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Modernization of the left bank irrigation system of the Kaudulla reservoir of Sri Lanka

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ABSTRACT

Irrigation water management in the paddy cultivation area under the left bank canal of the Kaudulla reservoir (Kaudulla tank) in the North Central Province of Sri Lanka has become a serious issue due to limited water availability and inefficient water distribution infrastructure at present. Insufficient storage capacities of the village tanks in the cultivation area, low rainfall during some months and regulated inflow from the transbasin diversion to Kaudulla tank have had a significant impact on yield in the two cultivation seasons of the year. In this article, modernization of irrigation infrastructure in the command area was investigated for effective utilization of limited available water. The results of the calibrated and validated Hydrologic Engineering Centre - Hydrologic Modeling System (HEC-HMS) model and Crop Water and Irrigation Requirements Program (CROPWAT) model were used with Water Evaluation and Planning Model (WEAP) to evaluate the water balance and demand to identify the best investment for improving irrigation water supply to maximize the return. Economic analysis was carried out using the net present values for different modernization options. Accordingly, the construction of a new canal system and augmentation of the capacities of village tanks from the present total capacity of 3.8–20 MCM was found to be the most appropriate option. This intervention will increase the income from yield by 205 million with a payback period of 12 years in the Yala season.

Key words: CROPWAT, irrigation water management, Kaudulla reservoir, paddy cultivation, WEAP

HIGHLIGHTS

- Insufficient storage capacities of minor tanks, low rainfall during some months in the tank catchments and regulated diversion to the Kaudulla tank have had a significant impact on the cultivation area under Kaudulla tank situated in the North Central Province of Sri Lanka.
- A calibrated and validated HEC-HMS model and the CROPWAT model were used with WEAP to evaluate the water balance and demand to identify the best investment for improving the irrigation system based on the economic return.

INTRODUCTION

The Kaudulla reservoir (the Kaudulla tank) and the areas irrigable from the tank fall under Mahaweli system 'D' and are situated in Medirigiriya District Secretariat Division of the North Central Province of Sri Lanka (Figure 1). Drought is frequently experienced in the region; for example, 1,110 people from 350 families in Medirigiriya were affected by drought in the latter part of 2017 (Jayarathne 2016). Water scarcity for irrigated paddy cultivation in the area has led to poor cropping intensity, especially in the Yala (April–August) season, which is one of the two seasons in which paddy is cultivated every year, the other being Maha (November–March). An irrigation water management study implemented to investigate the efficiency under normal operating conditions at Kaudulla indicates that water management is comparatively efficient during Yala even with the limited water resource, but that rainfall over the demand area could be used more effectively as a substitute for irrigation water during the Maha season (Holmes *et al.* 1978). A case study carried out centering on the Wadigewewa and Nikahena small tanks in the irrigation area strongly recommends an increase of the tank capacities to store the ample rainwater received in the rainy season (Rekha 2014).

The existing cultivation areas amounting to 7,160 ha have the potential to receive water from the left bank (LB) canal of the Kaudulla reservoir (the Kaudulla tank). However, only 3,790 ha are supplied directly by the left bank canal at present, and the rest is by 35 rainfed small village tanks. Limited storage capacities of the tanks, low rainfall in the dry season and regulated inflow

