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Research Paper

Estimating irrigation water requirement in rice by integration of satellite data and agrometeorological indices in Palakkad, Kerala

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ABSTRACT

The sustainability of irrigated agriculture is jeopardized by catastrophic climate change, with projected forecasts indicating that by 2025, one out of every four people on the planet will be experiencing extreme water scarcity. In this context, an attempt was made for scheduling irrigation at a regional scale combining satellite data and agrometeorological indices over major rice growing tracts of Palakkad district in Kerala. Normalized Difference Vegetation Index (NDVI) product of MODIS (MOD13Q1) with a temporal resolution of 16 days and a spatial resolution of 250 m was utilized to establish a relationship with crop coefficient (K_c) of rice during the *Mundakan* rice season (September-October to December-January) of 2020-21 and 2021-22 in 30 ground truth locations. The results revealed that NDVI values have strong relationship with K_c values with an R^2 value of 0.82. Crop coefficient (K_c) maps developed using satellite derived NDVI provided K_c values at a regional scale during different stages of crop growth and it helped to estimate crop evapotranspiration with greater accuracy. Based on this crop water demands maps depicting the spatial and temporal distribution of irrigation requirement were generated for the whole study area. These maps can be used as a tool for the estimation of the crop water requirement of a rice field if the geographical coordinates of the location are known. The total crop water requirements estimated during *Mundakan* season 2020-21 and 2021-22 in Palakkad district were in the range of 611-976 mm and 560-897 mm respectively. Integration of remote sensing & agrometeorological techniques has scope for regional-scale crop water requirement estimation in a cost-effective and time-bound manner.

Keywords: Crop coefficient, crop evapotranspiration, irrigation scheduling, Normalized Difference Vegetation Index, rice, water requirement

India is one of the leading producers of rice in the world, which contributes to 20% of the world's production. The major production system followed in rice cultivation is irrigated lowland system which accounts for 75% of the world's production from an area of 93 million hectares (Rao *et al.,* 2017). Appropriate irrigation scheduling in rice is very crucial to avoid wastage of irrigation water in fields. Earlier, empirical equations and lysimeters were used to estimate crop evapotranspiration (ET_c) by scientists. This method of estimating crop water requirements has limitations because this is recognized as a point-based technique and cannot be used at a regional scale. To arrive at water conservation, it is necessary to monitor irrigation scheduling over large areas by adopting novel technologies to estimate crop water demands accurately. Advanced geospatial techniques could be used to overcome the drawbacks of traditional methods, since, these methods help to estimate crop water requirement on a regional scale with limited time (Javed and Ahamad, 2020).

The health status of the crop could be assessed from the vegetation indices provided by the satellite images, which shows variation depending on crop cover, crop growth stage and other biotic or abiotic stresses in the microclimatic region (Shanmugapriya *et al.,* 2022). A vegetation index is a mathematical combination of two or more spectral bands that enhances the contrast between plant cover, bare soil, man-made structures etc. Since its debut in the 1970s, the Normalized Difference Vegetation Index (NDVI) has been one

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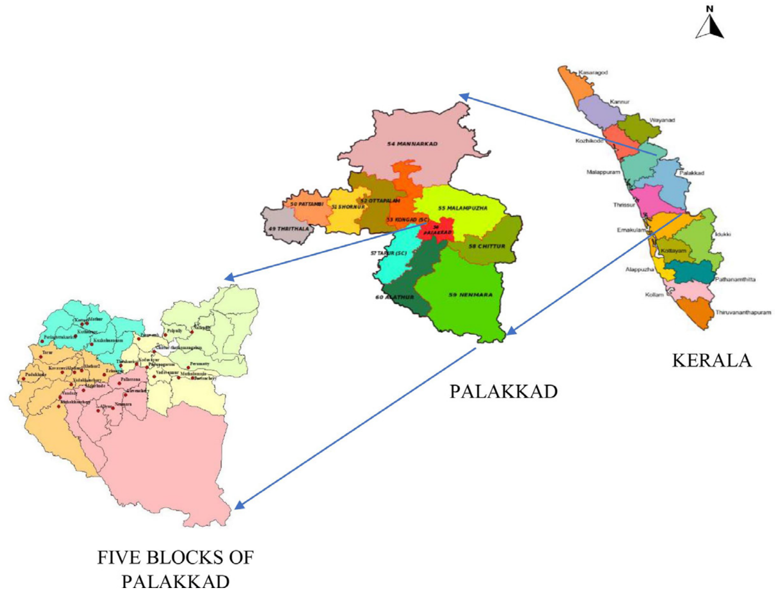

