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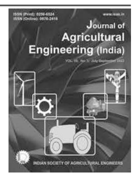

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Water Delivery Performance of Canal Irrigation: A Case Study of Chalakudy River Diversion Scheme

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ABSTRACT

The role of irrigation is important in mitigating the challenges involved in food production under the changing climate scenarios. Adequacy and equity in water distribution are the primary concern regarding the performance of any irrigation scheme. Conveyance efficiency and two adequacy indicators, namely, Relative Water Supply and Adequacy were used to evaluate the performance of Chalakudy River Diversion Scheme (CRDS) located in central Kerala, India, in the present study, Water withdrawal data collected from Irrigation Department, and data collected from field measurements of canal discharge and seepage loss were used in the study. Irrigation requirement of the canal command area was worked out using the FAO's CROPWAT 8.0 software. The results revealed that the average annual irrigation demand of the CRDS command area is 46.90 Mm^3. Measured flow rate through the canal system showed that the flow decreases towards the tail end. Loss of water through seepage from the canal was high in the irrigation scheme due to the highly damaged condition of canal lining and poor maintenance. The CRDS canal system's overall conveyance efficiency was found to be 51%. Based on Relative Water Supply and Adequacy Indicator, functioning of the irrigation scheme falls in the category of 'fair'. Apart from proper repair and maintenance of canal system, conjunctive use of groundwater and canal water for irrigation is suggested towards the tail reaches to alleviate irrigation water inadequacy problems in the CRDS command area.

Irrigation is an inevitable part of agriculture for sustainable production even in humid tropical regions. Water scarcity occurs during the summer months in these regions due to temporal variability in rainfall. Climate change and long dry spells created challenges for timely and sufficient water supply to meet agricultural demand (Barkhordari and Shahdany, 2022). Better performance of irrigation schemes, which distribute surface water to the fields, is essential for the success of agricultural systems. It is estimated that the irrigation schemes in India have only 38% overall efficiency. Proper management can increase the efficiency of surface irrigation systems from 35-40% to 50-60% and groundwater irrigation systems from 67-70% to 72-75% (Chaudhari *et al*., 2016). Improving performance of irrigation schemes is one way to conserve water resources, reduce water losses, and minimize the agricultural water scarcity issue. Water is wasted from irrigation canals during operation due to seepage and conveyance losses (Mohammadi *et al.*, 2019). Hence, an irrigation scheme performance is assessed to improve the management of irrigation schemes and/or to compare it with other schemes (Fan *et al*., 2018; Molden *et al.,* 1998). The aim of any assessment is to get more production by proper utilisation of available water. For effective planning and management of existing irrigation projects, their performance status is very important. (Elnmer *et al.*, 2018).

In recent studies, several performance indicators and evaluation perceptions have been used for the evaluation of the functioning of irrigation schemes (Molden and Gates, 1990; Sakthivadivel *et al*., 1993; Molden *et al.,* 1998). Adequacy, which is the basic objective of any irrigation system, is the capacity of the system to meet the irrigation demands (Fan *et al*., 2018). Chandran and Ambili (2016) conducted a study in the Kozhikode district of Kerala to evaluate the performance of two minor irrigation schemes. Several indicators, *viz.* relative water supply, relative irrigation supply, standardized gross value of production were used in the study for the assessment of performance of irrigation schemes. The authors reported that water availability constraint does not exist in the command area because of the well-maintained water distribution channels. Renthlei *et al.,* (2017) studied the adequacy of water delivery services and the irrigation potential achieved in a canal irrigated area at Allahabad using the relative water supply, delivery performance ratio, field application ratio, depleted fraction, and irrigation potential as the indicators. Study revealed that the adequacy was not fulfilled in the command area as the irrigation potential achieved was only 66.6%. Paul and Panigrahi (2019) assessed the performance of Puri main canal irrigation system in Odisha and found it to be "fair" with regards to its efficiency, equity, and reliability. In a study conducted in China, Fan *et al.* (2018) reported poor performance of the Jiamakou irrigation scheme, China, due to inadequate, inefficient, and unequal allocation and distribution of water. Devi *et al.* (2012) studied the performance of water delivery system in the command area of Parambikkulam Aliyar Palar irrigation project in Tamil Nadu, and recommended implementing demand-based irrigation supply systems based on observed results. Rajput *et al*. (2017) evaluated the status of water delivery from the left main canal of Bhimsagar irrigation scheme in Rajasthan using adequacy, equity, dependability, relative irrigation supply, and relative water supply as indicators. The study found that the project's performance was "poor" highlighting the need for improved management policies. In another study, Mishra *et al.* (2002) reported a saving of 18.36% irrigation water with an alternative rotational delivery schedule developed for the Left Bank Feeder Canal system of Kangsabati irrigation project.