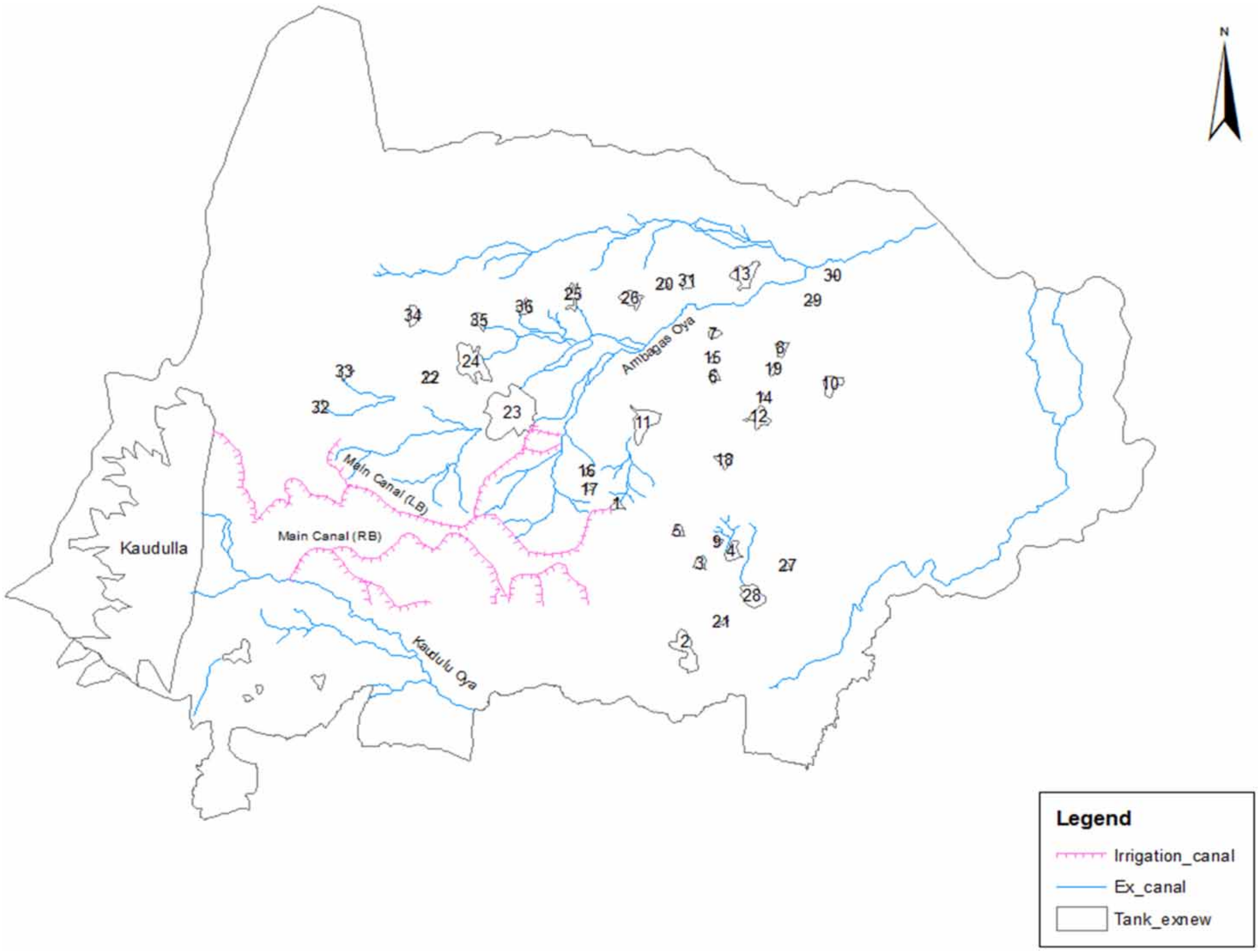

Figure 1 | Existing irrigation system used for the WEAP model.

to the Kaudulla tank have caused a significant temporal variation in paddy yield in the Kaudulla LB command area. It is against this background that this study is being carried out to propose appropriate modernization of the existing irrigation system to increase the yield derived from the LB command area. The study develops a model for water management in the left bank area to select the best intervention to maximize the return from investment while producing satisfactory yield under limited water availability, to support the farming families. The HEC-HMS model was applied to calculate the catchment yields of 35 village tanks. The results of the crop water requirement generated from the CROPWAT model were used with WEAP to evaluate the water balance and demand area coverage to identify the best investment for improving irrigation water supply to maximize the return. The best intervention among a few feasible structural interventions was identified based on the economic return.

METHODOLOGY

A calibrated and validated rainfall–runoff model generated using HEC-HMS was applied to calculate the catchment yields of 35 village tanks under the left bank canal of the Kaudulla tank (Figures 1 and 2; Table 1). The results of the crop water requirement generated from the CROPWAT model were used with WEAP to evaluate the water balance and demand area coverage.

An analysis was carried out using the CROPWAT and WEAP model applications to identify the best investment for improving irrigation water supply to maximize the return.

Method of analysis

LB canal irrigation areas are supplied with water by different methods. The cultivation area at the side of the first section of the LB canal is supplied with water directly from the canal through the anicut (weir) system. The rest of the area falls under

