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Modelling the irrigation demand profile of Chalakudy river diversion scheme using CROPWAT and GIS tools

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ABSTRACT

Irrigation planning for a command area necessitates a proper assessment of irrigation water required by the crops in the area. Net irrigation water demand mainly depends on the cropping pattern and the areal extent. In a vast command area collection of accurate data on cropping pattern and their areal extent is a tedious job. Remote sensing technology and geographic information systems could be utilized effectively for easy and accurate data collection. Rainfall is another important factor in the calculation of irrigation water requirement. Effective rainfall retained in the root zone of crops reduces irrigation requirement. In the present study the average rainfall of the entire command area was calculated using the Thiessen polygon method. The land use map of CRDS command area was prepared using remote sensing and GIS tools. From the prepared land use map, areal coverage of crops in the command area was assessed for the computation of irrigation water requirement. Cultivated crops covered more than 80 per cent of the CRDS command area that comprised paddy 10.51 per cent, mixed crops 37.77 per cent, coconut-dominant mixed crop 31.83 per cent and rubber 12.80 per cent. CROPWAT 8.0 software was used for the computation of irrigation water requirement. The average annual net irrigation demand of CRDS command area was obtained as 46.90 Mm^3.

Keywords: ArcGIS; command area; CROPWAT; irrigation planning; land use; water requirement

INTRODUCTION

When rainfall is inadequate crops need irrigation to satisfy their water requirement. In a tropical humid area like Kerala, total annual rainfall is several times more than the annual water requirement of most of the crops. Even then crops face acute shortage of water during summer months due to spatial and temporal variation of rainfall and irrigation is necessary to avoid water stress and to maintain the productivity of crops (Surendran et al 2015, 2017). Distribution and delivery of irrigation water requires accurate planning for the judicial use of this precious natural resource (Gangwar et al 2017).

Water scarcity towards the tail-end of the main canal and distributaries is a major problem associated with almost all the canal irrigation schemes. Chalakudy river diversion scheme (CRDS) is such a scheme situated in the central region of Kerala. Rotational system of water delivery tries to eradicate this issue but is seldom found successful in many irrigation commands. Poor maintenance of lined canals, use of unscientific methods of irrigation, overuse of water in the upstream portion of canal system etc are the hindrances to avoid the problems of tail-end farmers. Proper planning can reduce the losses and thereby the inadequacy of water at the tail-end fields if surface water is available sufficiently. Assessment of exact requirement of irrigation water for the command area is a key factor for planning even distribution of water through canals. Hence this study was undertaken to model the net irrigation demand profile of the command area of CRDS.

Among several methods available for the estimation of evapo-transpiration and thereby irrigation requirement, physical process-based methods like Penman method, Penman-Monteith method etc are more reliable (Surendran et al 2015). Based on the Penman-Monteith method, Food and Agricultural Organisation (FAO) has developed a model, CROPWAT which is used to calculate ET and irrigation requirement. Depending on the input parameters viz meteorological parameters, rainfall data, soil parameters and crop growth stage parameters the software gives ET, crop water requirement and irrigation schedule as output (Clarke et al 1998). Several researchers used the CROPWAT model for determination of actual evapo-transpiration, crop water requirement and for scheduling irrigation (Kuo et al 2001, Zhiming et al 2007, Bana et al 2013, Knežević et al 2013, Abdulla et al 2015, Bouraima et al 2015, Bhat et al 2017, Kumari 2017, Trivedi et al 2018, Rajput et al 2018). Researchers have also estimated the irrigation requirement for future scenarios considering the expected climate changes (De Silva et al 2007, Acharjee et al 2017). As a result of such a study Acharjee et al (2019) recommended shifting of planting date of Boro rice to reduce the irrigation requirement

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The cropping pattern of the command area and the areal extent plays an important role in determining irrigation demand of the area. Land use map preparation and analysis using GIS software enables the estimation of actual irrigated area (Ahearn et al 2005, Mohammed 2017). Thus the present study which intended the estimation of irrigation water requirement of the command area of Chalakudy river diversion scheme (CRDS) utilizes ArcGIS tools for collection and analysis of data and CROPWAT 8.0 software for computation of irrigation requirement.

