CROPWAT and GIS tools for AEU based Irrigation Demand Estimation of the Chalakudy River Diversion Scheme (CRDS) command area

E.B. Gilsha Bai[1*], K.P. Rema[2], Asha Joseph[2], Mini Abraham[3] and Anu Varughese[2]

[1]*Krishi Vigyan Kendra, Palakkad, Kerala Agricultural University, Mele Pattambi 679 306, Kerala, India*
[2]*Kelappaji College of Agricultural Engineering and Technology, Kerala Agricultural University, Tavanur 679 573, Kerala, India*
[3]*Agronomic Research Station, Chalakudy, Kerala Agricultural University 680 307*

Received 28 January 2022; received in revised form 15 November 2022; accepted 04 December 2022

Abstract

Irrigation is one of the major factors affecting the productivity of crops. Planning of irrigation schemes and efficiency assessment of the existing schemes require an accurate estimation of irrigation demand. Cropping patterns and their areal extent determine the quantity of irrigation water required. Crops and cropping pattern of a place and its water requirement mainly depends on the agroecological situation of the area. Hence, estimating irrigation demand considering parametric variations of agro-ecological units is necessary for planning irrigation. However, estimation of the cropped area and cropping patterns, which decides the capacity of irrigation schemes, is tedious without using GIS tools. The present study conducted in the command area of the Chalakudy River Diversion Scheme (CRDS) utilized the Image processing software ERDAS Imagine for the preparation of land use/ land cover map and ArcGIS for other spatial analyses of the maps. There were seven different agro-ecological units in the study area. The irrigation requirements of the crops/cropping pattern in these agro-ecological units were estimated using the CROPWAT 8.0 software developed by FAO. The results indicated that the water requirement of crops, especially that of paddy, varies with the agro-ecological unit. The total irrigation demand of different agro-ecological units was found to be proportional to the cropped area, but the seasonal variations in irrigation demand were similar in all agro-ecological units of the study area. The estimated average annual net irrigation requirement of the CRDS command area was obtained as 46.90 Mm^3. The average annual water release through the canal system was found deficient to meet this demand due to the lack of management and maintenance of the canal system.

Keywords: Agro-ecological unit, ArcGIS, Chalakudy River Diversion Scheme, CROPWAT, ERDAS Imagine, Irrigation requirement.

Introduction

Irrigation is a prime necessity to enhance crop production to attain food security for the growing population. In India, 56% of the food grain production comes from irrigated agriculture. But, water is becoming a scarce commodity day-by-day for agricultural purposes. On the other hand, the irrigated area needs to be extended to achieve more production. Hence, proper planning is required for scheduling irrigation and land utilization.

Agro-ecology involves agricultural, environmental, and social concepts for sustainable agricultural production (Wezel et al., 2009). Soil, climate, rainfall and topographic features of a place are the environmental factors of agro-ecology that determines flora and fauna suitable for that natural

*Author for Correspondences: Phone: 9495062840, Email: gilsha.bai@kau.in

condition (Gajbhiye and Mandal, 2000). The growth of plants varies according to agro-ecology, especially the soil. Hence, ecological farming is necessary for sustainable crop production. Crop selection, farming operations, irrigation, etc. should be in accordance with the agroecology of the location. In the case of irrigation, water requirement of the crops and irrigation schedule varies with climate and soil type of different agroecological units (Surendran et al., 2019). Thus, the computation of crop water requirement according to agro-ecological unit is important for proper planning of irrigation projects. Existing irrigation schemes should also be analyzed for their efficiency.