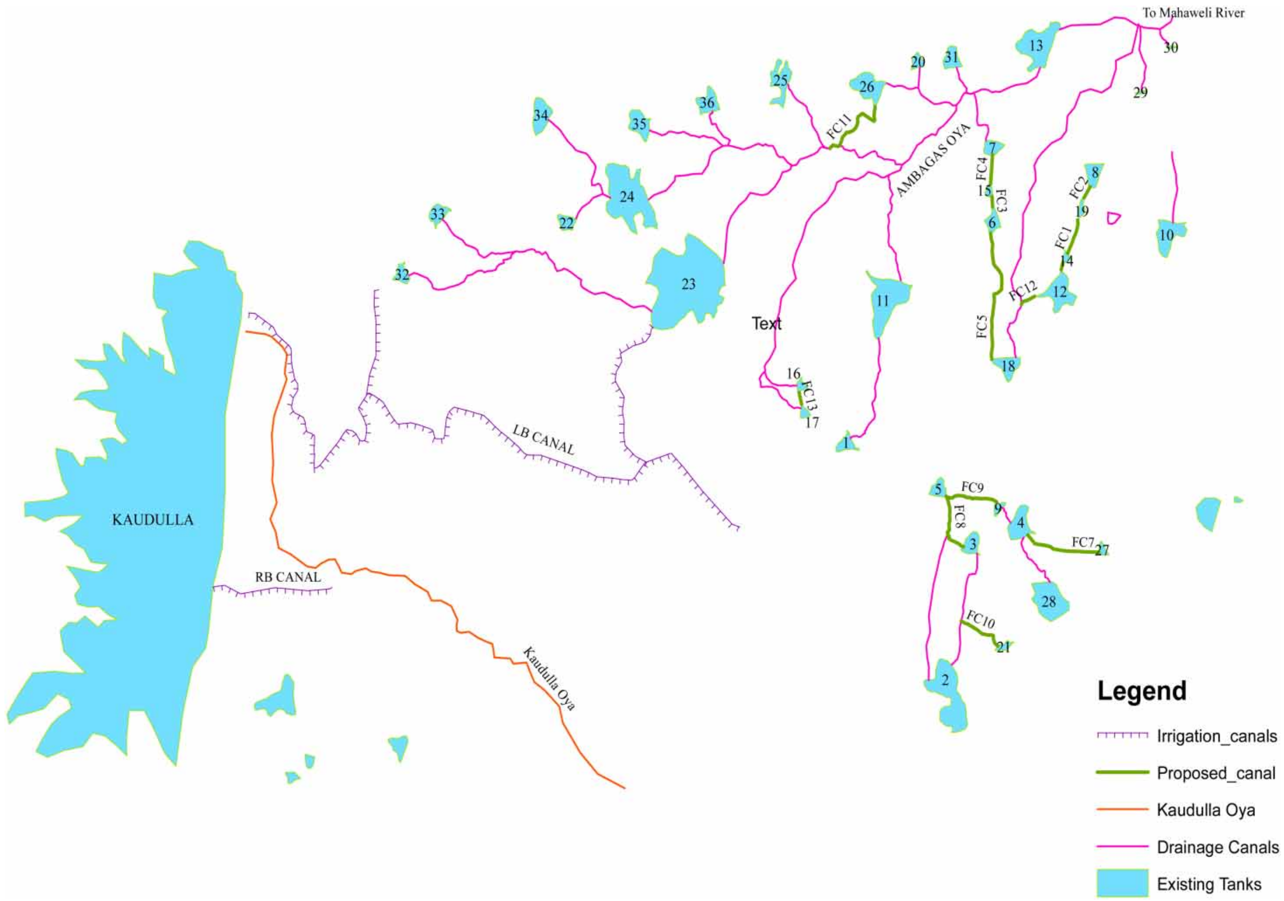

Figure 2 | Proposed irrigation system used for Case 1.

the command areas of 35 tanks and is supplied with water from the tanks, and these are supplemented by the LB canal of the Kaudulla tank to varying degrees depending on the availability of water in the Kaudulla tank.

Accordingly, two cases are considered for the analysis of irrigation water requirements in the LB canal irrigation area:

1. The irrigation demands of the area under minor tanks are met only by the tanks that are under improvement of the system independent of water from the Kaudulla tank, except for the anicut system. Simulation is done considering that the tanks receive inflow from their own catchments.

Five sub-cases are considered for simulation with augmentation of tank capacities under two options as per Table 2 and Figures 1 and 2.

2. The unmet irrigation demands of the area under minor tanks under Case 1 above are also met from the Kaudulla tank as shown in Figure 3.

Both cases are financially analyzed using the net present value method to ascertain the feasibility of the proposals.

The proposal for the new canal system is shown in Table 3 for supplying water to the village tanks to supplement the water release requirements in the season from these tanks. Feeder canals FC1–FC13 are considered for Case 1, and FC1–FC25 are considered for Case 2. Most of the feeder canals are tributaries of the Ambagasoya stream.

RESULTS AND DISCUSSION

The study carried out for the period of 2013–2017 reveals that the water available in the Kaudulla tank, which is fed by its own catchment and from the controlled releases from the Minneriya tank at present, is not sufficient to cultivate 3,790 ha of

Table 1 | Details of minor tanks

No.	Tank name	Coordinates Easting (m)	Northing (m)	Capacity (MCM)	Irrigable land (ha)	Catchment area (ha)
1	Damsopura wewa	231,116	328,505	0.116	371	53
2	Aluthwewa	233,321	323,600	1.111	216	254
3	Illukpitiya wewa	233,787	326,535	0.284	102	93
4	Gaminipura wewa	234,809	326,912	0.289	72	175
5	Rambawewa	233,093	327,614	0.305	88	94
6	Meegaswewa	234,236	332,918	0.261	85	139
7	Pathokwewa	234,214	334,368	0.174	56	53
8	Nikahenawewa	236,371	333,835	0.222	76	202
9	Sathpaththini	234,368	327,228	0.033	22	58
10	Elabatuwewa	237,997	332,665	0.347	78	242
11	Baybiya wewa	231,974	331,352	1.406	128	726
12	Kumbukunawa	235,681	331,505	0.958	71	366
13	Wadiga wewa	235,208	336,386	0.579	187	155
14	Kuda wewa	235,810	332,170	0.044	28	24
15	Badde wewa	234,172	333,500	0.043	15	17
16	Jayagampurawewa	230,154	329,648	0.048	32	44
17	Ekamuthu wewa	230,206	329,119	0.030	25	33
18	Rota wewa	234,569	330,037	0.173	262	177
19	Naripotawewa	236,809	332,975	0.059	32	47
20	Kadurugaswewa	232,616	336,034	0.102	74	95
21	Aruna wewa	234,501	324,480	0.100	159	73
22	Wedikachchiya	225,089	332,873	0.579	48	63
23	Halmillawewa	226,406	333,418	0.740	172	97
24	Weeragollawa wewa	229,735	335,670	0.050	50	70
25	Migollawawewa	231,579	335,525	0.056	97	107
26	Dambagodawela wewa	236,589	326,387	0.180	44	13
27	Palliyagodella wewa	235,476	325,394	0.320	337	73
28	Unakatuwa wewa	237,414	335,471	0.055	12	43
29	Kumarakanda wewa	238,034	336,341	0.060	203	139
30	Gallendiwala wewa	233,346	336,108	0.040	24	110
31	Tank T	221,570	331,824	0.035	26	28
32	Tank U	222,321	333,040	0.045	47	68
33	Tank W	224,551	335,025	0.030	44	107
34	Tank V	226,649	334,823	0.065	49	104
35	Tank S	228,155	335,218	0.055	39	54

paddy area fed by the left bank canal in the Yala season (Figure 4). Enhanced diversion from the Minneriya tank is unlikely in the near future due to the limited water allocation to the tank from the Mahaweli river development scheme.