METHODOLOGY

Description of the study area and data sources

Chalakudy river diversion scheme (CRDS) is a major irrigation project in the Kerala state and the command area of this scheme formed the study area. It is located in the Thrissur and Ernakulam districts between the north latitude of 10° 8’ 45" and 10° 24’ 28" and the east longitude of 76° 12’ 37" and 76° 22’ 17". Water from the river is diverted through the 3.96 m high Thumboormoozhi weir to command area of 13,895 hectares out of a total area of 39,685 hectares. The canal system has two main branches, right bank canal (RBC) and left bank canal (LBC). RBC which is 48.2 km long distributes water to the command area through 24 branch canals and their distributaries. LBC having a length of 33.2 km covers its command area with 14 branches and their distributaries (Fig 1).

The area has a humid tropical climate with an average annual rainfall of 3,194 mm. Meteorological parameters recorded at the Agronomic Research Station, Chalakudy, Kerala located almost at the center of the command area was used for the study. Rainfall data recorded at three IMD rain gauge stations near but outside the command area were also used in addition to data from Agronomic Research Station, Chalakudy, Kerala to account for the variation in rainfall over the vast command area. Theissen polygon method under the GIS platform was used to compute the average rainfall over the command area.

National Bureau of Soil Survey and Land Use Planning prepared the agro-ecological zone map of Kerala state in coordination with the state planning board in 2012. Out of the 24 agro-ecological units of Kerala, six units are there in the command area. Soil characteristics of respective agro-ecological units were used to find out water requirement of crops in the command area of each branch canal using CROPWAT 8.0 model.

The command area of CRDS is covered mainly by water-demanding crops like paddy, coconut, nutmeg, banana and vegetables. Land use map of the command area was prepared using GIS software and tools to identify the crop intensity and pattern in the command area. Data to account for the percentage coverage of various crops in a particular cropping pattern were collected from state agricultural department offices located in the command area

Software and tools used

ArcGIS version 10.3.1 developed by Environmental System Research Institute (ESRI) was used for the study. ArcGIS10.3.1 is capable of doing spatial analysis through a lot of geo-processing tools incorporated in the software. Reclassifying tools, conversion tools, data management tools, data analysis tools and extraction tools like clip, buffer etc were used for the study.

Water requirement of individual crops in the command area was computed from meteorological data using CROPWAT 8.0 software developed by FAO (Allen et al 1998). Irrigation requirement of major cropping patterns in the command area was also obtained from the software as scheme schedule. Outputs from this software were used to compute the total irrigation requirement of the culturable command area of CRDS.