Computation of crop water requirement is accurate and easy with the models like CROPWAT 8.0 and AquaCrop developed by FAO (Pushpalatha et al., 2021). CROPWAT 8.0 is a software widely used for research purposes. Kuo et al. (2006) estimated the irrigation water requirement of paddy and upland crops with the help of CROPWAT model using the crop coefficients derived from the field experiments in Taiwan. In 2019 Acharjee et al. assessed the potential crop water requirement, effective rainfall, and irrigation requirement of Boro rice using the CROPWAT 8.0 software for different planting dates for future years. The precise estimation of an area's irrigation requirement depends on the area's land use/land cover. Acquiring data on land use/land cover and cropping patterns of an area has become easy with the incorporation of remote sensing and GIS tools. Use of GIS tools and CROPWAT 8.0 software have been used widely by researchers for estimating the crop water requirement and scheduling of irrigation (Al-Najar, 2011; Gangwar et al., 2017; Zhiming et al., 2017).

Kerala, falls under the humid tropical region and is characterized by relatively high humidity, temperature, and rainfall. The uneven temporal distribution of rainfall creates an extended summer season of around six months in Kerala (Krishnakumar et al., 2009). Irrigation is required during these months to maintain productivity. Spatial variation in rainfall is also there, enabling the cultivation of various crops. However, the irrigated area in Kerala is only 20% of the total cropped area, as per Economic Review, 2020. To enhance the area under irrigation, and thus the productivity, the relationship between climate, geology, topography, and crop production needs to be utilized for planning. Recommendation of crops and irrigation should be based on the agro-ecology of the location.

Chalakudy River Diversion Scheme (CRDS) is a major irrigation project in central Kerala that faces inadequate water availability problem towards the tail end of the canal system. To assess this problem accurately, the present study was taken up by computing the irrigation demand of the command area of CRDS canal system for the present land use pattern and agroecological variations.

Materials and Methods

Study Area

The study was conducted in the command area of Chalakudy River Diversion Scheme (CRDS), one of Kerala's major irrigation projects. The command area lies in two districts, Ernakulam and Thrissur and is located between the north latitudes 10^{o} 8'45" and 10^{o}24' 28" and the east longitudes 76^{o} 12' 37" and 76^{o} 22' 17" (Fig.1). The area falls in the humid

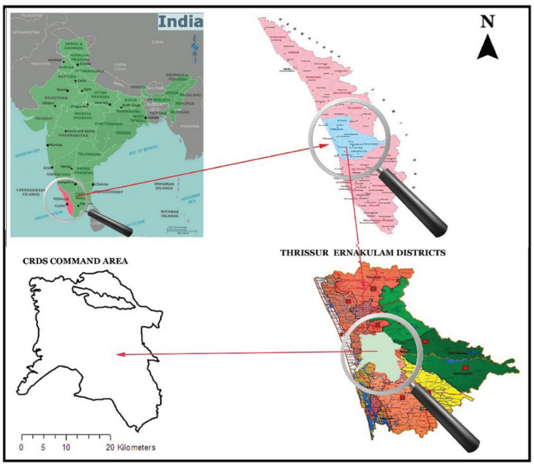

Figure 1. Location map of the study area

tropical region with an average annual rainfall of 3193.5 mm and temperature varies from 25.77°C to 35.12°C. Laterite is the predominant soil type in this region. Water from the Chalakudy River is diverted through a canal system by constructing a weir across the river at Thumboormoozhi. The canal system supplies water to a cultivable command area of 13,895 hectares out of a total area of 39685 hectares through two main canals, branch canals and distributaries.

Agro-ecological units (AEU) in the command area

The variability in soil type and altitude divides the command area into different agro-ecological units, though the rainfall variation is low in the area. There are seven AEUs in the command area out of the 23 units of the state (Table 1). AEU map of the command area was delineated from the agro-ecological zone map of Kerala prepared by NBSS&LUP (Fig.2).