Therefore, under this situation, it is not realistic to consider feeding the minor tanks from the Kaudulla tank during the water scarce months in the Yala season. Thus, the demand areas of the existing village tanks have to depend on their own catchment yields to cultivate 3,370 ha of land. Different investment options were considered, including the augmentation of eight selected tanks and construction of new canals.

Table 2 | Options for Case 1

Item	Tank name	Capacity (MCM)			
		Existing	**Proposed**	**Potential increase without acquisition of additional lands**	**Increase through acquisition of additional lands**
Option 1	Nikahena	0.222	3	0.44	2.56
	Elabatuwewa	0.347	2.5	0.71	1.79
Option 2	Babiya	1.406	4	1.45	2.55
	Halmiila	0.74	2	0.84	1.16
	Meegaswewa	0.261	1.5	0.42	1.08
	Migollawa	0.056	4	0.24	3.76
	Pathowewa	0.174	1	0.21	0.79
	Wadigewewa	0.579	2	0.74	1.26

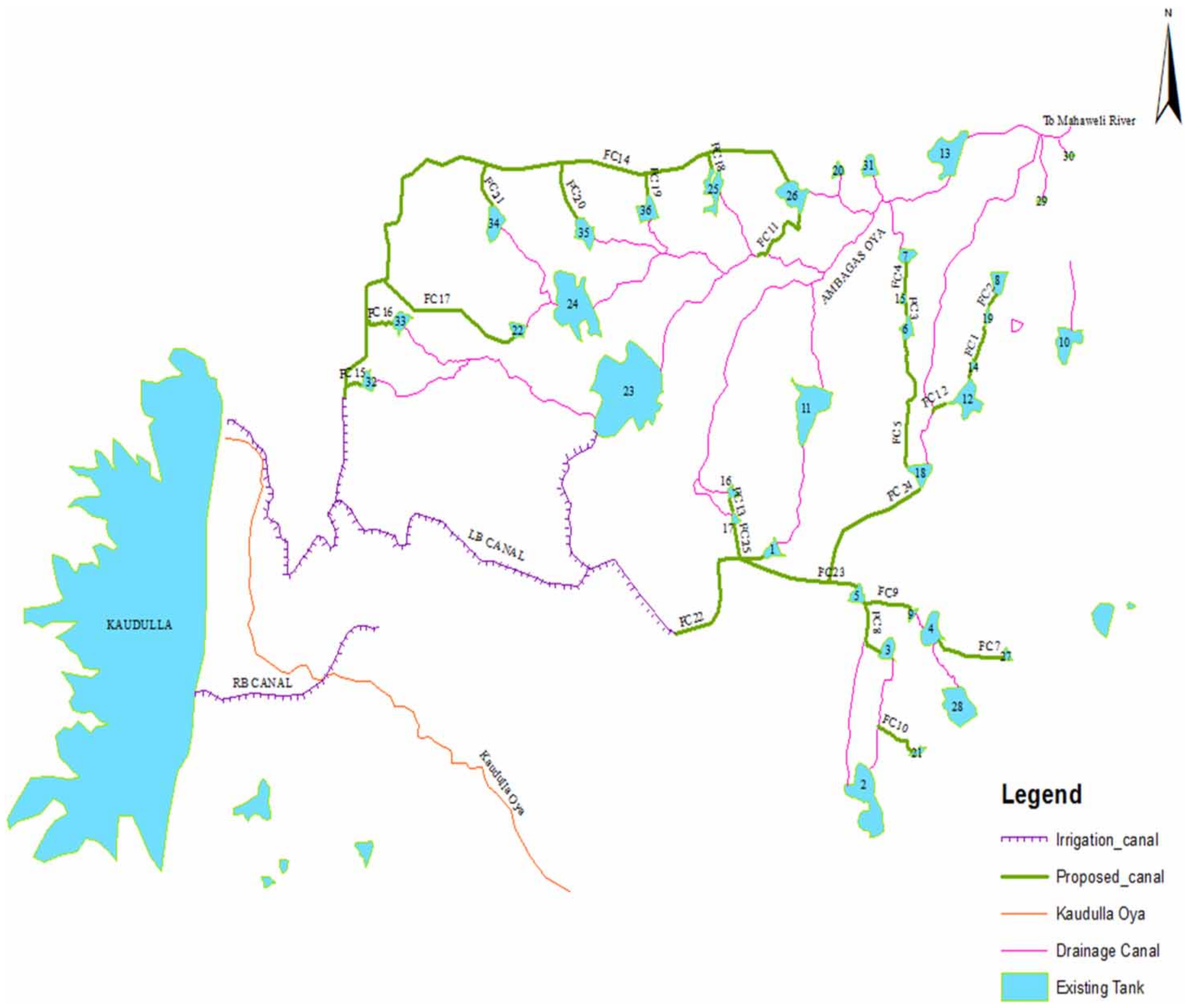

Figure 3 | Proposed irrigation system used for Case 2.