Some researchers assessed the performance of irrigation schemes using remotely sensed data. Ray *et al.* (2002) assessed the functioning of Mahi Right Bank Canal (MHRC) in Gujarat, using the Indian Remote Sensing Satellite (IRS)-1C, Linear Imaging and Self Scanning-III (LISS-III), and Wide Field Sensor (WiFS) data to identify the irrigation management problems in distributaries. They concluded that the use of remote sensing (RS) data and Geographic Information Systems (GIS) in estimating performance indices would assist irrigation managers in efficiently managing the irrigation schemes. Suresh Babu *et al.* (2012) explored the use of high-resolution satellite imagery along with field data on water distribution for efficient water resource management through corrective measures. Vibhute *et al*. (2016) developed a water distribution schedule for the Jhajjar distributary of the Western Yamuna Canal Command in Haryana, using Geospatial tools *viz*. ArcGIS 10.0 software, ERDAS Imagine 10.0 software, and the Food and Agriculture Organization's (FAO) CROPWAT model. The study recommended modifying the existing schedule based on the crop water requirements in the command area, canal supply, and availability of groundwater in the command area. Elnmer *et al.* (2018) developed a framework with external (e.g., water supply, agricultural, and economic performance indicators such as irrigation efficiency, relative evapotranspiration, crop water-use efficiency, and gross value of crop production) and internal (e.g., temporal and spatial performance indicators such as adequacy, equity, and dependability) components for assessing the irrigation water performance in the Nile Delta. A 30 m resolution Landsat images and Surface Energy Balance Algorithm for Land (SEBAL) model were used to estimate the irrigation requirement, and poor functioning of the irrigation scheme was reported.

Most of the irrigation schemes in India faces low adequacy of irrigation water and poor equity in distribution (Rajput *et al.* 2017; Renthlei *et al*., 2017; Paul and Panigrahi, 2019). Tail end farmers of the command area are the losers, always. They are forced to find out another water source to meet the irrigation requirements. Proper planning and timely maintenance of the canal system are needed to solve the issues to some extent. There is a need for regular performance evaluation of the existing canal systems to solve the issues on adequacy, equity and reliability, and suggest possible remedial measure including repair and maintenance of canal systems. Chalakudy River Diversion Scheme (CRDS) is such an irrigation project in the central Kerala that faces inadequacy problem towards the tail end of the canal system. Hence, a study was conducted to evaluate the current water supply along the CRDS canal system and to suggest measures for improving the performance of CRDS canal systems.

MATERIALS AND METHODS

Study Area

The study was conducted in the Chalakudy River Diversion Scheme command area, which is in two neighbouring districts of Kerala, Thrissur and Ernakulam as part of a Doctoral Research at Department of Irrigation and Drainage Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, Kerala, India.

The command area lies between the north latitudes 10° 8'45" and 10°24' 28" and the east longitudes 76° 12' 37" and 76° 22' 17" (Fig. 1). A weir structure constructed across the river Chalakudy diverts water to fields in both the left and right banks through a canal system. The canal system supplies water to a cultivable command area (CCA) of 13,895 ha out of a gross command area of 39,685 ha with its two main canals, Left Bank Canal (LBC) and Right Bank Canal (RBC), through their 38 branch canals and distributaries (Madhusoodhanan and Eldho, 2012; Bai, 2020). The diagram shown in Fig.2 gives a schematic illustration of the CRDS canal system.

The average temperature in the area ranges from 25.8°C to 35.1°C, making it a humid tropical climate (Bai, 2020). The region receives 3193.5 mm of average annual rainfall. The South-West monsoon contributes around 70% of the average annual rainfall, whereas the North-East monsoon and summer rains contributes 18% and 12%, respectively. Laterite soil having high porosity is the predominant type of soil in this region. Alluvial soil is also found in some low-lying patches in the area (CGWB, 2013; Varma, 2017; Bai, 2020). Weathered rock and hard rock formations can be found beneath the lateritic layer. The lateritic zone's thickness in the region varies from 3 to 15 m, and its transmissivity ranges from 22 to 288 $m^2.day^{-1}$ (Varma, 2017; Bai, 2020). The groundwater levels of dug wells, recorded by the State Groundwater Department, revealed that the average depth to the water table in the study region varies from 0.59 to 14 m below the ground level (CGWB, 2013; Varma, 2017; Bai, 2020).

Multiple cropping system with coconut, nutmeg, banana and vegetables as major crops is followed in the area where paddy is not cultivated (Bai, 2020). Paddy is cultivated mainly in two seasons, *Kharif* and *Rabi*. In the third season, paddy cultivation is less and summer fallow is cultivated by vegetable crops. Irrigation is needed during *Rabi* and summer season. The CRDS canal system that supplies water to the area has been lined almost 90 % of its length. But it is worn out and damaged at many places in almost all branch canals and towards the tail end of main canal.