Fig. 1: Location map of Palakkad district

of the most extensively used vegetation indices in remote sensing and it's scale runs from -1 to +1. NDVI for bare soil ranges from 0.1-0.2, whereas, for dense vegetation, it occurs between 0.5-0.8. The minute variations in vegetation cover will be reflected in NDVI value until the crop attains it's maximum vegetative growth and further increase in LAI will lead to only slight variations in NDVI value. The crop coefficient (K_c) based method is a standard method for estimating crop water requirements (Allen *et al*., 1998). The-real-time K_c values can be estimated using NDVI values because of the high correlation between K_c and NDVI (Campos *et al*., 2017). The field-scale K_c values for different crops were estimated based on vegetation indices derived through remote sensing techniques in crops like cotton and maize (Hunsaker *et al.,* 2005), potato (Jayanthi *et al.,* 2007), sorghum, alfalfa, soyabean and corn (Singh and Irmak, 2008).

The irrigation requirement for rice cultivation has been studied by scientists all over the world, in Italy, the water requirement of rice was reported in amounts ranging from 700 to 800 mm (Spanu *et al*., 2009). In Taiwan irrigation requirement for rice was reported to be in the range of 962-1114 mm (Kuo *et al.,* 2006). The net irrigation water required for cultivating Boro rice in the western region of Bangladesh was 849 mm (Hossain *et al*., 2017). The variation in irrigation requirement in rice from one region to another could be ascribed to the changes in prevailing weather conditions and stage and state of the crop. Remote sensing has potential to assess the current crop condition and agrometeorological indices will provide a clear idea about the weather experienced. Hence, combining both helps in accurate assessment of irrigation requirement which is essential for irrigation scheduling and planning of farm irrigation systems (Mushtaq *et al.,* 2020).

Palakkad district is one of the major rice growing tract of the state and studies for estimating irrigation requirement on a regional scale in rice is lacking. Hence, study was conducted in selected rice fields of Palakkad district in Kerala during *Mundakan* (September-October to December-January) crop season of 2020-21 and 2021-22 to estimate the crop water requirement on a regional scale by integrating remote sensing and agrometeorological techniques.

MATERIALS AND METHODS

Ground truthing and image acquisition

The Palakkad district is one among 14 districts of the state of Kerala which extends over an area of 4,48,200 ha. The district is located in Central Kerala at 10° 95' North latitude and 76° 54' East longitude, bordered on the northwest by Malappuram District, on the southwest by Thrissur District of Kerala, on the northeast by Nilgiris District, and on the east by Coimbatore District of Tamil Nadu (Fig. 1). The major rice-growing tract of Palakkad district is spread over 5 blocks *viz.,* Alathur, Nenmara, Kollengode, Chittur and Kuzhalmannam, each block having more than 10,000 hectares of land under rice cultivation as gross cropped area. A total of 30 locations were selected from 29 panchayats through random sampling technique representing the whole rice area and ground truth information was obtained from these locations using Global Positioning System (GPS) and camera during *Mundakan* (September-October to December-January) rice season (2020-21 and 2021-22). Details regarding dates of sowing and commencement of various stages of the crop were recorded by frequent field visits.

The 16-day composite of MODIS-NDVI (MOD13Q1), a standard product of Moderate Resolution Imaging Spectroradiometer (MODIS) with a spatial resolution of 250 m was used for the study. A total of 16 tiles coinciding with the season were downloaded from *http://lpdaac.usgs.gov.* during the period from 15th October 2020 to 28th February 2021 and from 15th October 2021 to 28th February 2022.