Table 3 | Proposed feeder canal system

Feeder canal	Length (m)	From	To
FC1	708	Kudawewa	Naripotawewa
FC2	264	Naripota	Nikahenawewa
FC3	209	Meegaswewa	Baddewewa
FC4	584	Baddewewa	Pathokwewa
FC5	2,726	Rotawewa	Meegaswewa
FC6	148	Kumbukunawawewa	Kudawewa
FC7	1,639	Gaminipurawewa	Dambagodawelawewa
FC8	1,281	Rambawewa	Illukpitiyawewa
FC9	1,143	Rambawewa	Sathpaththiniwewa
FC10	1,015	Illukpitiya wewa	Anurawewa
FC11	1,726	Ambagasoya bifurcation	Migollawa wewa
FC12	365	Rotawewa	Kumbukunawa
FC13	248	Ekamuthuwewa	Jayagampurawewa
FC14	15,108	LB Canal bifurcation	Migollawa wewa
FC15	383	FC 14 bifurcation	Tank T
FC16	746	FC 14 bifurcation	Tank U
FC17	3,544	FC 14 bifurcation	Wedikachchiya wewa
FC18	291	FC 14 bifurcation	Weeragollawa wewa
FC19	434	FC 14 bifurcation	Tank S
FC20	1,232	FC 14 bifurcation	Tank V
FC21	936	FC 14 bifurcation	Tank W
FC22	3,273	LB Canal bifurcation	Damsopura wewa
FC23	2,857	FC 22 bifurcation	Rambawewa
FC24	3,100	FC 23 bifurcation	Rotawewa
FC25	700	FC 22 bifurcation	Ekamuthuwewa

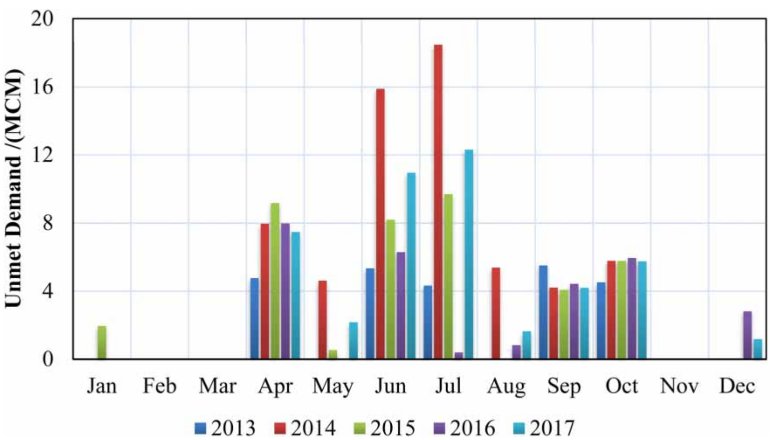

Figure 4 | Unmet water demand under the Kaudulla left bank canal.

WEAP model results

The unmet irrigation demands of the area under minor tanks of the existing system that are not dependent on water from the Kaudulla tank and are instead fed from inflows from their own catchments, for the period 2013–2017, are shown in Figure 5.

The analysis reveals that the annual unmet water demand from 2013 to 2017 varies from 33.75 to 51.86 MCM. The highest unmet demand is shown in the year 2015. Figure 6 shows the monthly unmet demand in 2015.

The maximum monthly unmet water demand of 16.58 MCM is seen in July 2015 of the Yala season.

A proposal for a new canal system is shown in Table 3. Feeder canals FC1–FC13 are considered for Case 1, and FC1–FC25 are considered for Case 2. Most of the feeder canals are tributaries of the Ambagasoya stream.

Figure 7 illustrates the results of the simulation carried out for monthly unmet demand for 2015 with a proposed improvement to the canal system of Case 1-b. The improvement reduces the unmet water demand from 16.58 to 16.35 MCM in July 2015, which is the most water-stressed month of the Yala season.

Figure 8 is the result of a decrease of unmet water demand to 16.35 MCM for the proposed new canal system with the augmentation of tank capacities without inundation of upstream infrastructures as described in Table 4 for July 2015 in the Yala season.

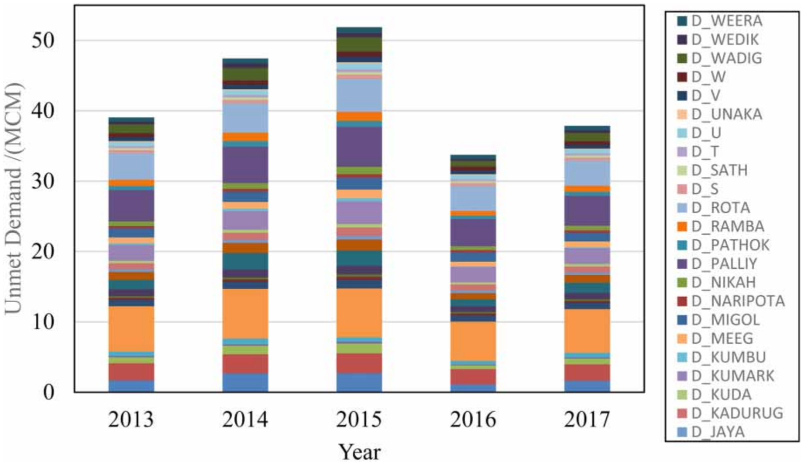

Figure 5 | Unmet demand for Case 1-a from 2013 to 2017.