Data Used

The various data required for the estimation of irrigation requirement are climatic data, rainfall, soil, crop and

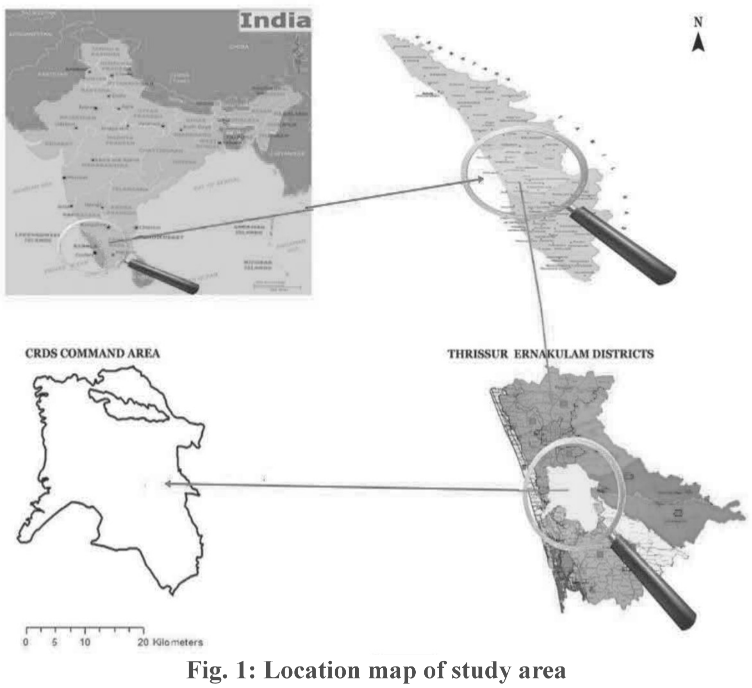

Fig. 1: Location map of study area

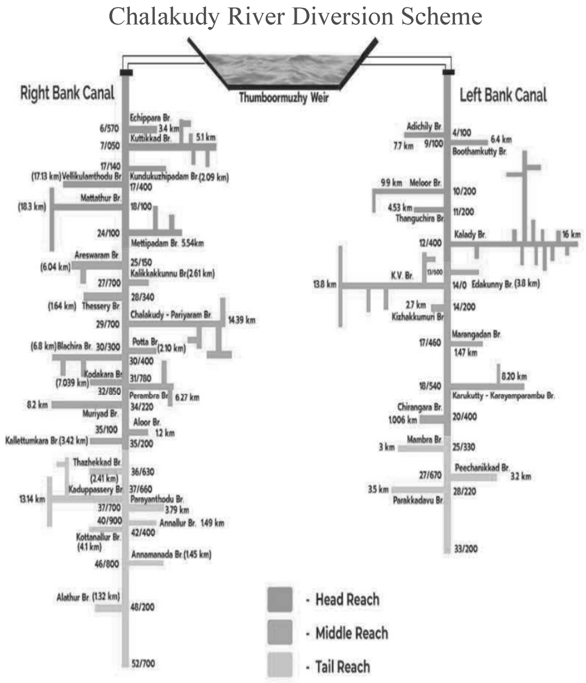

Fig. 2: Schematic diagram of CRDS canal system (Adopted from Bai, 2020)

cropping pattern. Rainfall data (1991-2014) used in this research were obtained from Agronomic Research Station of the Kerala Agricultural University situated in the command area, and two nearby India Metrological Department (IMD) rain gauge stations located at Kodungallur and Perumbavoor. Twenty-seven years daily data, 1990-2016, on other climatic parameters such as maximum and minimum temperature, humidity, sunshine hours were also collected from the Agronomic Research Station, Chalakudy. Soil characteristics of the Agro-Ecological Units (AEU) through which the canal passes were taken from the agro-ecological zone map of Kerala prepared by National Bureau of Soil Survey and Land Use Planning. The State Agricultural Department provided data on the main crops grown in a particular cropping pattern in the command area. The yield response factor and crop coefficient values of the various crops grown in the region were collected from the literature (Anjana *et al*., 2015; Surendran *et al*., 2017).

Inflow to the canal system is an essential data for the evaluation of its performance. The State Irrigation Department provided 15 years, from 2004 to 2018, data on monthly water diversion through the CRDS canals. During the initial days of the irrigation season every year, a major part of the canal water was used for filling the ponds and *chira* (temporary water storage structure) or bund in the command area. This diverted water was used for irrigating areas other than cultivable command area of the canal system through lift irrigation. Details of the volume of these storage ponds were collected from the State Minor Irrigation Department. Data on the groundwater level of the observation wells for the period 1996 to 2014 were obtained from the Central Ground Water Board and the State Groundwater Department.