Analysis of data

Analysis of data includes pre-processing of images, image analysis and extracting information on rice spectrum. Pre-processing

Table 1: Irrigation requirement of rice during various growth stages in Alathur block during *Mundakan* season in 2020-21 and 2021-22

Location	Sowing date	Crop stage	Duration (Days)	K_c	ET_c	Effective rainfall (mm)	Water required to compensate crop evapotranspiration (mm)	Water required to maintain standing water in fields during each crop stage (mm)	Irrigation requirement during the crop period (mm)
Alathur I	16-11-2020	Early vegetative/ seedling stage	21	0.77	94.33	31.8	62.53	30	93
		Late vegetative stage	40	1.22	174.13	7.7	166.43	100	266
		Reproductive stage	30-35	1.23	167.42	47.7	119.72	100	220
		Ripening stage	30	0.81	141.54	1.1	140.44	50	190
		Total			577.41	88.3	489.11	280	769
Alathur II	16-11-2021	Early vegetative/ seedling stage	21	0.66	74.46	112.57	0	30	30
		Late vegetative stage	40	1.11	160.45	83.72	76.73	100	177
		Reproductive stage	30-35	1.07	142.95	0	142.95	100	243
		Ripening stage	30	0.71	115.65	0	115.65	50	166
		Total			493.52	196.29	335.33	280	615

K_c = Crop coefficient ET_c = Crop evapotranspiration

involves the collection of MODIS images, image cropping, geographic coordinate transformation and related procedures. HEQ Tool (MODIS Reprojection Tool) was used to convert NDVI imageries downloaded in Sinusoidal Projection to Universal Transverse Mercator projection system. The pre-processed images were transformed from hierarchical data format "hdf" to "img" format using ArcGIS software's "Export raster data" feature. With the use of Map Algebra's "raster calculator" function, NDVI values for each pixel were computed from the "img" raster file. The "Extract multivalues to points" provision in ArcGIS software was used to retrieve NDVI values for 30 ground truth locations in Palakkad district. The concept of Normalized Difference Vegetation Index (NDVI) was put forth by Rouse *et al.* (1973) based on spectral bands in Near Infrared (NIR) and Red domain using the equation;

$$NDVI = (NIR - Red)/ (NIR + Red)$$

NDVI values are considered as a reliable indicator for tracking the spatial and temporal variation in crop growth and distribution (Kaushalya *et al*., 2014), biotic and abiotic stresses in fields (Olsen *et al.,* 2015) and crop yield (Anil Kumar *et al*., 2022). The table K_c values were obtained from literature and these values were used to set up a relationship between NDVI and was expressed in the form of a linear equation.

Irrigation requirement based on effective rainfall and Crop evapotranspiration (ET_c)

Based on weather data collected for the study area during October 2020 to February 2021 and October 2021 to February 2022, from India Meteorological Department (IMD), reference evapotranspiration (ET_o) was calculated using FAO Penman Montieth equation (Allen *et al.,* 1998) with the help of PET calculator. The effective rainfall received during the crop period was calculated using Potential evapotranspiration/ Precipitation ratio method suggested by FAO (FAO, 2021). The crop evapotranspiration (ET_c) was obtained as a product of crop coefficient (K_c) and ET_o. Water lost through crop evapotranspiration is compensated by effective rainfall and water supplied through irrigation. In rice fields, additional water has to be supplied to maintain standing water in the fields, so it was also added up to estimate the net irrigation requirement in rice. The stage-wise irrigation requirement and total irrigation requirement for the crop season were hence estimated.

Preparation of K_c maps and crop water demand maps

The MODIS-NDVI retrieved images were used to generate K_c maps of the study area using provisions in ArcGIS software. The K_c value for each pixel was retrieved using raster calculator in map algebra, based on the relationship established between NDVI and K_c values. The crop water demand maps corresponding to the rice pixels during early vegetative stage, late vegetative stage, reproductive stage and maturity stage were developed. The flow chart of overall methodology of the study is represented in Fig.2.