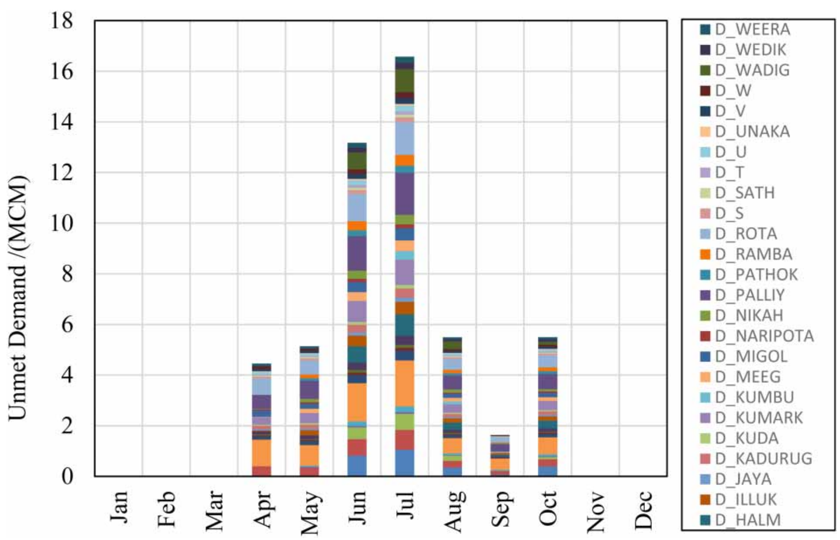

Figure 6 | Monthly unmet demand for Case 1-a for 2015.

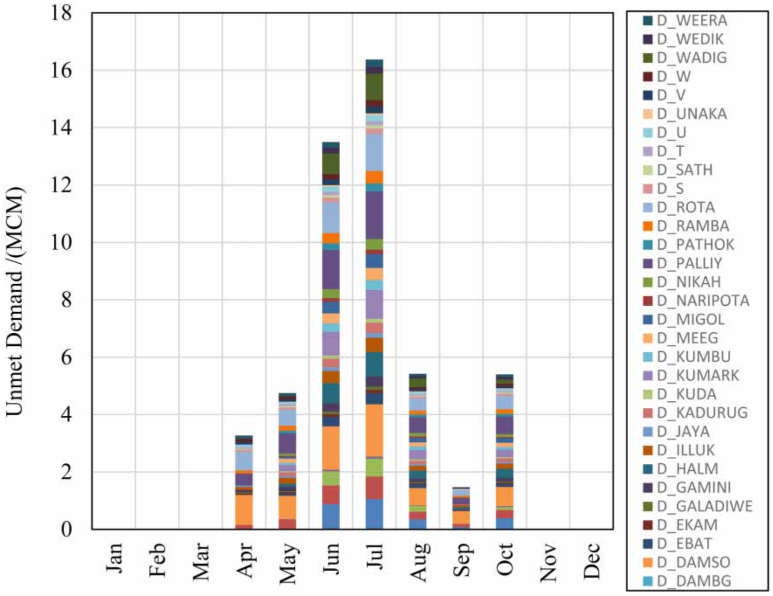

Figure 7 | Monthly unmet demand for Case 1-b for 2015.

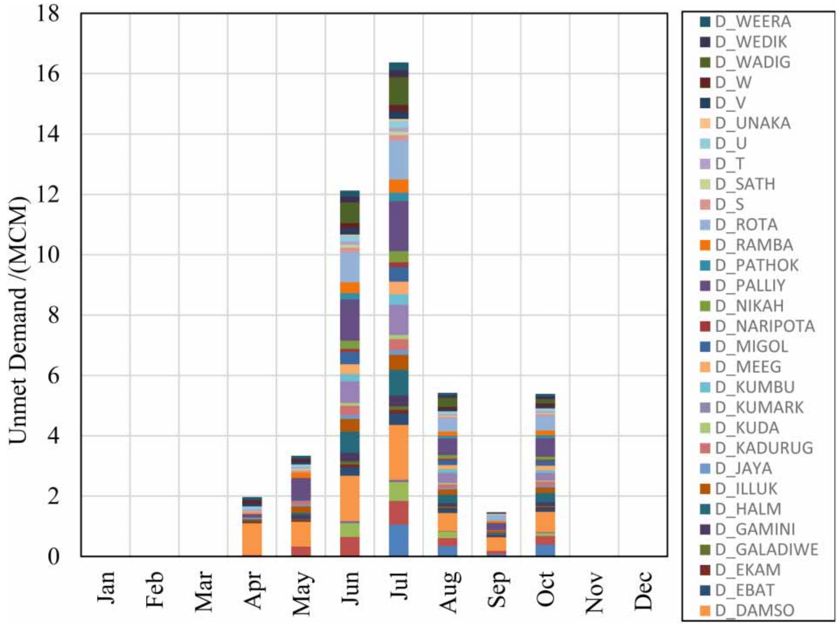

Figure 8 | Monthly unmet demand for Case 1-c for 2015.