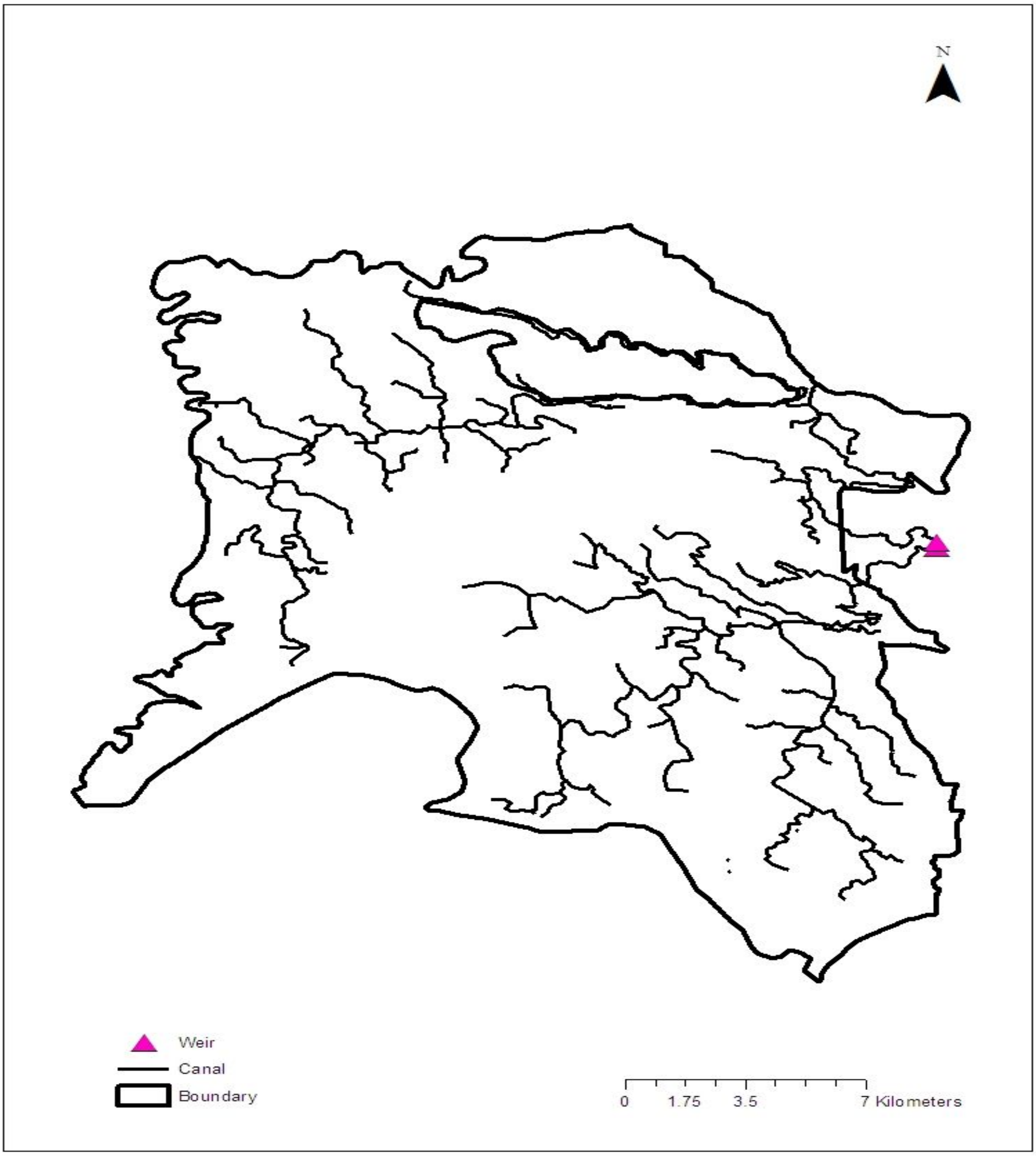

Fig 1. CRDS boundary and canal system

For the estimation of reference crop evapotranspiration, CROPWAT 8.0 uses the Penman-Monteith equation (Allen et al 1998):

$$ET_0 = \frac{0.408\Delta(Rn - G) + \gamma(900/(T+273))u_2\,(es - ea)}{\Delta + \gamma\,(1 + 0.34\,u_2)}$$

where ETo= Reference evapotranspiration (mm/day), Rn= Net radiation at the crop surface (MJ/m^2/day), G= Soil heat flux density (MJ/m^2/day), T= Mean daily air temperature at 2 m height, (°C), u_2= Wind speed at 2 m height (m/s), es= Saturation vapour pressure (kPa), ea= Actual vapour pressure (kPa), es-ea= Saturation vapour pressure deficit (kPa), Δ= Slope vapour pressure curve, (kPa/°C), Γ= Psychrometric constant (kPa/°C)

ET_{crop} was calculated from ET_0 by multiplying with crop coefficient:

$$ET_C = K_C \times ET_0$$

where K_C = Crop coefficient

Irrigation requirement was computed by subtracting effective rainfall P_{eff} from ET_C:

$$\text{Irrigation requirement} = ET_C - P_{eff}$$

There are options in the software for selecting methods to calculate effective rainfall. USDA soil conservation service method was selected in this study. The calculations are as follows:

$$P_{eff(dec)} = Pdec * (125 - 0.6 * P_{dec})/125 \text{ for } P_{dec} \leq 250/3 \text{ mm}$$

$$P_{eff(dec)} = (125/3) + 0.1 * P_{dec} \text{ for } P_{dec} > 250/3 \text{ mm}$$

where P_{eff} = Effective rainfall (mm), P_{dec} = Rainfall for 10 days (mm)

