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Performance evaluation of buried PVC pipelines for tank irrigation: a case study of Deevanur tank

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ABSTRACT

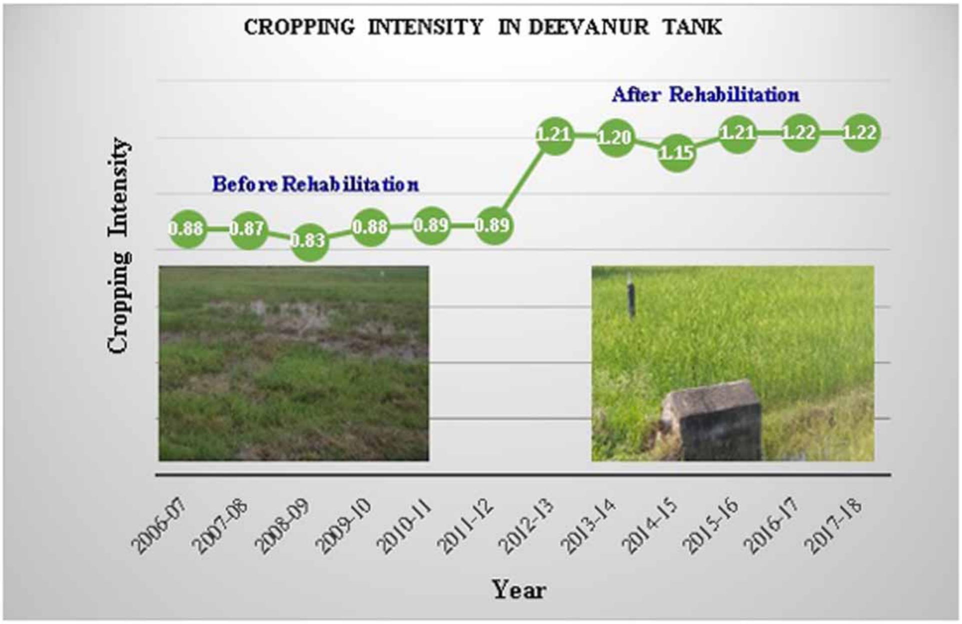
Water is vital to life and development in all parts of the world. Since rain or other precipitation is the only source of water, it should be carefully harvested, stored, conserved and managed for the benefit of the largest number by optimizing the use of the amount available. The available water should be utilized judiciously so that the future generation is saved from deterioration stress. This study was conducted in the Deevanur tank located in Tindivanam Taluk in Tamil Nadu, India. The study was carried out in the crop calendar years from 2006–07 to 2017–18. The performance of the tank irrigation system in this study was evaluated using a Cropping Intensity indicator. This study reveals that Cropping Intensity was increased to more than 100% after rehabilitation of the tank irrigation system and is easily observed. Before rehabilitation of the tank, the average Cropping Intensity value was only 0.87. After rehabilitation of the tank, the average Cropping Intensity value increased to 1.20. The Cropping Intensity indicator is good for evaluating the modernization of the tank irrigation system.

Key words: command area, cropping intensity, performance evaluation, PVC buried pipelines, tank irrigation

HIGHLIGHTS

- The study was carried out in crop calendar years from 2006–07 to 2017–18.
- The performance of the tank irrigation system in this study was evaluated using a Cropping Intensity indicator.
- Rehabilitation of the tank irrigation system is easily observed.
- The average Cropping Intensity value is calculated.

GRAPHICAL ABSTRACT



INTRODUCTION

Water, considered as the elixir of life, is a precious gift of nature to mankind and all other living beings inhabiting Earth. Its indiscriminate use has led to water becoming a scarce commodity in most parts of the world. Water is vital to sustaining life and plays a critical role in enabling development in all parts of the world. Since rain or precipitation is the only source of water, it should be carefully harvested, stored, conserved and managed for the benefit of all by optimizing the use of the available limited quantity. It is necessary to assess, plan and meet society's water needs without compromising the sustainability of vital environmental systems. The proper planning and management of this finite natural resource form an important part of policies and strategies devised for optimal use in a sustainable manner and the protection of clean water sources. Water use and water management are interdisciplinary fields that require the concerted participation of all stakeholders at all levels such as governmental, non-governmental, private, executive, administrative and research organizations as well. The available water should be utilized judiciously to preserve them for future generations and avert a water crisis. The Global Water Partnership (GWP) established in 1996 is fostering Integrated Water Resources Management (IWRM) as the key to future development through an international network. The takeaway from the World Water Forums held in Kyoto, Japan to ensure global water security is, 'Caring for water is everybody's business' (MohanaKrishnan 2004).