Satellite imagery, Sentinel 2 level 1C of the study area, captured during the month of March, 2017 was downloaded from the United States Geographical Survey (USGS) website in order to prepare a land use and land cover map of the CRDS command area, and to determine the irrigation water requirement in the command area.

Methodology

Estimation of Irrigation Requirement

Irrigation water requirement of the command area was calculated using the FAO CROPWAT software. The Penman-Monteith equation (Allen *et al*., 1998) was used in the FAO CROPWAT 8.0 to determine the reference crop evapotranspiration, and calculated as follows:

$$ET_o = \frac{0.408\, \Delta\, (Rn - G) + \gamma \left(\frac{900}{T+273}\right) u_2 (e_s - e_a)}{\Delta + \gamma\, (1 + 0.34\, u_2)} \quad \ldots(1)$$

Where,

ET_o = Reference crop evapotranspiration, mm.day^{-1},

Rn = Net radiation at crop surface, MJ.m^{-2}.day^{-1},

G = Soil heat flux density, MJ.m^{-2}.day^{-1},

T = Mean daily air temperature at 2 m height, °C,

u_2 = Wind speed at 2 m height, m.s^{-1},

e_s = Saturation vapour pressure, kPa,

e_a = Actual vapour pressure, kPa,

e_s-e_a = Saturation vapour pressure deficit, kPa,

Δ = Slope vapour pressure curve, kPa.°C^{-1}, and

γ = Psychrometric constant, kPa.°C^{-1}.

ET_{crop} was then calculated as:

$$ET_C = K_C \times ET_0 \quad ...(2)$$

Where, K_C is the crop coefficient.

Irrigation requirement was then computed as:

$$\text{Irrigation requirement} = ET_c - P_{eff} \quad ...(3)$$

The effective rainfall, P_{eff}, was calculated using the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) method (Surendran *et al*., 2017) that was available in the FAO CROPWAT model.

The output from the software was multiplied by the areas occupied under different cropping patterns to get the irrigation water requirement of the cultivable command area in volumetric units. ERDAS Imagine software, which performs geospatial analysis of vector, raster, and hyper spectral images, was used to create a land use land cover map of the CRDS command area in order to understand the crops and their areal distribution. Digital image processing based on the reflectance of materials on the earth's surface was used for land use classification. The land use map was created using unsupervised classification available in the software's Iterative Self-Organizing Data Analysis Method (ISODATA) algorithm. From the prepared land use map, the CCA of each branch canal was clipped using the ArcGIS software. The data derived from these clips were used for the computation of the irrigation water requirement of the whole CCA of the CRDS canal system.

Measurement of Seepage Loss

Field measurement of losses of water through seepage from the canal system were carried out for assessing the performance of the canal system. Inflow -outflow method was used for the computation of seepage loss (Akkuzu *et al*., 2007). Measurements were done from several sections (48 sections) along the right and left bank main canals, and from selected branch canals during the summer months of 2019. Two branch canals were selected from each reach, at the head, middle, and tail of the canal system. Flow rate was measured using a pigmy-type current meter, which could measure flow rate between 0.1 to 3.5 m.s^{-1} by area – velocity method in main canals as well as in branch canals. Seepage loss rate of each section of main canal was multiplied by the length of the section and duration of flow through that section in a year to get annual seepage loss from main canals. Following the same procedure adopted for the main canal sections, the annual seepage losses from the branch canals were estimated. Average of the seepage loss rate of selected branch canals was taken as the common seepage loss rate of all the branch canals. Annual seepage loss was deducted from annual water diversion to the canal system to get the water delivered to the field. Table 1 shows the key characteristics of the two main canals.

Performance of Canal System

Performance of the canal system was evaluated by estimating conveyance efficiency (Eq. 4), and adequacy indicators *viz.*, Relative Water Supply (Eq. 5), and Adequacy (Eq. 6). The average of the water diverted

Table 1. Main features of the main canals of Chalakudy River Diversion Scheme

Main canal	Reach	Cross sectional area, m^2	Length, km
Right bank canal	Head	14.10	24.6
	Middle	6.07	16.1
	Tail	2.77	12.0
Left bank canal	Head	16.37	13.0
	Middle	7.75	12.2
	Tail	3.00	8.0

through the canal system during the five-year (2014 to 2018) was taken as the average annual water diverted to the canal system.

$$\text{Conveyance efficiency} = \frac{\text{Water delivered to the field}}{\text{Water diverted to the canal}} X\ 100 \quad ...(4)$$

Relative Water Supply is the ratio of total water supply to total water demand (Sakthivadivel *et al*., 1993), and is computed as:

$$\text{Relative water supply} = \frac{(\text{IW} + \text{Re})}{(\text{ET} + SP)} \quad ...(5)$$

Where,

IW = Irrigation water delivery, mm,

Re = Effective rainfall, mm,

ET = Crop evapotranspiration, mm, and

SP = Seepage and percolation loss, mm.