Preparation of digital database

A digital database was necessary for conducting the study. Base map and land use map of the command area were prepared using ArcGIS and Google Earth. CRDS boundary and canal system layout were obtained from the water resources information system website maintained by Ministry of Water Resources and National Remote Sensing Centre. The command area boundary was digitized using ArcGIS software. Image of the canal system was downloaded, digitized, geo-referenced and overlaid as a layer above the boundary of the command area (Fig 1).

Preparation of land use map

Shape file of the boundary of the command area was prepared in ArcGIS and exported to Google Earth as KML file. Classification of land use was done at this stage by adding polygon features representing various land use classes to this file. After completing the classification of land use within the boundary in Google Earth it was saved in KML format and converted to a layer in ArcGIS. Merging of similar land use classes was done in the ArcGIS software. Different land use classes were given different symbols (Mohammed 2017).

Extraction of the cropped area from land use map

Digitization of the canal branches was done separately in ArcGIS software. The area commanded by each branch canal was extracted using the extraction tool 'buffer'. From the prepared land use map of the whole command area of CRDS, land use in the culturable command area of each branch canal was clipped out using the buffer area as clipping feature in the ArcGIS software. Details extracted from these land-use clips were used for the computation of water requirement of the command area.

Irrigation requirement of the command area

Climate, rainfall, crop and soil parameters were given as input to the respective windows of the CROPWAT 8.0 model. Soil parameters were entered according to the agro-ecological unit where the branch canal lied. Crop parameters, especially crop coefficient values were obtained from the literature. Crop coefficient of seasonal crops varies according to growth stages (Anjana et al 2015). In the case of perennial crops, crop coefficient corresponding to the late stage of growth was used for the computation of crop water requirement over the whole year (Surendran et al 2017). Water requirement obtained for each crop/cropping pattern was multiplied by the area occupied by the corresponding crop/cropping pattern in the branch canal command area to get the water requirement in volumetric units. This area occupied by crops/cropping pattern was taken from the land-use clip of each branch canal command area. Irrigation requirement of each branch canal was found separately and summed up to find out the total irrigation requirement of the entire command area.

RESULTS and DISCUSSION

Reference crop evapo-transpiration

CROPWAT 8.0 software computed the reference crop evapo-transpiration on a daily basis. Average daily ET_0 was maximum during the month of March and minimum during the month of July (Table 1). High temperature due to peak summer in March caused maximum ET_0 during this month. Whereas in July due to southwest monsoon both temperature and sunshine hours were low which reduced ET_0 value. Surendran et al (2015) and Gangwar et al (2017) also reported maximum ET_0 during peak summer and minimum during the rainy season. This variation in ET_0 is reflected in the irrigation demand also.

Table 1. Average daily meteorological parameters and reference crop ET of the CRDS command area

Month	Temperature (°C)		Humidity (%)	Sunshine (h)	Radiation (MJ/m²/day)	ETo	
	Minimum	Maximum				mm/day	mm/month
January	20.2	33.4	73	8.4	19.7	4..58	141.98
February	21.4	34.5	73	8.5	21.1	5.0	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

Average rainfall over the command area

Thiessen polygon method was used for the computation of average rainfall over the command area. Thiessen polygons were prepared in ArcGIS software. Only three rain gauge stations, one inside the command area and two outside the command area had an influence on the average rainfall of the area. Average monthly rainfall over the entire command area is shown in Table 2. It is clear that the outside rain gauge stations had little influence on the average rainfall over the entire command area.

From the average rainfall for the entire CRDS command area the effective rainfall was computed using CROPWAT 8.0 software using the USDA method. Mean monthly rainfall in the command area and effective rainfall computed by the software are presented in Table 3. During summer and winter months most of the rain was retained in the root zone as effective rainfall. Runoff losses were more during monsoon periods. The results agree with the findings of Gowda et al (2013) and Saravanan and Saravanan (2014).