Over 97% of the world's water resources are in the oceans and seas which are too salty to be used. Two-thirds of the remainder are locked up in ice caps, glaciers, permafrost, swamps and deep aquifers. About 108,000 cubic kilometers (km^3) precipitate annually on the earth's surface. About 60% (61,000 km^3) evaporates directly back into the atmosphere, leaving 47,000 km^3 flowing toward the sea. If this amount was evenly distributed, it would be approximately 9,000 m^3 per person per year. However, much of the flow occurs during seasonal floods. It is estimated that only 9,000 to 14,000 km^3 may ultimately be controlled. At present, only 3,400 km^3 are withdrawn for use (Seckler *et al.* 1998).

Global water supplies are expected to come under greater stress due to increased demand caused by population growth, rising income levels, dietary changes, rapid urbanization, and increasing industrial demand. Most of the world's fresh water resources are currently used to produce food and that is likely to still be the case in 2050. Agricultural water use is expected to shrink over the next 30 years. However, it is anticipated that industrial and household demand will continue to rise. Groundwater sources are likely to come under the greatest amount of pressure from steadily increasing demand for clean water resources, but well-managed aquifer recharge could help reduce some of that pressure. While reducing water consumption by upgrading infrastructure and implementing measures for efficient use of available water resources remain the best options to reduce water stress, these measures are not always viable. Water recycling and desalination are other policy options that could help alleviate the water scarcity problem, but are unlikely to completely eradicate global water insecurity.

In India, it has been estimated that the average annual per capita water availability in the years 2001 and 2011 was 1,820 and 1,545 cubic meters, respectively. It is anticipated that this may reduce further to 1,341 and 1,140 cubic meters in the years 2025 and 2050, respectively, as shown in Figure 1 (Department of Water Resources and Ministry of Jal Shakthi 2014).

In India, metropolitan cities like Chennai in Tamil Nadu grapple with a huge water scarcity problem. This water scarcity problem has in turn directly led to serious issues such as increased costs of developing new water distribution systems, reduction in the quantum of water available for irrigation systems, rapid depletion of ground water and commercialization of scarce water resources.

Tank irrigation systems in India

There are 208,000 irrigation tanks of varied capacities in India, most of them are several centuries old and were built in the pre-British era. These tanks facilitate the irrigation of around 3% of the net irrigated area in India (Vaidyanathan 2001). Tank irrigation contributes significantly to agricultural production in many parts of South and Southeast Asia. Especially in South India and Sri Lanka, tank irrigation has a long history with many currently used tanks constructed in the past centuries. Tanks have existed in India from time immemorial, and have been an important source of irrigation, particularly in Southern India. They account for more than one-third of the total irrigated area in Andhra Pradesh, Karnataka and Tamil Nadu state. The tank irrigation system is invaluable to a large number of marginal and small-scale farmers who depend entirely on these community tank systems to irrigate their fields as they are less capital-intensive and have wider geographical distribution than large irrigation projects (Palanisami 2000).

The tank irrigation system is exclusively used in peninsular countries like India due to the presence of hard rocks below the surface of the land. This leads to difficulties in digging and establishing canals and wells.

Rajni *et al.* (2019) concluded that the rapid depletion of the water table, low irrigation efficiency and frequent droughts indicated that India was heading toward a water crisis in the near future, if the existing water use pattern was not rectified at the earliest.

Kiran *et al.* (2020) concluded that modernization of tanks leads to an improvement in agricultural production and livelihood of tank water users.

Tank irrigation systems in Tamil Nadu

In Tamil Nadu, tank irrigation systems play a very important role as they account for nearly one-third of the irrigated extent. Tamil Nadu has the second largest area of 589 thousand hectares under tank irrigation. As per Tamil Nadu State Government data, the state has 41,127 tanks serving small ayacuts (irrigated areas) (33,142 tanks $<$ 40 ha) and large ayacuts (7,985 tanks $>$ 40 ha). The registered ayacut of all tanks is little more than one million hectares (Department of Economics and Statistics 2018).