Adequacy indicator (P_A) is the ratio of the quantity of water delivered to the quantity of water required for an area R for a period T (Molden and Gates, 1990; Elnmer *et al.,* 2018), and is computed as:

$$P_A = \frac{1}{T}\sum_T \left[\frac{1}{R}\sum_R \left(\frac{Q_D}{Q_R}\right)\right] \quad ...(6)$$

$P_A = \frac{Q_D}{Q_R}$ if $Q_D < Q_R$

$P_A = 1$, otherwise

Where,

T = Time period, min,

R = Area/region,

Q_D = Water delivered, mm, and

Q_R = water required, mm.

Three performance classes proposed by Molden and Gates (1990) for categorization of irrigation systems in accordance with the adequacy indicator (Table 2) were used to evaluate the the canal system performance.

RESULTS AND DISCUSSION

Land Use Map of Command Area

The command area of CRDS was classified into ten land use classes (Fig. 3). Among these, five are cultivated with different crops/cropping patterns. More than 80% of the cultivable command area is occupied by these three land use classes: coconut based cropping system (31.83%), multiple crop (37.77%) and paddy (10.51%). The remaining portion of the command area occupies plantation crops (13.53%), barren land (0.7%), built ups areas (3.63%) etc. Coconut based cropping system, multiple crops in which coconut, areca nut, nutmeg, banana etc. are occupied in almost equal proportion and paddy are the crops/cropping pattern requiring irrigation in the command area.

Assessment of Irrigation Requirement

The extracted data from the land use clips of the cultivable command areas of the branch canal revealed that the left bank canal delivered water to a larger area compared to the right bank canal (Table 3). Left and right bank canals supplied water to 7,786.27 ha and 6,078.73 ha of land, respectively. Hence, the total cultivable command area clipped from the land use map was 13,865 ha, which was near to the reported cultivable command area of 13,895 ha of the CRDS canal system (Madhusoodhanan and Eldho, 2012). The CCA of branch canals were occupied with cultivated crops and other land uses. Hence, the irrigation

Table 2. Performance standards of adequacy indicator

Indicator	Performance classes		
	Good	Fair	Poor
P_A	0.90-1.00	0.80- 0. 90	< 0.80

Source: Molden and Gates (1990)

Table 3. Average annual net irrigation requirement of command area

Canal segment	Area, ha		Net irrigation requirement, Mm^3			
	Cultivable command area (CCA)	Cropped area	Kharif/ Virippu	Rabi/ Mun-dakan	Zaid/ Puncha	Annual net irrigation requirement
Left bank canal	7,786.27	5,372.09	1.452	5.461	16.119	23.03
Right bank canal	6,078.73	5,532.04	1.158	4.953	17.754	23.87
Total	13,865.00	10,904.13	2.610	10.414	33.873	46.90

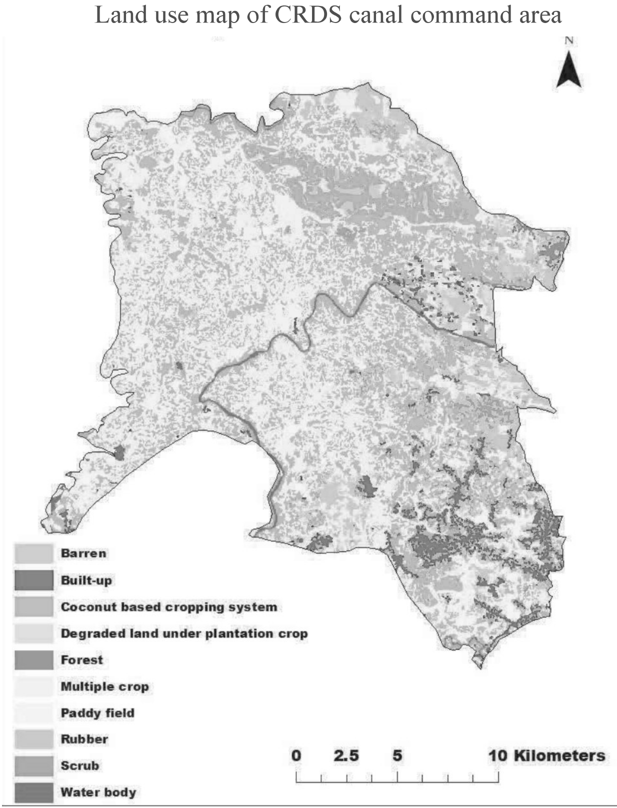

Fig. 3: Land use/land cover map of CRDS command area

requirement of each branch canal CCA was found to be proportional to the area occupied by the irrigation demanding crops.