Table 4 | Scenarios for Case 1

Case	Description
1-a	Present condition of tanks and canal system as in Figure 1
1-b	Proposed improvement to the canal system as in Figure 2
1-c	1-b and alternate by raising of spill level without inundation of upstream of eight tanks in Table 2
1-d	1-b and augmentation of proposed tank capacities of Option 1 as in Table 2
1-e	1-d and augmentation of proposed tank capacities of Option 2 as in Table 2

Figure 9 shows the decrease in unmet water demand to 14.78 MCM in July 2015 in the Yala season as a result of the proposed new canal system with augmentation of tank capacities of Option 1 in Table 4.

Figure 10 shows a further decrease in unmet water demand to 11.37 MCM in July 2015 in the Yala season because of the proposed new canal system with augmentation of tank capacities of Option 2 in Table 4.

The demand area coverage shown in Figure 11 of 12 selected demand sites varies from 0 to 100% in five cases analyzed in Case 1 for July 2015.

Figure 12 shows the unmet demand for Case 2 for 100% crop intensity.

Case 2 is shown to be the most favorable to reduce the water scarcity in the study area. However, this option is possible only if sufficient water is supplied from the Kaudulla tank to the minor tanks. It is evident from Figure 3(1) that even the supply of irrigation water from the Kaudulla left bank canal to the left bank irrigated area is not fulfilled in the Yala season. Hence, it is

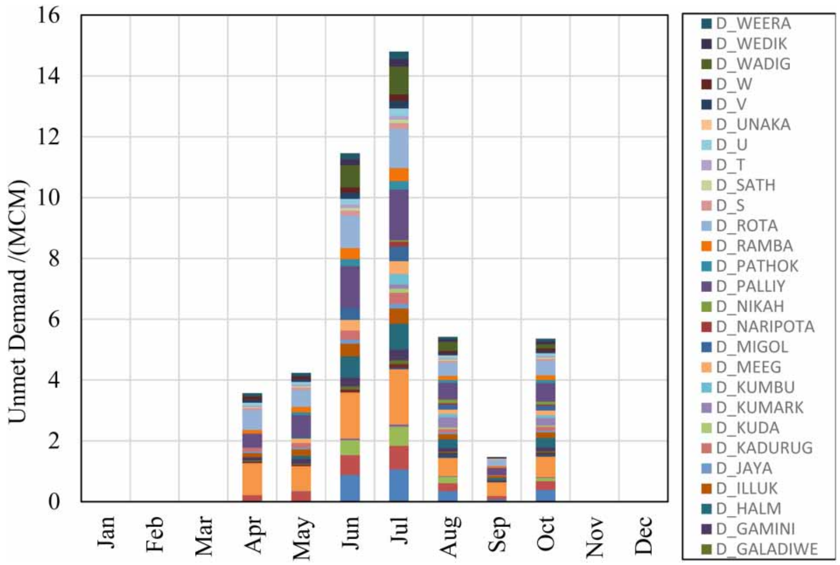

Figure 9 | Monthly unmet demand for Case 1-d for 2015.

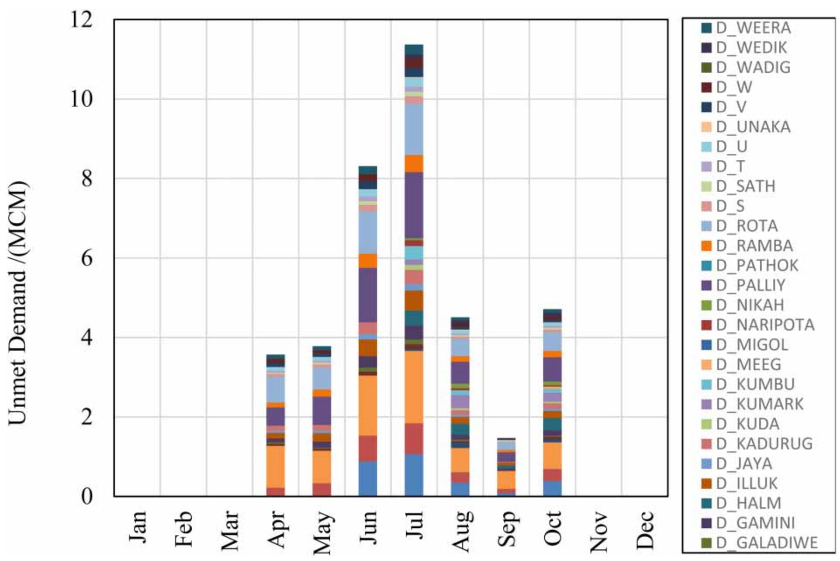

Figure 10 | Monthly unmet demand for Case 1-e for 2015.