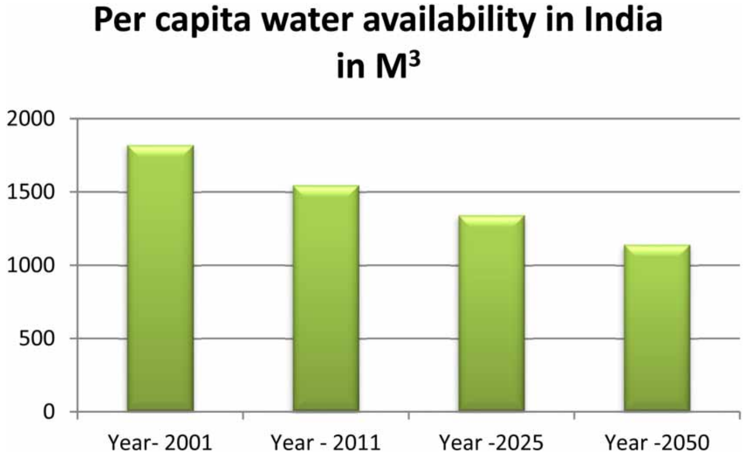


Figure 1 | Per capita water availability in India.

These 41,127 tanks fall under the charge of Public Works Department (PWD, including Ex-Zamin tanks) and Panchayat Unions, in Tamil Nadu. Kanchipuram, Chengalpattu, Tiruvellore, Tiruvannamalai, Vellore, Tirupattur, Ranipet, Cuddalore, Kallakurichi and Viluppuram districts have a higher intensity of tank irrigation in Tamil Nadu (Vaidyanathan & Sivasubramaniyan 2001).

Out of 13.00 million hectares, which is the geographical area of the Tamil Nadu state, the area sown is 5.70 million hectares and cropping intensity is about 1.20. The size of the holding is low with about 49% below 0.5 hectare and another 22% between 0.5 and 1.0 hectare. Rice is the main crop grown in about 37% of the sown area followed by sorghum in about 11%. Groundnut occupies about 13% of the sown area and is mainly cultivated as a rain-fed crop (Department of Economics & Statistics 2018).

Sivasubramaniyan (2019) explained that in order to resolve the inadequacy of water supply from tanks, most farmers supplemented their irrigation needs with well water. The drainage problem was mitigated through proper regulation of supply in the tank sluice.

Importance of tank irrigation systems in Tamil Nadu

Tamil Nadu is one of the tank intensive states in the country and accounts for about 14% of the total existing tank irrigation systems. One-third of the potential area of irrigation, nearly a million hectares, is through tanks and hence their upkeep and development is vital for the agricultural production of the state (Palanisami & William Easter 1983; Palanisami *et al*. 2008).

Ashraf *et al.* (2021) observed that there was minimum water loss in the buried pipeline irrigation system. The command area can be increased by providing a buried pipeline distribution system.

Next to the lift irrigation system through wells which are, of course, individually owned, tanks are the simplest water sources that can be easily and economically maintained by the Government jointly with the beneficiaries and bring about substantial benefits to the agricultural sector. Furthermore, the tank irrigation system is of special significance to the poorer sections in the rural sector as a very large number of them are solely dependent on tank irrigation for their cultivation water needs.

Most of the tanks in South India are approximately 100 years old. These tanks have lost much of their original ayacut or cultivated area due to the non-availability of sufficient water supply for irrigation. Inadequate tank water supplies and the poor distribution of available water are the main problems that have reduced the cropping intensity of the tank irrigation system.

The main aim of this research study is to improve the cropping intensity of the tank irrigation system by increasing water productivity.

To improve the cropping intensity, the tank irrigation system is modernized by providing buried PVC pipeline water distribution system in the tank command area.

In this context, Deevanur tank is selected for this study to assess the cropping intensity before and after the modernization of the tank irrigation system.

STUDY AREA

Tamil Nadu is located in the Southern part of India, having a land area of 1,30,058 km^2 (50,216 square miles), and is the eleventh largest State in the nation. Tamil Nadu constitutes 3.96% of the total area of the country. It lies between 8°51′00″ and 13°35′00″ North Latitudes and between 76°15′00″and 80°20′00″East Longitudes. Tamil Nadu physiography is comprised of Western Ghats, Eastern Ghats, Plateaus, Coastal and Inland plains.