Nutmeg and banana, two major components of both coconut-based cropping system and multiple cropping pattern, are high water demanding crops next to paddy. Even the left bank canal supplied water to more CCA, the area occupied by the irrigation demanding crops/cropping pattern was less in the CCA of left bank canal (5,372.09 ha) than that of right bank canal (5,532.04 ha). Irrigation requirement of the command area was found to be proportional to the cropped area within the CCA. Right bank canal with more cropped area required more annual irrigation water of 23.87 Mm^3. Annual irrigation requirement of left bank canal was found as 23.03 Mm^3. Season wise split-up of the irrigation requirement showed that maximum irrigation was required during the summer, and minimum during the *Kharif* season (Table 3). During the *Kharif* season, water was needed mainly for land preparation and growing paddy nursery. Due to the high rainfall and low daily temperature, evaporation was less in *Kharif* season. In summer (*Zaid*) season, low rainfall and hot environment increased the irrigation requirement. The average annual net irrigation requirement of the CRDS command area, thus, was estimated as 46.90 Mm^3.

Water Diverted through Canal System

Water diverted through the canal system during the last 15 years is shown in Fig. 4. There was a decreasing trend in water diversion. Hence, the average water diverted during the last five years (2014 to 2018), 157.97 Mm^3 was taken as the average annual water diverted to the canal system. The data collected from the State Minor Irrigation Department showed that a portion of the water diverted through the canal system was kept aside in large ponds and temporary water storage structure (*chira)* in the command area. The water (4.66 Mm^3) equal in volume as that of large ponds and *chira* was used to irrigate the areas other than the CCA of the canal system using lift irrigation schemes. Hence, the volume of water (4.66 Mm^3) was deducted from the average water (157.97 Mm^3) diverted during the last five years. Thus, the average annual water diversion of 153.3 Mm^3 to the cultivable command area of CRDS was taken for further computations. A rotational water delivery system was followed, separately for both left bank canal and right bank canal to deliver water to the fields. The rotation was completed during a period of 20-22 days. Each branch canal had water for two days during this period. Gates are provided at the entrance of each branch canal to control the flow, and the un-gated spouts along the branch canal to deliver water to the fields.

Seepage Loss and Conveyance Efficiency

During March 2019, water flow through the canal system was measured to assess water availability in the command area. Seepage loss computed from the field measurements showed that there was increase in seepage loss rate from head to tail reach of the main canal. The branches Meloor and Mettippadam, that draw water from the head section of main canals showed less rate of seepage loss than other branches (Fig. 5). The rate of water flow was more in these branches while the water availability was less in the middle and tail end branches. This is the reason for the difference in rate of seepage loss between the selected branch canals. Higher rate of seepage loss in the tail reaches was mainly due to the damaged lining towards the tail end and poor maintenance of the canals. Though the seepage loss rate was high towards the tail reaches; but the duration / period of flow was less in a year through these reaches, resulting in reduced total annual seepage loss from tail reaches. Seepage losses from the head, middle, and tail reaches of the main canal system account for 41.3, 31.7, and 27.0%, respectively, of the total seepage loss of 54.57 Mm^3 from the main canal system (Table 4). The average annual water loss through seepage from the CRDS canal system was computed as 74.94 Mm^3 with main and branch canal contributing 72.8 and 27.2%, respectively, of total seepage losses from the CRDS canal system. High loss of water through seepage from the CRDS canal system indicated poor condition of the canal lining due to damages. Proper repair and maintenance are necessary to reduce the seepage.

Tables 5 and 6 illustrate the conveyance efficiency of the chosen canal branches and the overall conveyance efficiency of the CRDS canal system as determined by the field measurement of flow during the year 2019. The canal branches, which drew water from the head reach of the main canals, showed higher conveyance efficiency than the lower reache (middle and tail reach) canal branches. Higher flow velocity/ rate of water entry at the head reach was the reason for reduced seepage rate and higher conveyance efficiency of these branches. The highest conveyance efficiency

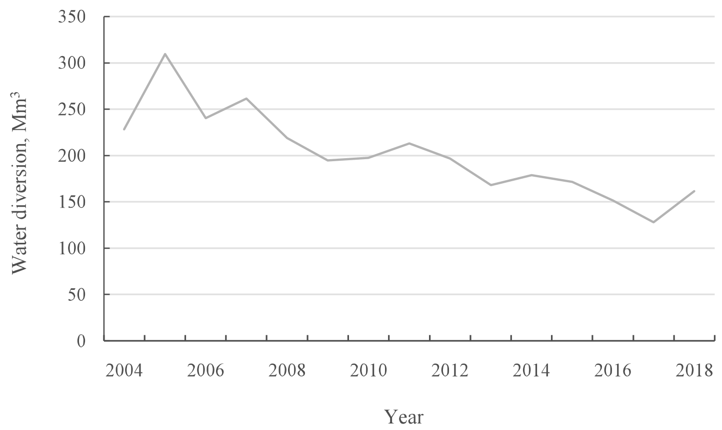

Fig. 4: Annual water diversion through CRDS canal system

Table 4. Average annual seepage loss from Chalakudy River Diversion Scheme (CRDS) canal system