Land use map

Land use map of CRDS command area was prepared using Google Earth and ArcGIS software. The prepared map is shown in Fig 2. In the prepared

Table 2. Rainfall data of the CRDS command area

Month	Rainfall (mm)			
	ARS Chalakudy	Kodungallur	Perumbavoor	CRDS (mean)
January	6.30	14.65	15.59	7.66
February	12.89	50.42	22.26	15.32
March	22.55	180.49	35.64	29.79
April	101.67	403.47	141.20	117.14
May	225.67	530.27	222.57	236.42
June	710.17	776.77	676.25	708.76
July	697.03	702.88	711.57	698.89
August	475.65	455.11	467.64	474.00
September	341.36	234.90	394.27	343.47
October	379.61	315.15	341.64	372.97
November	165.16	96.70	186.01	165.03
December	22.98	15.92	37.72	24.39

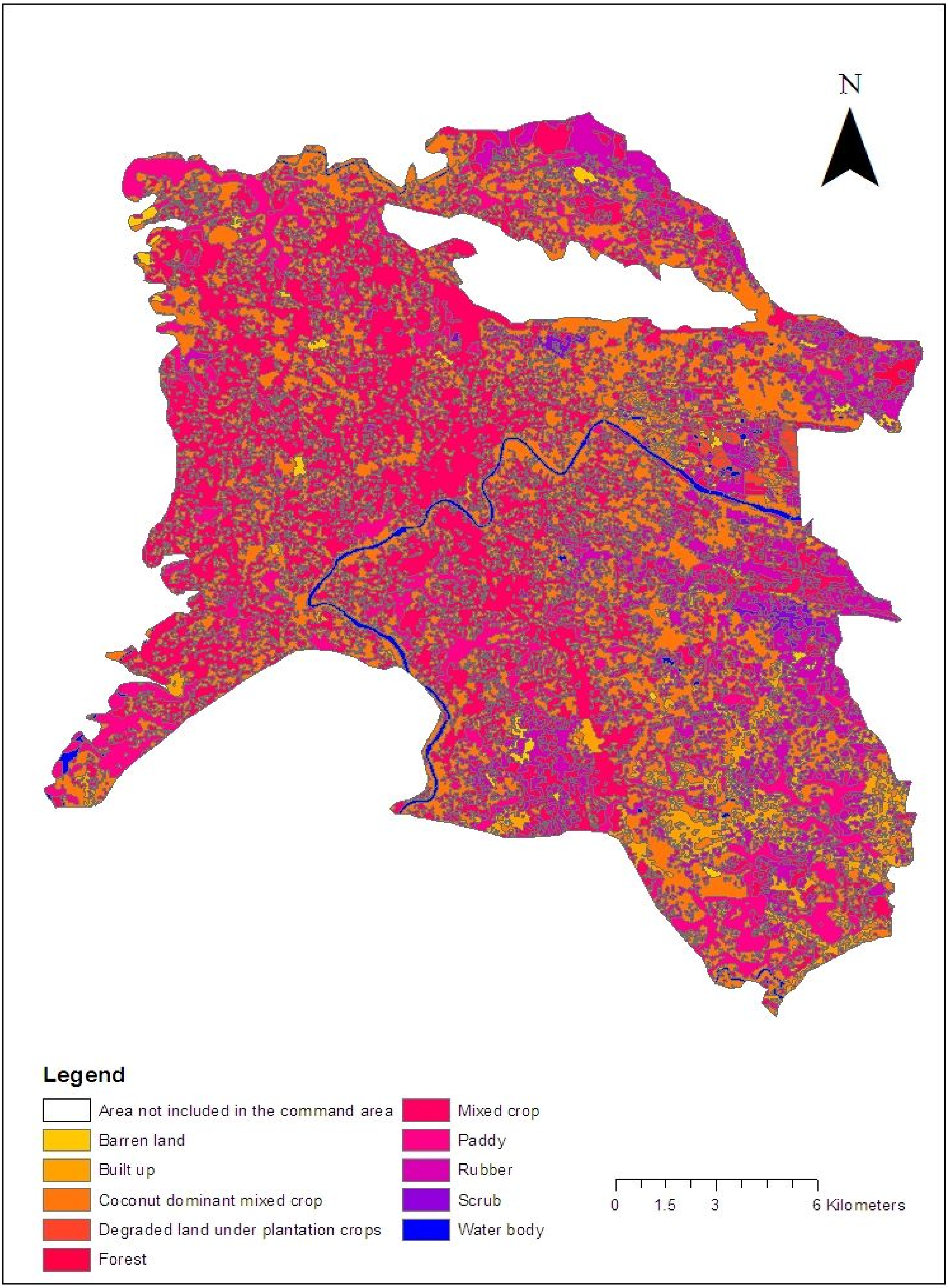

Fig 2. Land use map of the CRDS command area

land use map the whole area is classified into ten land use classes. Paddy, mixed crops, coconut-dominant mixed crops and rubber were the classes of cultivated crops. Among these rubber was cultivated as a rain-fed crop. While calculating irrigation water requirement vegetables cultivated in the paddy fields as summer crops were also considered. Built-up area, barren land, scrub etc were the other land use classes. Since the eastern portion of the command area was highland, forest was also taken as one of the land use classes.

Table 3. Mean monthly and effective rainfall

Month	Rainfall (mm)	Effective rainfall (mm)
January	7.6	7.4
February	15.3	14.9
March	29.8	28.2
April	116.9	94.7
May	236.5	144.0
June	709.0	195.9
July	698.6	194.9
August	474.1	172.4
September	343.6	159.4
October	373.1	162.3
November	165.3	113.9
December	24.5	23.4
Total	3194.3	1311.4

Land use classes and area covered by each land-use class is shown in Table 4. Paddy area covered 10.51 per cent of the command area. Mixed crops and coconut-dominant mixed crops were almost equally extended and were important land use classes in the command area. They covered 37.77 and 31.83 per