The main river of the State is Cauvery, which flows into Tamil Nadu from adjoining Karnataka. The other major rivers flowing through the State are Palar, Adyar, Courtaliar, Pennaiyar, Vaigai and Tamiraparani. The southwest monsoon feeds the plateau and retreats after which the northeast monsoon brings rain to the east coast. The average annual temperature in the state is 28.8 °C. The temperature ranges from 2 °C in the hills to 45 °C in other areas. The average rainfall of Tamil Nadu is 998 mm.

The research study was carried out in the Deevanur tank in Tindivanam Taluk of Viluppuram District in Tamil Nadu, India. Details of the sluice-wise and reach-wise extent of the Deevanur tank command area are shown in Table 1. This tank is located in the Deevanur village of Mailam Block (Figure 2). The hydraulic particulars of the Deevanur tank have already been described in an earlier study conducted by Neelmudiyon *et al.* (2020).

Table 1 | Sluice-wise and reach-wise extent of the Deevanur tank command area

Serial No.	Reaches	Sluice-1 (ha)	Sluice-2 (ha)	Total ayacut (ha)
1.	Head	20.90	3.95	24.85
2.	Middle	20.85	3.90	24.75
3.	Tail	18.85	3.74	22.59
4.	Total	60.60	11.59	72.19

Figure 2 | Location of Deevanur tank.

Modernization of the Deevanur tank

In view of the vital importance of water for the sustenance of all living beings, maintaining the fragile ecological balance, promoting economic growth, fostering developmental activities of all kinds and taking into consideration its increasingly prevalent scarcity, the Deevanur tank was modernized under the World Bank Scheme in the year 2012–13. During the upgradation initiative, the conventional open field channel irrigation was modernized with the installation of buried PVC pipelines in the ayacut area for the conveyance of water for irrigation purposes. This tank initially irrigated the ayacut area through open natural field channels up to 2011–12. With the implementation of modernization measures, underground PVC pipelines were laid to irrigate the ayacut area, thereby significantly reducing the conveyance, evaporation and infiltration water losses (Figure 3).

In order to assess the impact of the modernization measures implemented in the Deevanur tank, a long-term comparative research study was conducted for evaluation of the performance of the tank irrigation system, from 2006 to 2012 for pre-evaluation and from 2012 to 2018 for post-evaluation (Figure 4).

METHODOLOGY

The cropping intensity in the command area of the tank irrigation system depends on the existing and improved physical conditions of the tank. Channel lining and sluice management help in enhancing the cropping intensity of the tank irrigation system. In the Deevanur tank irrigation system, buried PVC pipelines are introduced to facilitate the conveyance of the water stored in the tank to the fields for irrigation. The performance of the Deevanur tank is evaluated using the performance indicator, Cropping Intensity (Bos *et al.* 2005). It is calculated based on the ratio of the actual cropped area to the irrigable area of the tank in a particular year.

$$\text{Cropping Intensity} = (\text{Actual cropped area}/\text{Irrigable area})$$

Figure 3 | Water distribution system in Deevanur tank.

Figure 4 | Air vent pipe in the distribution system in Deevanur tank.

RESULT

Crop cultivated area

The area-wise cultivation of crops with the distribution of water through the sluices to the head, middle and tail reach of the Deevanur tank command area during the period of 2006–07 and 2017–18 is given in Table 2.

The first season of paddy cultivation, paddy-I (Samba) starts in September and ends in December. The second season of paddy-II (Navarai) growing starts in January and ends in April. The annual sugarcane crop cultivation commences in July and ends in April.

Sluice-wise tank performance

The sluice-wise tank performance is calculated, and it is shown in Figures 5 and 6 for sluices nos. 1 and 2, respectively. In sluice no. 1, in the head reach, the highest value of cropping intensity is observed as 1.48 in the year 2014–15, whereas the lowest value of cropping intensity is seen to be 0.83 in the year 2008–09. In the middle reach of the same sluice, the highest value of cropping intensity is reported to be 1.33 in the year 2012–13 and the lowest value of 0.83 is found in the year 2008–09. In the case of tail reach of sluice no. 1, the highest and lowest values of cropping intensity are 1.04 and 0.75 recorded in the years 2016–17 and 2014–15, respectively.