Table 1. Agro-Ecological Units in the CRDS command area

Agro-Ecological Unit	Description
AEU 5	Pokkali Lands
AEU 6	Kole lands
AEU 9	South Central Laterites
AEU 10	North Central Laterites
AEU 12	Southern and Central Foothills
AEU 14	Southern High Hills
AEU 15	Northern High Hills

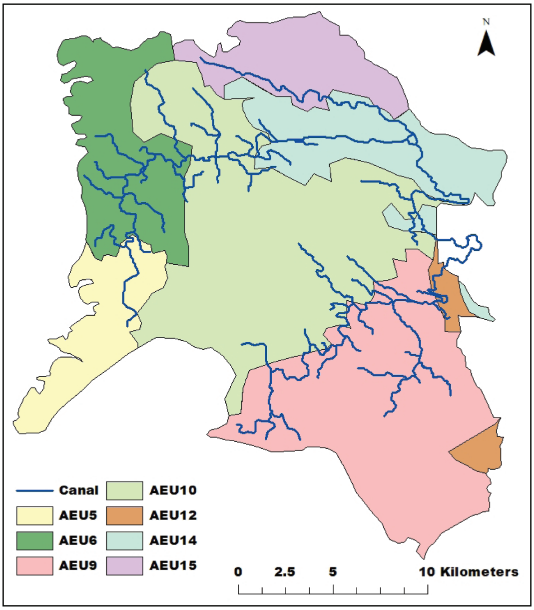

Figure 2. Agro-ecological units in the CRDS command area

Data sources

Images of CRDS command area boundary and canal system were taken from the 'India-WRIS' website for the preparation of a digital database for conducting the study. The data on rainfall and other weather parameters for 27 years (1990- 2016) were collected from Agronomic Research Station, Chalakudy, located in the study area. Rainfall data from two more nearby IMD stations were also collected. The average rainfall over the command area was computed using Thiessen polygon method in the ArcGIS software.

Soil characteristics of the seven agro-ecological units present in the command area were taken from the report of agro ecological zones of Kerala prepared by NBSS&LUP. Land use/ land cover map of the study area was prepared using the satellite imagery downloaded from the USGS website. Data on various crops /cropping patterns of the area were obtained from the nearby offices of the State Department of Agriculture.

Preparation of digital database

ArcGIS and ERDAS Imagine software were used for the preparation of the digital database. ArcGIS version 10.3.1 was used in this study. The command area boundary and canal network obtained from the 'India-WRIS' website were used for preparing a base map of the study area in ArcGIS software. ERDAS Imagine 2015 developed by Intergraph, USA was used for the preparation of land use/land cover map of the study area. Cloud free satellite imagery, Sentinel 2 level 1C of the study area downloaded from USGS Earth Explorer website, captured during the month of March, 2017 was used for this purpose. The unsupervised classification method was applied to prepare the land use map. From the land use map of the command area of CRDS, the land use of the cultivable area of each branch canal was clipped using the buffer tools in ArcGIS software. Thus, the area under different crops/cropping patterns in the command area of each branch canal was extracted and used for the computation of the water requirement of crops in the area.

Irrigation requirement

CROPWAT 8.0, the software developed by FAO based on Penman- Monteith method, was used for the computation of reference crop evaporation (ET_0) (Allen et al., 1998). The equation is as follows.

$$ET_0 = \frac{0.408\Delta(Rn - G) + \gamma(900/(T+273))\, u_2\, (e_s - e_a)}{\Delta + \gamma(1 + 0.34\, u_2)} \quad \text{(Eq. 1)}$$

where,

ETo -Reference crop evapotranspiration, mm day^{-1}

Rn - Net radiation at the 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 $°C^{-1}$

Ã - Psychrometric constant, kPa $°C^{-1}$

The software computed the crop water requirement according to the given crop coefficients using the following equation.

$$ET_C = K_C \times ET_0 \quad \text{———— (Eq. 2)}$$

Where, ET_C is the crop water requirement and K_C is the crop coefficient.