Canal	Reach	Seepage loss, Mm^3
Main	Head	22.53
	Middle	17.32
	Tail	14.72
Branches		20.37
Total seepage loss, CRDS		74.94

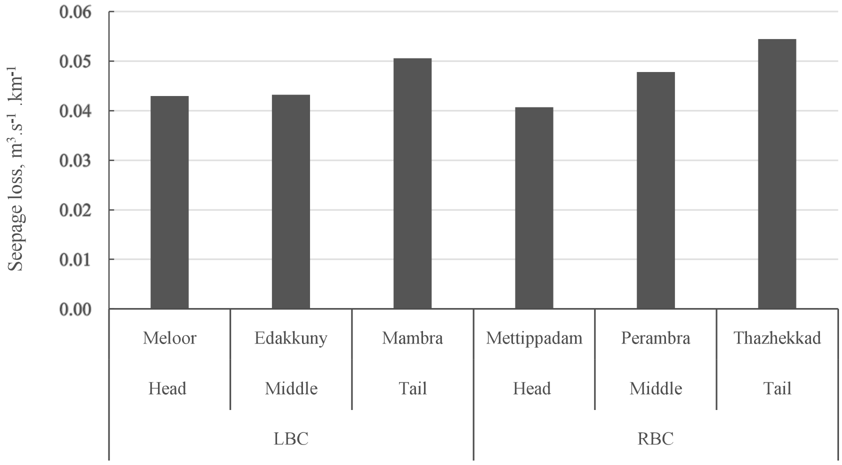

Fig. 5: Rate of seepage loss in selected branch canals

Table 5. Conveyance efficiency of selected branches of CRDS canal system

Main canal	Reach	Branch	Rate of water diverted to branch, $m^3.s^{-1}$	Rate of water delivered to field, $m^3.s^{-1}$	Conveyance efficiency, %
Left Bank Canal	Head	Meloor	0.408	0.258	63.15
	Middle	Edakkuny	0.236	0.128	54.27
	Tail	Mambra	0.094	0.018	19.08
Right Bank Canal	Head	Mettippadam	0.549	0.406	74.03
	Middle	Perambra	0.574	0.383	66.68
	Tail	Thazhekkad	0.216	0.085	39.51
Average					52.78

Table 6. Conveyance efficiency of CRDS canal system

Particular	Volume of water, Mm^3
Net water diverted through canal system	153.31
Seepage loss from canal water	74.94
Water delivered to field	78.37
Conveyance efficiency	51.1%

of 74% was observed in the Mettippadam branch of RBC whereas the lowest conveyance efficiency of 19% was observed in Mambra branch which is at the tail end of the left bank canal. The conveyance efficiency of the right bank canal was comparatively higher (40-74%) than that of the left bank canal (19-63%), which pointed to the worse situation of canal lining along the left bank canal. The results indicated the inadequate water distribution in the main canals from head to tail reach.

Several researchers have reported similar performance of irrigation systems (Unal *et al*., 2004; Fan *et al*., 2018; Elnmer *et al.,* 2018). The average of overall conveyance efficiency of these selected branches was 52.78 per cent. According to the measured seepage loss, the overall conveyance efficiency of the canal system was 51.1 per cent (Table 6). Santhosh *et al*. (2019) also reported 50% seepage loss from CRDS canal water flow. The seepage loss from canal water contributed water to the groundwater pool in these areas. Hence, conjunctive use of canal water and groundwater should be practiced to meet the irrigation requirements of the command area.

Relative Water Supply (RWS)

The Relative Water Supply determined from the field measurement of flow during 2019 was used to evaluate the adequacy of irrigation water delivered in the command area by the canal system. Table 7 shows the relative water supply values of selected branches and CRDS canal system. Irrigation water supply could be seen (Table 7) to be inadequate in the command area. Among the selected branch canals, Mettippadam, a

Table 7. Relative water supply of selected branches and CRDS canal system

Main canal	Name of branch/canal system	Irrigation water delivery, Mm^3	Effective rainfall, Mm^3	ET_{crop}, Mm^3	Seepage and percolation, Mm^3	Relative Water Supply
Left bank canal	Meloor (Head reach)	0.64	1.40	4.60	0.43	0.405
	Edakkuny (Middle reach)	0.37	0.48	1.50	0.27	0.478
	Mambra (Tail reach)	0.15	0.83	2.66	0.13	0.349
Right bank canal	Mettippadam (Head reach)	0.85	0.25	0.82	0.54	0.812
	Perambra (Middle reach)	0.89	1.02	3.43	0.60	0.476
	Thazhekkad (Tail reach)	0.34	0.61	1.96	0.27	0.424
Chalakudy River Diversion Scheme (CRDS)		153.31	43.44	113.66	114.12	0.864