Table 2 | Details of crop cultivation during the time periods of 2006–07 and 2017–18

Serial No.	Year	Sluices / Season Period	Reaches	Crop cultivated area in Ha. Paddy-I Samba September to December	Paddy-II Navarai January to April	Sugarcane Annual July to April	Fallow land –
1	2006–07	Sluice-1	Head	9.58	–	8.79	2.53
			Middle	9.50	–	8.77	2.58
			Tail	8.53	–	7.93	2.40
		Sluice-2	Head	1.80	–	1.66	0.49
			Middle	1.78	–	1.64	0.48
			Tail	1.70	–	1.57	0.46
2	2007–08	Sluice-1	Head	9.23	–	8.82	2.85
			Middle	9.50	–	8.80	2.89
			Tail	8.53	–	7.95	2.68
		Sluice-2	Head	1.80	–	1.67	0.55
			Middle	1.78	–	1.65	0.54
			Tail	1.70	–	1.58	0.52
3	2008–09	Sluice-1	Head	9.25	–	8.16	3.49
			Middle	9.17	–	8.14	3.54
			Tail	8.24	–	7.36	3.26
		Sluice-2	Head	1.74	–	1.54	0.67
			Middle	1.72	–	1.52	0.66
			Tail	1.65	–	1.46	0.64
4	2009–10	Sluice-1	Head	9.99	–	8.46	2.45
			Middle	9.91	–	8.44	2.50
			Tail	8.89	–	7.63	2.31
		Sluice-2	Head	1.88	–	1.60	0.47
			Middle	1.86	–	1.58	0.46
			Tail	1.78	–	1.51	0.46
5	2010–11	Sluice-1	Head	9.71	–	8.91	2.28
			Middle	9.63	–	8.89	2.33
			Tail	8.64	–	8.04	2.17
		Sluice-2	Head	1.82	–	1.68	0.44
			Middle	1.80	–	1.66	0.44
			Tail	1.73	–	1.59	0.42
6	2011–12	Sluice-1	Head	7.66	–	10.95	2.29
			Middle	7.59	–	10.93	2.33
			Tail	6.82	–	9.88	2.18
		Sluice-2	Head	1.43	–	2.07	0.45
			Middle	1.42	–	2.04	0.44
			Tail	1.36	–	1.96	0.41
7	2012–13	Sluice-1	Head	6.89	6.89	14.01	–
			Middle	6.87	6.87	13.98	–
			Tail	2.84	2.27	12.64	3.37
		Sluice-2	Head	1.30	1.30	2.65	–
			Middle	1.29	1.29	2.61	–
			Tail	0.58	0.48	2.51	0.64
8	2013–14	Sluice-1	Head	6.35	6.35	14.55	–
			Middle	6.34	6.34	14.51	–
			Tail	2.91	2.30	13.12	2.82
		Sluice-2	Head	1.20	1.20	2.75	–
			Middle	1.18	1.18	2.72	–
			Tail	0.61	0.49	2.60	0.53
9	2014–15	Sluice-1	Head	10.07	10.07	10.83	0.00
			Middle	10.05	3.36	10.80	0.00

(*Continued.*)

Table 2 | Continued

Serial No.	Year	Sluices / Season Period	Reaches	Crop cultivated area in Ha. Paddy-I Samba September to December	Paddy-II Navarai January to April	Sugarcane Annual July to April	Fallow land –
			Tail	4.55	0.00	9.77	4.53
		Sluice-2	Head	1.90	1.90	2.05	0.00
			Middle	1.88	0.67	2.02	0.00
			Tail	0.94	0.00	1.94	0.87
10	2015–16	Sluice-1	Head	6.49	6.49	14.41	0.00
			Middle	6.47	6.47	14.38	0.00
			Tail	3.29	2.53	13.00	2.56
		Sluice-2	Head	1.22	1.22	2.73	0.00
			Middle	1.21	1.21	2.69	0.00
			Tail	0.68	0.53	2.58	0.48
11	2016–17	Sluice-1	Head	6.16	6.16	14.74	0.00
			Middle	6.14	6.14	14.71	0.00
			Tail	3.50	2.83	13.30	2.06
		Sluice-2	Head	1.17	1.17	2.78	0.00
			Middle	1.15	1.15	2.75	0.00
			Tail	0.71	0.57	2.64	0.40
12	2017–18	Sluice-1	Head	6.44	6.44	14.46	0.00
			Middle	6.43	6.43	14.42	0.00
			Tail	3.44	2.66	13.04	2.37
		Sluice-2	Head	1.22	1.22	2.73	0.00
			Middle	1.20	1.20	2.70	0.00
			Tail	0.69	0.55	2.58	0.46

In the head reach of sluice no. 2, the highest cropping intensity is observed as 1.48 in the year 2014–15, whereas the lowest value of cropping intensity is seen to be 0.83 in the year 2008–09. In the middle reach for the same sluice, the highest value of cropping intensity is recorded as 1.33 in the year 2012–13 and the lowest value found in the year 2008–09 is 0.83. In the case of tail reach of sluice no. 2, the highest and lowest values of cropping intensity are 1.05 and 0.77 recorded in the years 2016–17 and 2014–15, respectively.