Irrigation requirement is the difference between the crop water requirement and effective rainfall for a particular period. There are four methods, *viz.* fixed percentage of rainfall, dependable rainfall, Empirical formula, USDA soil conservation service method, available in the CROPWAT 8.0 software for the computation of effective rainfall. Among the four methods the USDA Soil Conservation Service method was opted to calculate the effective rainfall in the study. The method used following formulae for the computation of effective rainfall.

$$P_{eff\,(dec)} = P_{dec} * (125 - 0.6 * P_{dec}) / 125 \text{ for } P_{dec} <= 250/3 \text{ mm} \quad \text{—— (Eq. 3)}$$

$$P_{eff\,(dec)} = (125/3) + 0.1 * P_{dec} \quad \text{for } P_{dec} > 250/3 \text{ mm} \quad \text{— (Eq. 4)}$$

where,

P_{eff} - Effective rainfall, mm

P_{dec} – Rainfall for 10 days, mm

Crop coefficient values (Kc) of various crops in the command area were collected from literature. Variations in Kc values with respect to growth stages were accounted for in the case of seasonal crops whereas Kc values corresponding to the late stage of growth were used in perennial crops (Surendran et al., 2017). The irrigation requirement of cropping patterns in the CCA of each branch canal was obtained from the scheme schedule of CROPWAT 8.0 software. Irrigation requirements of paddy and other cropping patterns differ in different agro-ecological units. Hence, depending upon the agro-ecological unit through which a branch canal passes, the corresponding depth of irrigation was assigned to the crop/cropping patterns existing in its command area. This depth of irrigation was multiplied by the area occupied by the corresponding crop/cropping pattern in the branch canal CCA to get the irrigation requirement in volumetric units. The area was taken from the land-use clip of each branch canal command area. By adding the irrigation requirement of all such branch canals in each agro-ecological unit the total irrigation requirement of the AEU and by adding the irrigation requirement of all AEU's, the total irrigation requirement of the entire cultural command area of CRDS was obtained.

The total irrigation water to be delivered to the fields of the CRDS command area was computed after assessing the conveyance efficiency of the canal system. Flow rates through the canal were measured at several sites using a pigmy type current meter during 2018-19 to estimate the seepage loss of canal.

Inflow-outflow method was used for the measurement of seepage loss, and the conveyance efficiency of the canal system was computed using the following formula.

$$\text{Conveyance efficiency} = \frac{\text{Water delivered to the Field}}{\text{Water diverted to the canal}} \times 100 \quad \text{(Eq. 5)}$$

Adequacy of water was checked using the canal release data of CRDS canal system collected from the state irrigation department.

Results and Discussion

Base map and land use map of the study area

The base map of the study area prepared in ArcGIS software has an area of 40,127 ha, approximately equal to the reported area of 39,685 ha for the CRDS command area (Madhusoodhanan and Eldho, 2012). The land use/land cover map of the CRDS command area prepared in the ERDAS Imagine software is shown in Fig.3. The whole land use was classified into ten classes. Paddy, multiple crop, coconut-based cropping system, and rubber are the cultivated land cover classes. Multiple crop includes nutmeg, banana, coconut, arecanut, etc. in more or less same proportion where as in the coconut-based cropping system coconut is dominant. Other crops nutmeg, banana, arecanut, pepper, vegetables etc. are also included in the coconut-based cropping system. The other land use classes identified in the area are built-up area, barren land, scrub, etc. The paddy area covers 10.51 percent of the command area. The multiple crops and coconut-based cropping systems are almost equal in the command area. Land use clip of each branch canal command area was the subset of this land use map and was used to get the

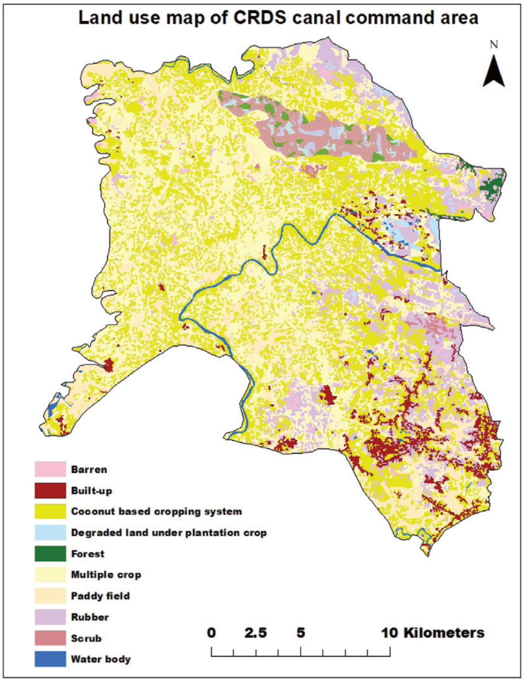

Figure 3. Land use/land cover map of CRDS command area.