cent area of the canal command respectively. Ground truthing was done by comparing the land use class in the map and actual field condition. During field visits it was understood that nutmeg which is a high water demanding dry crop was the main crop next to coconut in mixed and coconut-dominant mixed cropping patterns. Banana was also a major crop in these cropping patterns. Rainfed plantation crops like rubber covered 12.80 per cent of the command area. The cultivable command area of CRDS canal system extracted from the land use map of the area is shown in Fig 3. As shown in Table 5 the CCA extracted from land use map (13,865 ha) using the 'buffer' tool of ArcGIS agrees with the reported CCA (13,895ha) of the CRDS command area (Madhusoodhanan and Eldho 2012). Almost 35 per cent of the whole command area was cultivable. Left bank canal supplied water to 56 per cent of this area and right bank canal to rest of the area.

Irrigation water requirement of the command area

Irrigation water requirement of the CRDS command area was estimated using CROPWAT 8.0 software. Annual net irrigation requirement of the command area and its season-wise split up are shown in Tables 5 and 6 respectively. Requirement of water was lowest in the kharif or Virippu season (2.610 Mm^3) and highest in the summer (Puncha) season (33.873 Mm^3). High rainfall and low evapo-transpiration (ET_0) during the kharif season might be the reason for this lowest net irrigation requirement. During this season water was required mainly for land preparation and growing paddy nursery. Minimum rainfall and hot weather increased the irrigation requirement in summer season. The result substantiates the finding of Surendran et al (2015). Banana and nutmeg, two major water-demanding dry crops were the main components of mixed cropping patterns of the area. All these would have resulted in the high demand for irrigation water during summer.