DISCUSSION

In Figure 7, year vs. total cropping intensity is plotted at water storage tank level. The highest value of total cropping intensity is 1.22 in the year 2017–18, whereas the lowest total cropping intensity value of 0.83 is recorded in the year 2008–09. After the rehabilitation of the tank irrigation system, farmers opted for a second crop. The assured availability of stored water could be the reason for the increase in the actual cultivated area more than the actual ayacut area; this may be the cause for the increase in the total cropping intensity value to more than 1.0. The same reason is also behind more than 1.0 of total cropping intensity value found in Figures 5 and 6 in sluice-wise and reach-wise distribution.

From this figure, it is evident that the overall performance of the tank is significantly improved in terms of the field assessment of the cropped area after the rehabilitation of the tank irrigation system implemented in the year 2012–13 as the modernization offered in water distribution and better water productivity.

CONCLUSIONS

A higher cropping intensity is observed with farmers moving from single crop to double crops following the modernization of the irrigation tank system, as it facilitated the availability of a dependable supply of water to meet their irrigation requirements. A comparison is made between the cropping intensity values of the reaches in sluice no. 1. The highest value of 1.48 is seen in the head reach during the time span of 2014–15. The lowest cropping intensity value recorded in the same

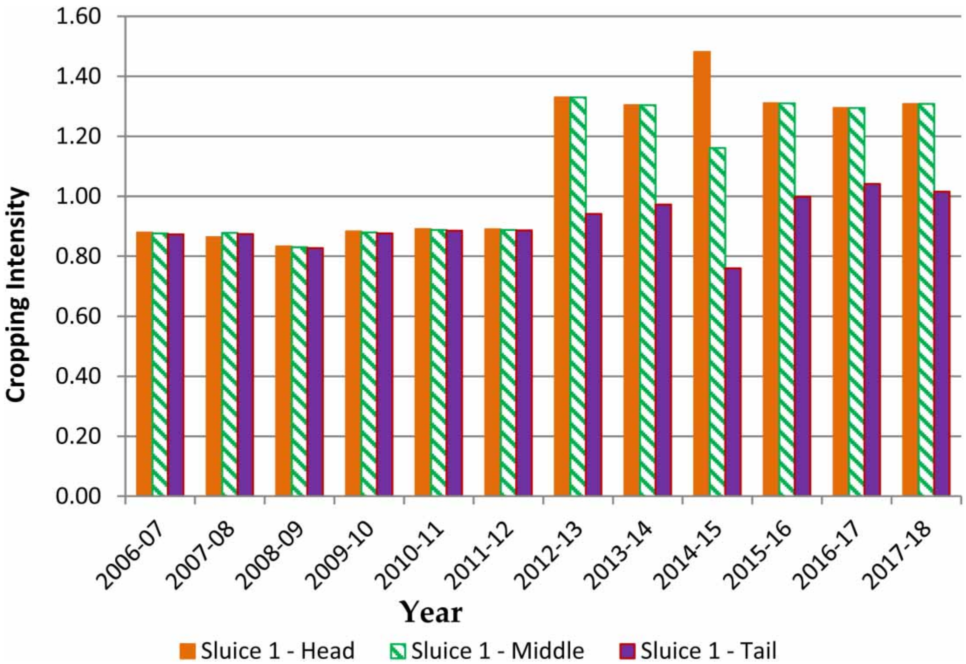


Figure 5 | Reach-wise Cropping Intensity in Sluice no. 1.