RESULTS AND DISCUSSION

Among the 16 images of MOD13Q1 obtained during the crop period, some images showed very low NDVI values due to cloud interferences. The NDVI time series was smoothened using standard statistical procedures to overcome this problem. A linear equation was developed, between NDVI values obtained from

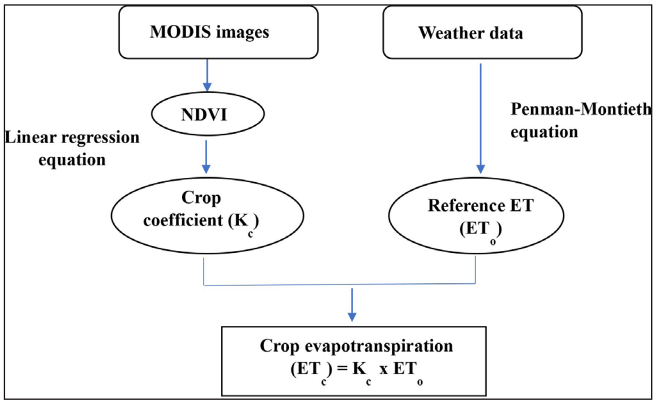

Fig. 2: Flow chart of overall methodology of the study

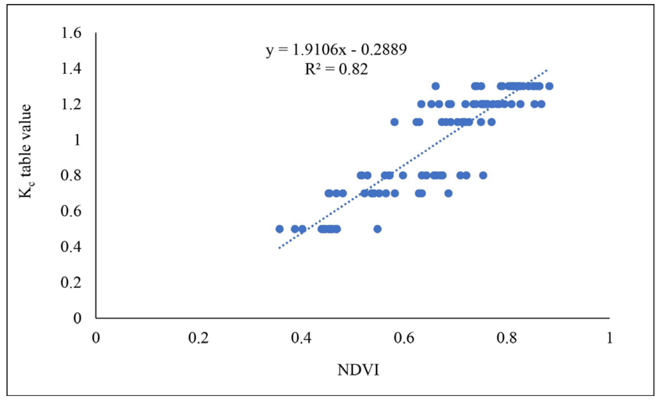

Fig. 3: Graph showing linear relationship between NDVI and crop coefficient (Kc)

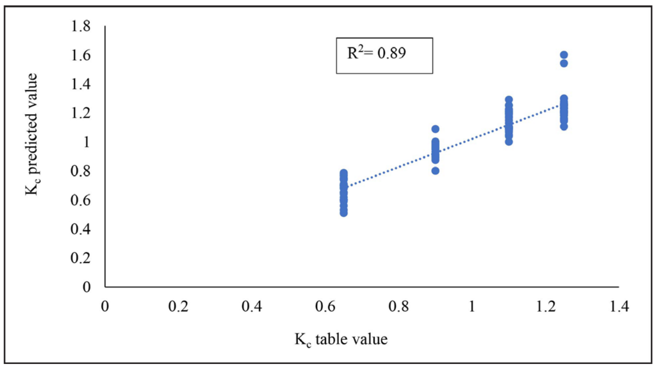

Fig. 4: Validation of the relationship between NDVI and crop coefficient (Kc)

MOD13Q1 and crop coefficient (K_c), during 2020-21 and an R^2 value of 0.822 was obtained (Fig.3). The equation was validated using MODIS derived NDVI and predicted K_c during 2021-22. During validation, a fairly high R^2 value of 0.899 was observed and this shows that a strong relationship exists between NDVI and K_c (Fig 4). The K_c predicted values during early vegetative stage were in the range of 0.5-0.8, towards the late vegetative stage, showed an increasing trend from 0.8 to 1.2, during the reproductive stage it increased to 1.3, and when the rice crop reached maturity stage K_c values decreased to 0.58. The MODIS-NDVI also showed a similar relationship with the age of rice plant.

González *et al.* (2018) established a relationship between NDVI derived from satellite images and K_c from literature. This relationship was used to create new K_c values for corn and alfalfa using additional overpass dates. Similarly, the potential of estimating crop coefficient (K_c) values as a function of remote sensing-based vegetation index has been studied by Kamble *et al*. (2013) in Maize fields of USA. A simple linear regression model was developed to establish a relationship between NDVI from a moderate resolution satellite data (MODIS) and K_c values were calculated from the flux data measured for different crops and cropping practices available as a product in Ameriflux sites. Thus, several research workers have proved that a strong positive relation exists between NDVI values and K_c and this study also conforms to their findings. The reference evapotranspiration is calculated using FAO Penman Montieth equation based on weather variables only. Hence, based on availabilty of weather data for all the locations in a single block, same value was taken. Since the crop evapotranspiration varies depending on the growth stage of the crop, it will be different for each ground location.