Table 4. Land use classes and areal extent in the command area of CRDS

Land use class	Area (km^2)	Per cent of total area
Barren land	2.832	0.70
Built up	14.652	3.63
Coconut-dominant mixed crops	128.292	31.83
Degraded land under plantation crops	2.928	0.73
Mixed crops	152.268	37.77
Paddy	42.384	10.51
Rubber	51.61	12.80
Scrub	1.896	0.47
Waterbody	4.872	1.21
Forest	1.38	0.34

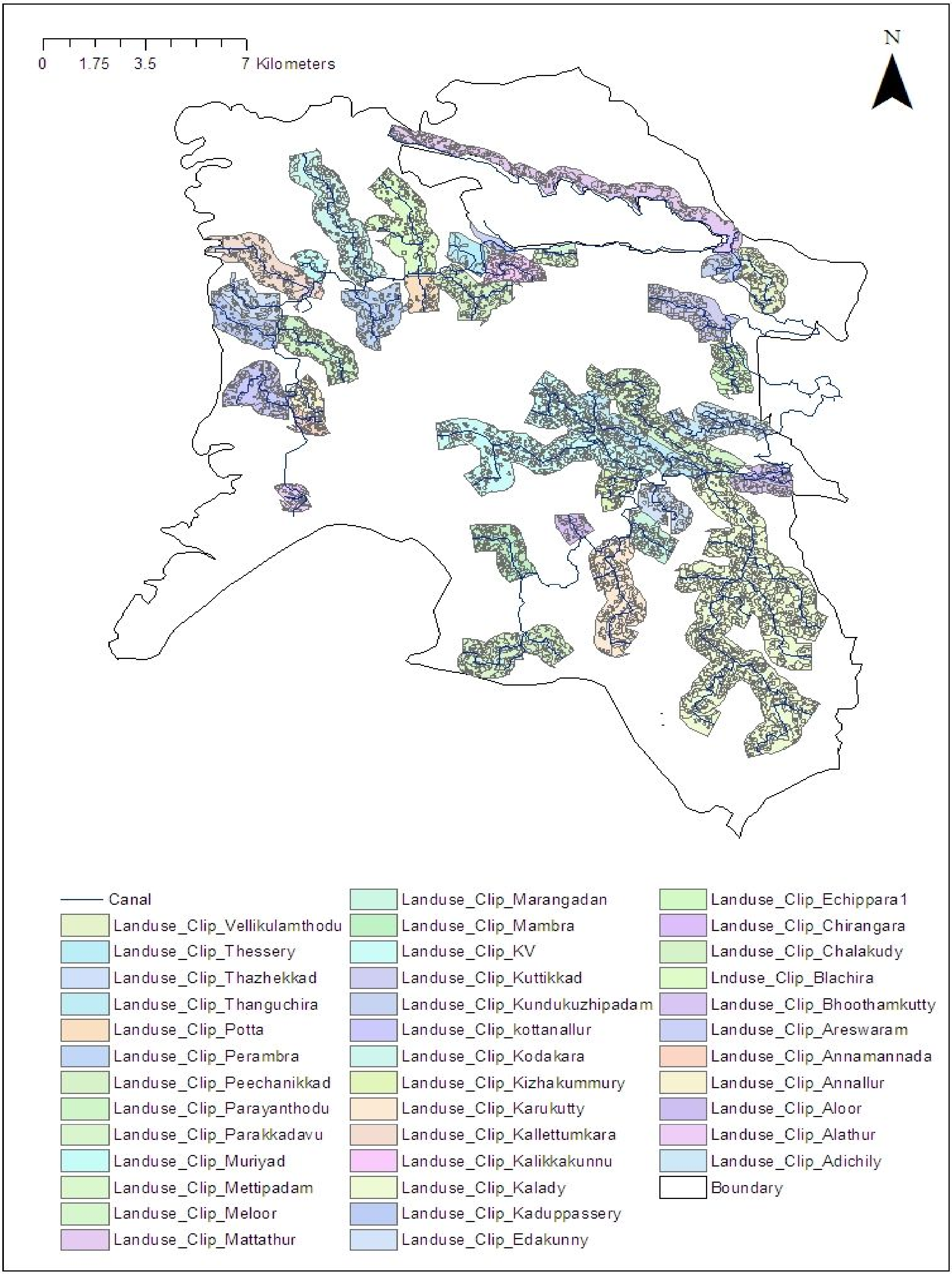

Fig 3. Cultivable command area of CRDS canal system

Table 5. Annual net irrigation requirement of CRDS command area

Canal segment	CCA (ha)	Major crop/cropping pattern (area covered in percentage of CCA)	Annual net irrigation requirement (Mm^3)
LBC	7,786	Paddy (10%), mixed crops (27%), coconut-dominant mixed crops (32%)	23.03
RBC	6,079	Paddy (6%), mixed crops (52%), coconut-dominant mixed crops (33%)	23.87
Total CRDS	13,865		46.90

Table 6. Season-wise irrigation water requirement of crops in the command area

Canal segment	Kharif/Virippu (Mm^3)	Rabi/Mundakan (Mm^3)	Zaid/Puncha (Mm^3)	Total irrigation requirement (Mm^3)
LBC	1.452	5.461	16.119	23.03
RBC	1.158	4.953	17.754	23.87
Total	2.610	10.414	33.873	46.90

Water requirement of the canal command area was proportional to the type of crops and their areal extent. In the case of LBC, the cultivated area was less (53.72 km^2) compared to RBC (55.32 km^2). So the annual irrigation requirement of LBC (23.03 Mm^3) was less than that of RBC (23.87 Mm^3). The average annual net irrigation demand of CRDS command area was 46.90 Mm^3.

Data on water diverted through the CRDS canal system for the last 15 years are presented in Table 7. This showed a decreasing trend from 2004 to 2018. Average water diverted was 201.11 Mm^3 per year. Considering the last five years, the water release average was reduced to 157.97 Mm^3 per year. Both these average quantities were several times more than the present average annual net irrigation requirement (46.90 Mm^3) of the command area. Conversion of paddy fields into built-up areas and upland fields could be the reason for this difference between diverted water and net irrigation demand. At the time of commissioning in 1956, the command area of CRDS