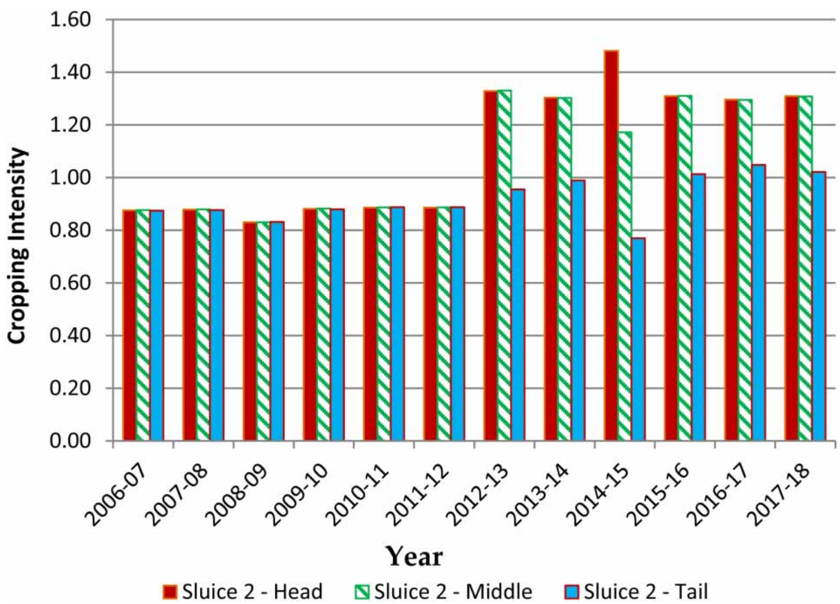


Figure 6 | Reach-wise Cropping Intensity in Sluice no. 2.

period in the tail reach is noted to be 0.76. For sluice no. 2, the highest cropping intensity of the tank is observed to be 1.48 in the head reach and the lowest cropping intensity value is 0.77 in the tail reach in the period 2014–15.

From this study, it is found that the cropping intensity values are more than 1.0 after the rehabilitation of the tank irrigation system and it is due to the cultivation of the second crop. It is found that the overall performance of the tank also improved after the implementation of the rehabilitation measures. Before modernization of the tank, the average value of cropping intensity is recorded to be 0.87 for the 6-year period of 2006–12. After rehabilitation of the tank irrigation system, the average value of cropping intensity is found to be increased to 1.20 during the time span of 2012–18.

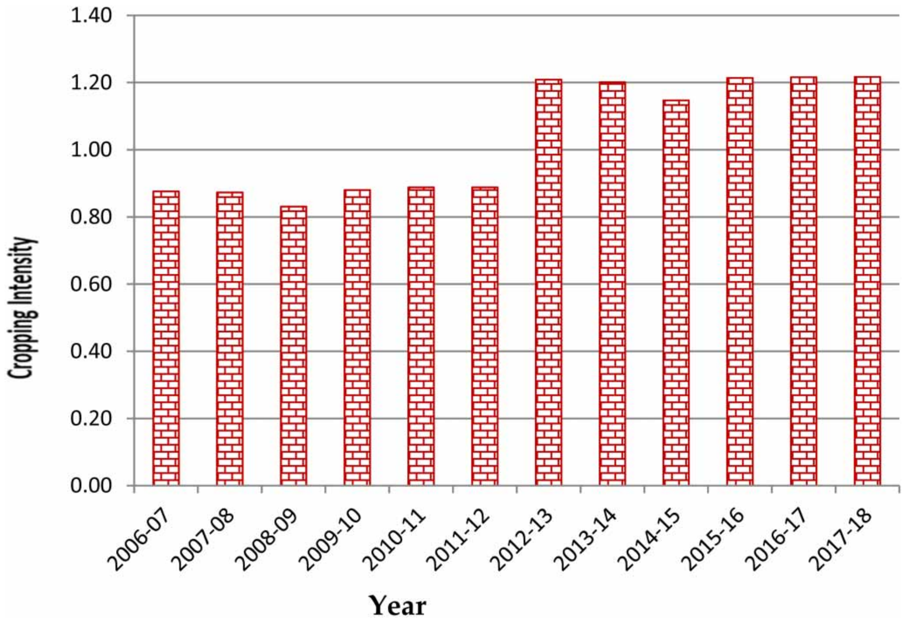


Figure 7 | Year-wise total Cropping Intensity at tank level.

Based on the findings of this investigative research work, it is recommended that all minor irrigation tanks be modernized with the provision of buried PVC pipelines for conveyance of water from the water storage tank to the agricultural fields to improve the cropping intensity and efficiency of the irrigation system.

The high initial cost of the buried PVC pipelines and the lack of social acceptance among the farmers are the two main limitations faced in the implementation of major irrigation projects for distribution of water in developing countries such as India.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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