area of crop/cropping pattern in the branch canal command area. The total area of land use clips of all branch canals of the CRDS canal system was found as 13865 ha (Table 2) and it is very near to the reported area of the CCA of the canal system, 13895 ha (Madhusoodhanan and Eldho, 2012).

The agro ecological units existing in the command area, its areal extent, and cropping patterns are shown in Table 2. North Central Laterites (AEU 10) covered more area compared to other AEUs in the CCA of the CRDS command area. Southern

Table 2. CCA and cropping pattern of agro-ecological units of the CRDS command area

Agro-Ecological Unit	Description	CCA (ha)	Cropping pattern
AEU 5	Pokkali Lands	304.14	Paddy (4%), Multiple crop (57%), Coconut based cropping system (37%)
AEU 6	Kole lands	1665.96	Paddy (5%), Multiple crop (64%), Coconut based cropping system (28%)
AEU 9	South Central Laterites	4343.66	Paddy (14%), Multiple crop (16%), Coconut based cropping system (31%)
AEU 10	North Central Laterites	5968.65	Paddy (5%), Multiple crop (48%), Coconut based cropping system (32%)
AEU 12	Southern and Central Foothills	201.11	Paddy (9%), Multiple crop (30%), Coconut based cropping system (11%)
AEU 14	Southern High Hills	708.84	Paddy (4%), Multiple crop (34%), Coconut based cropping system (38%)
AEU 15	Northern High Hills	672.84	Paddy (12%), Multiple crop (28%), Coconut based cropping system (55%)
Total		13865.2	

and Central Foothills (AEU 12) occupied the lowest area. Among the different AEUs, paddy was the maximum in the CCA coming under AEU 9. The area covered by the irrigation demanding crops was found maximum (98% of CCA) in AEU 5, whereas it was found to be minimum (50% of CCA) in the AEU 12. The CCA under the AEU 12 exists towards the eastern portion of the CRDS command area where plantation crops are more. This may be the reason for the reduced area of irrigation demanding crops in the CCA of the branch canals passing through the AEU.

Average rainfall over the command area and effective rainfall

Thiessen polygons were prepared in ArcGIS software to compute average rainfall over the command area. There are three rain gauge stations, one inside and two outside the command area, that influence the area's average rainfall. The rainfall recorded at Kodungallur and Perumbavoor stations have an influential area of 10 km^2 and 40 km^2, respectively. The remaining area of 350 km^2 is influenced by the rainfall recorded at Chalakudy station. The average monthly rainfall thus calculated was in close agreement with the average rainfall recorded at Chalakudy station.

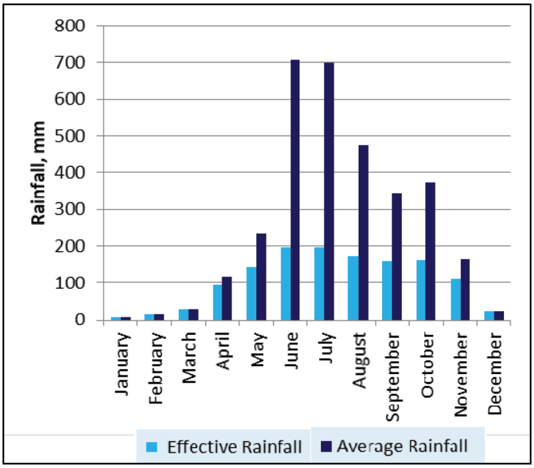

Figure 4. Mean monthly variation of average rainfall and effective rainfall

From the average rainfall, the effective rainfall was computed by CROPWAT 8.0 software using the USDA Soil Conservation Service method. The mean monthly rainfall and effective rainfall computed by the software is presented in Fig.4. It was found that during summer and winter months, most of the rainfall is retained in the root zone as effective rainfall while runoff losses were high during monsoon periods. Average annual effective rainfall over the entire CRDS command area was found as 1310.9mm, which was 41 percent of the average annual rainfall.

