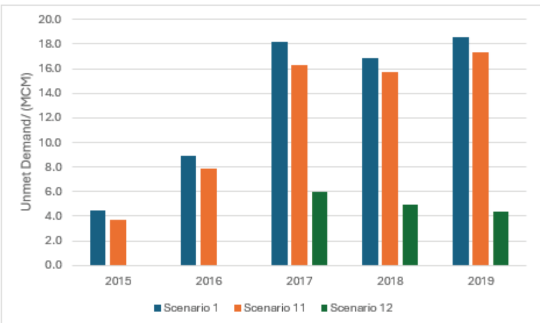


Figure 17 - Estimated Unmet Demands for Scenarios 11 and 12 in Yala Season

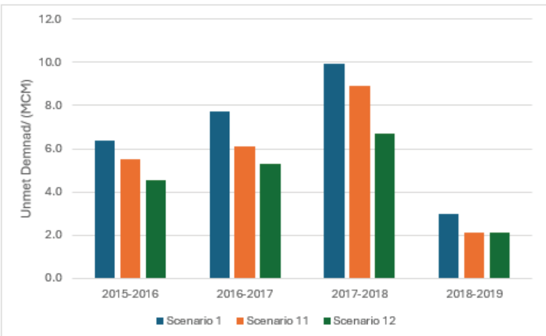


Figure 18 - Estimated Unmet Demands for Scenarios 11 and 12 in Maha Season

Since Scenario 11 addressed unmet demands by increasing the Minipe anicut discharge, it was integrated with Scenario 10 during the Yala season to form Scenario 12. In Yala season, increasing the discharge of Minipe anicut by 15% and modifying the water rotational schedule, including ensuring a continuous water supply for all growth stages and allocating 50% of the command area to paddy and 50% to OFCs, led to a 77.2% reduction in average seasonal unmet demand compared to BAU scenario. This adjustment results in a reduced average CWR of 3.1 MCM in the Yala season. In Maha season, the same 15% increase in discharge and continuous water supply strategy yielded a 31% reduction in average seasonal unmet demand relative to the BAU scenario, alongside a decrease in average CWR by 4.7 MCM. This analysis underscores Scenario 12 as the best-performing operational pattern for the Minipe LB canal under the assumed conditions during both Yala and Maha seasons, reflecting substantial enhancements in efficiency and resource management.

A summary of the percentage unmet demand reduction is given in Table 3 in comparison to the BAU Scenario.

Table 3 - Summary of the Unmet Demand Reduction

Reduction of Unmet Demands (%)												
Scenario	1	2	3	4	5	6	7	8	9	10	11	12
Yala	-	28.9	59.1	38.9	71.9	5.9	1.5	6.2	75.1	76.1	9.0	77.2
Maha	-	-	-	-	-	21.2	6.5	4.4	-	-	5.7	31.0

Figures 19 and 20 illustrate the stagewise unmet water demands for the Yala and Maha seasons, respectively, comparing Scenario 12 to Scenario 1. Since Scenario 12 demonstrates the most significant reduction in unmet demands, a stagewise analysis was conducted to quantify these improvements. The results indicate a substantial decrease in unmet water demands across all four stages in Scenario 12 compared to Scenario 1.

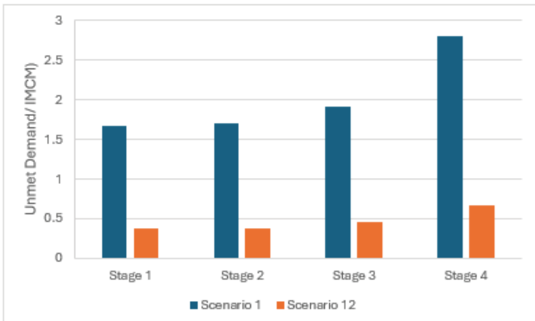


Figure 19 - Stage-wise Unmet Demands in Scenarios 1 and 12 in Yala Season

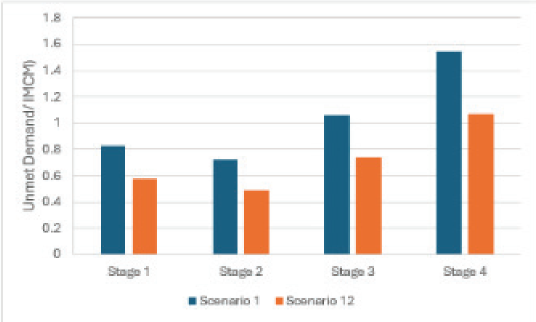


Figure 20 - Stage-wise Unmet Demands in Scenarios 1 and 12 in Maha Season

5. Conclusions

The study presents an enhanced operational pattern for the Minipe LB canal through scenario-based analysis. It was identified that the unmet water demands can be substantially reduced by 77.2% through the introduction of a crop pattern consisting of 50% paddy and 50% OFC at all stages, coupled with continuous water supply throughout these stages and a 15% increase in the Minipe anicut discharge during the Yala season. In the Maha season, unmet demands are notably decreased by 31% through the continuous supply of water for all stages, alongside a 15% increase in the Minipe anicut discharge.

Based on these findings, the adoption of Scenario 12 is recommended as the preferred operational strategy for the Minipe LB canal for the Yala and Maha seasons. This integrated approach significantly mitigates unmet demands, thereby enhancing operational efficiency.

6. Recommendations

To strengthen the reliability of the modelled unmet irrigation demand, future studies could incorporate validation on unmet demands by collecting field data on actual irrigated areas across different seasons. Much of the existing literature on unmet water demand at the tail end of the irrigation scheme is predominantly qualitative in nature, further quantitative research is needed to strengthen empirical evidence and improve assessments of irrigation performance. In this study, a uniform water application efficiency was assumed for all crops. However, efficiencies can vary by crop type, and incorporating crop-specific values is recommended for future research.

Further improvements in managing water scarcity could be achieved by investigating alternative crop combinations and rotation schemes, which can offer valuable insights into sustainable water management practices within agricultural systems. Furthermore, effectiveness of water use could be enhanced by adjusting planting dates. By assessing the impact of planting schedules on water usage and crop yields, strategies could be developed to maximize water conservation without compromising agricultural productivity. In addition to that, introducing intermediate field crops between the primary paddy cultivation seasons present an opportunity for further exploration. Studying the feasibility and benefits of integrating additional crops during fallow periods can contribute to enhancing overall agricultural sustainability and water resource management.

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