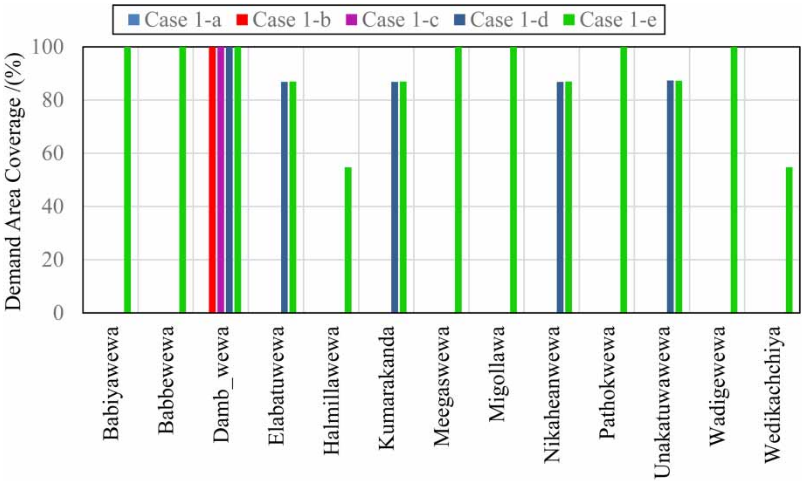

Figure 11 | Demand area coverage for Case 1.

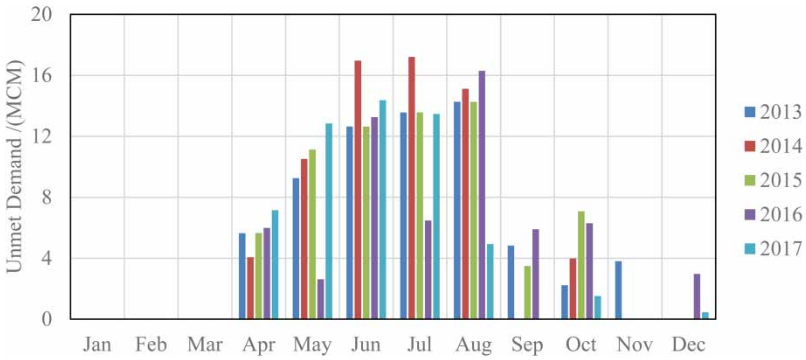

Figure 12 | Unmet demand for Case 2.

not practical to increase the cropping intensity by 100% as described in Case 2, unless there is an enhancement of diversion from Minneriya or Minneriya-Kanthale Yoda Ela to supplement these demands through the Kaudulla tank.

Financial analysis

The following analysis is carried out based on HSR 2016 (Government of Sri Lanka approved schedule of rates –2016) for construction.

Prime cost for the construction of the proposed feeder canal = Rs. 17,120 per meter length
(Capacity: 0.58 m^3/s and Reinforced Cement Concrete-lined (RCC) Canal: 1.2 m × 0.75 m)
Prime cost for augmentation of tank capacity by 1 MCM = Rs. 5,000,000
Prime cost for land acquisition including infrastructures = Rs. 6,000,000/ha
It is assumed that the inflation rate of 7.6% as at 2017 remains unchanged.

Table 5 shows the summary of financial analysis for Case 1.

Payback periods calculated using the net present value by considering 7.6% inflation rate for prime cost and turnover from the yield increment are shown in Table 5. Case 1-e shows that yield can be increased by Rs. 205 million by increasing the total cultivation area in the season through irrigation using minor tanks alone without depending on the water from the left bank canal of Kaudulla tank. That is, an increased area coverage and minimum payback period by augmenting tanks and constructing the proposed canals in Case 1-e.

An economic analysis was carried out using the net present values, and it was found that the option that includes the construction of a new canal system and the augmentation of capacities of village tanks, namely Nikahenawewa, Elabatuwewa,

Table 5 | Summary of cost–benefit for the proposed system

No.	Description	Prime cost (Rs. million) Canal	Tanks	Land acquisition	Total	Yield (Rs. million)	Yield increment (Rs. million)	Payback period using enhancement (years)
1	Case 1-a					0		
2	Case 1-b	206			206	9	9	>100
3	Case 1-c	206	6		212	9	9	>100
4	Case 1-d	206	25	390	621	71	71	15
5	Case 1-e	206	81	1,266	1,553	205	205	12

Babiyawewa, Halmillawewa, Meegaswewa, Migollawewa, Pathokwewa and Wadigewewa, from the total capacity of 3.8–20 MCM would be the most appropriate option. This intervention (a) increases the income from yield by 205 million with a payback period of 12 years and (b) also increases the area coverage of cultivation under the left bank canal cultivation area of the tank in the Yala season.

CONCLUSIONS

Irrigation water management in the left bank canal development area under the Kaudulla reservoir in the North Central Province of Sri Lanka was analyzed by the application of the HEC-HMS, CROPWAT and WEAP models. The best intervention among a few feasible structural interventions was identified based on the economic return.

Accordingly, the construction of a few new canals and augmentation of capacities of village tanks, namely Nikahenawewa, Elabatuwewa, Babiyawewa, Halmillawewa, Meegaswewa, Migollawewa, Pathokwewa and Wadigewewa tanks, to increase the total capacity from the present 3.8 to 20 MCM was found to be the most appropriate option. This intervention increases the income from the yield by 205 million with a payback period of 12 years.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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