Reference crop evapotranspiration

CROPWAT 8.0 software computes the reference crop evapotranspiration daily. The average daily ET_0 in the CRDS command area was found to be maximum during the month of March and minimum during the month of July (Table 3). The monthly variation of average daily temperature causes high

Table 3. Mean daily weather parameters and ET_0 computed by CROPWAT (1990– 2016)

Month	Mini Temp(°C)	Max Temp(°C)	Humidity (%)	Sun shine hours (h)	Radiation (MJm^{-2}day^{-1})	ETo (mm day^{-1})	ETo (mm month^{-1})
January	20.2	33.4	73	8.4	19.7	4.58	141.98
February	21.4	34.5	73	8.5	21.1	5.00	140.0
March	23.5	35.4	75	8.0	21.5	5.23	162.13
April	24.5	34.8	78	7.2	20.6	4.99	149.7
May	24.4	33.6	79	6.6	19.4	4.64	143.84
June	23.3	30.3	83	5.0	16.6	3.74	112.2
July	22.8	29.4	84	4.7	16.3	3.59	111.29
August	23.0	29.7	84	4.7	16.5	3.66	113.46
September	23.0	30.7	82	5.3	17.4	3.92	117.6
October	22.6	31.3	80	5.9	17.4	3.96	122.76
November	22.0	32.0	78	6.7	17.4	4.02	149.7
December	21.4	32.7	76	7.3	17.7	4.12	127.72

ET_0 during March and low ET_0 during July. Low sunshine hours during the southwest Monsoon also play an important role in the reduction of ETo during the rainy season. Many researchers have reported this variation in ET_0 with season (Al-Najar, 2011; Nivesh et al., 2019)

Irrigation requirement

Irrigation requirement of crops/cropping patterns in different agro-ecological units were computed using CROPWAT 8.0 model by taking into account of the soil, crop, and climate parameters of each unit. Table 4 shows the cropped area, annual irrigation requirement of various cultivated crops and annual net depth of irrigation for paddy in the CCA under different AEU of the CRDS command area.

The cultivable command area under each AEU is occupied not only by crops but also by built-up and other land use classes. Hence, the irrigation requirement of CCA under each AEU was found proportional to the area occupied by the irrigation demanding crops, which is evident from Table 4. The cropped area was found maximum in the AEU 10; hence this unit required the maximum irrigation water annually. The effect of soil characteristics on crop water requirement was clear in the case of paddy. Hence it is clear that there is a wide variation in the irrigation requirement of paddy under different AEUs in the CRDS command area.

Table 4. Annual net irrigation requirement of the CRDS command area

Agro-Ecological Unit	Cropped area (ha)	Annual net Irrigation requirement (Mm^3)	Net depth of irrigation required annually for paddy (mm)
AEU 5	299.50	1.293	1734.4
AEU 6	1628.22	6.547	1137.5
AEU 9	2660.00	11.672	1198.8
AEU 10	5079.59	21.608	1508.8
AEU 12	100.55	0.450	1198.8
AEU 14	538.06	2.356	1408.6
AEU 15	638.08	2.974	1979.3
Total	10904.0	46.9	

The seasonal net irrigation requirements of CCA under different AEUs in the command area are shown in Table 5. The irrigation requirement was found to be the lowest during Kharif/ Virippu season and highest during summer/puncha season in all AEUs. The high rainfall and low evapotranspiration (ET_0) during the Kharif season contributed to the low net irrigation requirement. During this season, water is required only for land preparation and growing paddy nursery. But the low rainfall and high temperature increased the irrigation requirement during summer. Banana and nutmeg are the two major high water demanding dry crops in the multiple cropped area during summer. All these contributed to the high irrigation demand during summer, irrespective of the AEU in which the cropped area lies. The net irrigation requirement of the entire CCA of the CRDS command area is 2.73 Mm^3 during Kharif and 33.81 Mm^3 during summer. The average annual net irrigation requirement of the command area was found as 46.90 Mm^3.