high reach branch of RBC, showed the highest RWS of 0.812. The conveyance efficiency was also higher for this branch canal (Table 5). There was no paddy crop with high water requirement in the CCA of this branch canal. Rate of water entry to this branch canal was higher compared to other selected branch canals. This might be due to its position along the main canal. Similar to the conveyance efficiency, the RWS of the right bank canal was relatively higher (0.81 - 0.42) as compared to that of the left bank canal (0.48 - 0.35) at all reaches. This might be due to less water delivery and a higher percentage of seepage from the delivered water in the selected left branch canal branches compared to the selected right branch canal branches. Along the left branch canal, the middle reach branch Edakkuny showed a lower RWS than the head reach branch Meloor due to the lower evapotranspiration requirement in its command area. The overall RWS of the CRDS command area was estimated as 0.864. The higher RWS of the canal system might be due to the low evapotranspiration requirement in the command area of branch canals other than the selected branches.

Adequacy Indicator

Adequacy indicator is another measure used to assess the effectiveness of an irrigation system. Table 8 shows the adequacy indicator of CRDS canal system and its selected branch canals based on the flow measurement during the year 2019. The selected branch canals of the canal system, except the Mettippadam branch canal, fell in the performance group 'poor' (Table 2) according to the computed adequacy indicator. This also confirmed the poor condition of lining of the branch canals. The adequacy indicator also pointed out that the overall performance of the CRDS canal system fell in the category of "fair." As a result, the irrigation water supplied in the command area of the CRDS canal system was insufficient to meet the demands. Regular repair and maintenance are also necessary to reduce the seepage loss, and thereby increase the conveyance efficiency and adequacy in irrigation.

The average annual water diverted to the canal system was 153.3 Mm^3, and was very high compared to the estimated net irrigation requirement (46.90 Mm^3) of

Table 8. Adequacy indicator of CRDS canal system

Canal system	Branch/ Canal system	Irrigation water delivered, Mm^3	Irrigation requirement, Mm^3	Adequacy	Performance
Left bank canal	Meloor	0.64	5.89	0.108	Poor
	Edakkuny	0.37	2.25	0.163	Poor
	Mambra	0.15	13.35	0.011	Poor
Right bank canal	Mettippadam	0.85	0.88	0.963	Good
	Perambra	0.89	4.04	0.221	Poor
	Thazhekkad	0.34	4.14	0.081	Poor
Chalakudy River Diversion Scheme (CRDS)		153.31	183.50	0.861	Fair

the command area. This revealed that the CRDS canal system had poor conveyance efficiency, which might lead to an unequal distribution of irrigation water along the canal. Tail end farmers suffered more due to the loss of water from the canal system. In addition to proper repair and maintenance, use of groundwater recharged from the seepage loss in conjunction with the canal water for irrigation is one of the possible remedial measures to meet the irrigation water demand of tail end farmers. Elnmer *et al.* (2018) also suggested the use of groundwater for irrigation at tail end branch canals along with reappropriation of distribution policies to alleviate adequacy problems of irrigation water in the Nile Delta.

CONCLUSIONS

The performance and adequacy in supply of irrigation water for the Chalakudy River Diversion Scheme (CRDS) canal command in central Kerala was evaluated. Conveyance efficiency was used to evaluate the efficacy of water distribution. Two indicators, Relative Water Supply and Adequacy Indicator, were used as the measures to appraise the adequacy of irrigation water supplied through the canal system. The major concerns of the tail-end farmers was the lack of water supply near the tail end of the CRDS canals. Worn out lining and improper maintenance were the main issues with the canal system. The conveyance efficiency of the right bank canal was comparatively higher (40–74%) than that of the left bank canal (19–63%), and the total conveyance efficiency of the CRDS canal system was found to be 51.1 per cent. Like the conveyance efficiency, the RWS of right bank canal was relatively higher (0.42 - 0.81) as compared to that of the left bank canal (0.35 - 0.48). Relative water supply and adequacy indicator showed that the performance of most of the branch canals were poor. The overall performance of the CRDS canal system fell in the “fair” category with adequacy indicator value of 0.86. Data on water diversion from the Thumburmuzhi weir clearly indicated that it was much higher than the net irrigation demands of the command area. Even then, adequacy was not achieved mainly due to substantial seepage loss and low conveyance efficiency across the canal system. Timely repair and maintenance of the canal system is thus necessary. These point out that unless and until the canal systems are well maintained and lined regularly, adequate supply of irrigation water in the command area would not be available. As the loss of water through seepage contributed to groundwater recharge, the conjunctive use of canal water and groundwater is suggested for the tail reach of the CRDS canal system.

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