Table 7. Water diverted from Thumboormuzhi weir to CRDS during 2004 to 2018

Year	Water diverted (Mm^3)		Total water diverted (Mm^3)
	LBC	RBC	
2003–04	117.20	110.71	227.91
2004–05	140.74	168.47	309.21
2005–06	109.85	130.20	240.05
2006–07	122.57	138.68	261.25
2007–08	108.47	110.41	218.88
2008–09	106.89	87.66	194.55
2009–10	105.51	91.99	197.50
2010–11	119.96	93.05	213.01
2011–12	115.89	80.64	196.53
2012–13	95.94	72.02	167.96
2013–14	108.45	70.10	178.55
2014–15	108.90	62.37	171.27
2015–16	82.73	68.43	151.16
2016–17	62.42	65.22	127.64
2017–18	95.60	65.61	161.21
Average	106.74	94.37	201.11
Average of last 5 years	91.62	66.35	157.97

was mainly occupied by paddy fields. Even then tail-end farmers encountered water shortage issues which indicated the high losses during conveyance.

CONCLUSION

Water requirement of crops as well as their areal extent determine the irrigation demand of any command area. Proper computation of crop water requirement and accurate estimation of areal coverage are equally important in the estimation of irrigation requirement. From the study conducted for the assessment of net irrigation demand of CRDS command area and the supply patterns, some critical insights on the efficacy of the canal irrigation system could be arrived at. Water requirement of the canal command area was proportional to the type of crops and their areal extent. Out of the total annual net irrigation requirement (46.90 Mm^3) RBC which had more cultivated area (55.32 km^2) required more irrigation water annually (23.87 Mm^3) as compared to LBC (23.03 Mm^3) that had less cultivated area (53.72 km^2). Average annual water diversion through CRDS canal system was more than three times the annual net irrigation requirement (46.90 Mm^3) of the command area. Conveyance losses were high in the CRDS canal system. Proper gauging has to be ensured to efficiently manage the supply-demand patterns of individual farm holdings. As any other canal system, CRDS also faces management and maintenance issues which need to be addressed urgently to reduce water scarcity towards the tail-end.

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