Water diverted through the CRDS canal system from 2013 to 2018 is shown in Table 6. The average annual water release was 157.97 Mm^3. From the released water, some portion, 4.66 Mm^3, is usually stored in several large ponds to operate lift irrigation schemes to cover the areas other than the CCA of the canal system. Thus, the average annual water diversion to the canal system was 153.3 Mm^3, which was taken for further computations. Measurement

Table 5. Seasonal net irrigation requirement of the CRDS command area

Season	Net Irrigation Requirement (Mm^3)							
	AEU 5	AEU 6	AEU 9	AEU 10	AEU 12	AEU 14	AEU 15	Total
Kharif/ Virippu	0.050	0.200	0.968	0.976	0.036	0.071	0.424	2.73
Rabi/ Mundakan	0.252	1.188	3.152	4.540	0.096	0.436	0.691	10.36
Zaid/ Puncha	0.990	5.159	7.551	16.092	0.317	1.849	1.859	33.81
Total	1.293	6.547	11.672	21.608	0.450	2.356	2.974	46.90

Table 6. Water diverted through CRDS canal system from 2013 to 2018

Year	Water diverted from Thumburmuzhi weir LBC(Mm^3)	RBC (Mm^3)	Total (Mm^3)
2013-2014	108.45	70.10	178.55
2014-2015	108.90	62.37	171.27
2015-2016	82.73	68.43	151.16
2016-2017	62.42	65.22	127.64
2017-2018	95.60	65.61	161.21
		Average	157.97

of seepage loss from the canal showed the average conveyance efficiency of the canal system as 51.1%. Management and maintenance problems in the canal system lead to this much low conveyance efficiency. Lack of water availability towards the tail end of the canal system and the branch canals, was the major complaint from the tail end farmers. Worn out and poorly managed linings were the major reasons for this situation.

Usually, rotational water delivery system is following in the branch canals. Since the released water from the canal has been applied to the field using surface irrigation methods, an application efficiency of 50% was assumed to compute the gross irrigation requirement. Thus, the computed annual gross irrigation demand of the CRDS command area was 183.56 Mm^3 (Table 7). This showed that there is a deficiency in irrigation water for the CRDS command area to meet the demand of the present cropping pattern existing in the various agro-ecological units of the command area.

Accurate estimation of irrigation demand of an area depends on accurate estimation of crop water requirement as well as the areal extent of crops/cropping patterns. Climate, soil, topography, and water availability period determine the existence of crops in a place. Irrigation demand of the crops invariably depends on these parameters which are uniform only in an agro-ecological unit. Thus, the study conducted to estimate the variability in irrigation requirement with the agroecology and areal extent of crops in the command area of the CRDS canal system revealed that variation in water requirement of all crops, especially for paddy, according to the agro-ecological units. Among the seven AEUs in the command area, AEU 15 (Northern High Hills) showed a maximum annual irrigation requirement (1979.3 mm) for paddy. AEU 10 (North Central Laterites) has the maximum areal extent and occupies a cropped area of 5079.59 ha. Hence, the annual net irrigation requirement of AEU 10 was maximum of 21.608 Mm^3 among the AEUs in the command area. Seasonal variation in the irrigation demand occurred in all the AEUs. The estimated average annual irrigation demand of the CRDS command area was found 46.90 Mm^3. The lack of maintenance and poor management of the canal system resulted in irrigation water loss and deficiency of water in the CRDS command area though the water release through the canal system was higher than that of the net irrigation demand of the command area.

Table 7. Gross irrigation requirement and deficiency in irrigation water

Particulars	Volume of water (Mm^3)
Net water diverted through the canal system	153.31
Conveyance efficiency	51.1%
Net irrigation requirement	46.90
Field application efficiency	50.00%
Gross irrigation requirement	183.56
Deficiency in irrigation water	30.25

Acknowledgement

The authors are thankful to Kerala Agricultural University for funding the project. Moreover, the first author is grateful to the University for granting three-year study leave to pursue doctoral studies.

References

Acharjee, T.K., van Halsema, G., Ludwig, F., Hellegers, P. and Supit, I. (2019). Shifting planting date of *Boro* rice as a climate change adaptation strategy to reduce water use. Agric. Syst., 168, 131-143.

Allen, R. G., Pereira, L. A., Raes, D. and Smith, M. (1998). Crop evapotranspiration –guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome, Italy, 293 p.

Al-Najar, H. (2011). The integration of FAO-CROPWAT model and GIS techniques for estimating irrigation water requirement and its application in the Gaza Strip. Nat. Resour., 2, 146-154. doi:10.4236/nr.2011.23020.

Gajbhiye, K.S. and Mandal, C. (2000). Agro-Ecological Zones, their soil resource and cropping systems. CED documentation on status of farm mechanization in India, 32 p.

Gangwar, A., Nayak, T.R., Singh, R.M. and Singh, A. (2017). Estimation of crop water requirement using CROPWAT 8.0 model for Bina command, Madhya Pradesh. Indian J. Ecol., 44, 71-76.

Krishnakumar, K.N., Rao, G.S.L.H.V. and Gopakumar, C.S. (2009). Rainfall trends in twentieth century over Kerala, India. Atmos. Environ., 43, 1940-1944. doi: 10.1016/j.atmosenv.2008.12.053.

Kuo, S.F., Lin, B.J. and Shieh, H.J. (2001). CROPWAT model to evaluate crop water requirements in Taiwan. In: Proceedings of 1st Asian Regional Conference 2001, International Commission on Irrigation and Drainage, Seoul, A25, 14p. https://www.researchgate.net/publication/265197839.

Madhusoodhanan, C.G. and Eldho, T.I. (2012). Impact of diversions in the Chalakudy basin and implications for integrated basin management. In: Proceedings of National Conference on Hydraulics, Water Resources, Coastal and Environmental Engineering (HYDRO-2012), 7 – 8 December 2012, IIT Bombay, India, 1-9.

Nivesh, S., Kashyap, P.S. and Saran, B. (2019). Irrigation water requirement modelling using CROPWAT model: Balangir district, Odisha. The Pharma Innovation J., 8(12), 185-188.

Pushpalatha, R., Sunitha, S., Santhosh Mithra V.S. and Gangadharan B. (2021). Modelling the yield, water requirement, and water productivity of major tropical tuber crops using FAO-AquaCrop - A study over the main growing areas of India. J. Trop. Agric. 59 (2), 155-161.

Surendran, U., Sushanth, C.M., Mammen, G. and Joseph, E.J. (2017). FAO-CROPWAT model-based estimation of crop water need and appraisal of water resources for sustainable water resource management: Pilot study for Kollam district – humid tropical region of Kerala, India. Curr. Sci., 112 (1), 76- 86.

Surendran, U., Sushanth, C.M., Joseph, E.J., Al-Ansari, N. and Yaseen, Z.M. (2019). FAO CROPWAT model-based irrigation requirements for coconut to improve crop and water productivity in Kerala, India. Sustainability, 11, 5132. doi:10.3390/su11185132

Wezel, A., Bellon, S., Dore, T., Francis, C., Vallod, D. and David, C. (2009). Agroecology as a science, a movement and a practice- A review. Agron. for sustain. Dev., 29, 503-515.

Zhiming, F., Dengwei, L. and Yuehong, Z. (2007). Water requirements and irrigation scheduling of spring maize using GIS and CROPWAT Model in Beijing-TianjinHebei region. Chinese Geogr. Sci., 17(1), 56-63.