Water lost through crop evapotranspiration is compensated by effective rainfall and water supplied through irrigation. As per Package of practice recommendations, KAU (2016) water level of 1.5cm should be maintained in rice fields during the time of transplanting. Further, it should be gradually increased to 5 cm as the crop reaches the active tillering stage and is maintained throughout the crop period. Complete drainage of the field is recommended 13 days before harvest. Irrigation could be provided 2 days after the disappearance of ponded water. The irrigation interval was scheduled to be 10 days in fields located in slopy areas, whereas 16 days in plain areas following farmer practice.

In Alathur block, the total rainfall received during the crop period was not suffcient to meet the water requirement of the crop, so the crop required irrigation between 762-912 mm during the crop seasonof 2020-21. But during the initial months of *Mundakan* season 2021-22, (i.e.October and November 2021) the effective rainfall received was sufficient enough to compensate crop evapotranspiration, but in the remaining months rainfall was very less. The effective rainfall received in 2021-22 crop period in all the four blocks under the study area, except Nenmara block was higher than 2020-21 crop period hence, the total irrigation requirement during *Mundakan* season 2021-22 (ie; 578-812 mm) was comparitively lesser than 2020-21. The total irrigation requirement in Nenmara block was in the range of 647-723 mm, in Kollengode block it was between 793-937 mm, in Chittur block 767-975 mm was observed and Kuzhalmannam block it was in the range of 667-886 mm during this crop season. But in 2021-22, sufficient rainfall was received during the early and late vegetative stages hence, irrigation requirement is low during these stages and maximum irrigation requirement was observed in the reproductive stage of the crop in all the 5 blocks.The total irrigation requirement in Nenmara block was in the range of 696-823 mm, in Kollengode block it was between 698-869 mm, in Chittur 663-838 mm and in Kuzhalmannam between 697-898 mm.

Table 1 represents the calculation of stage wise irrigation requirements in one of the block viz. Alathur during *Mundakan* season 2020-21 and 2021-22. The irrigation requirement was maximum during the late vegetative stage followed by reproductive

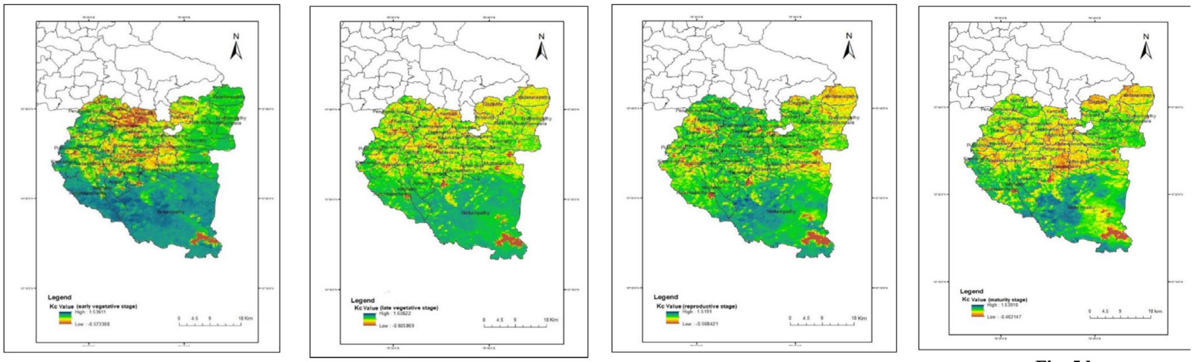

Fig. 5a. Fig. 5b. Fig. 5c. Fig. 5d.

Fig. 5: Kc mapsof rice during (a) early vegetative stage (b) late vegetative stage (c) reproductive stage and (d) maturity stage of Mundakan season in Palakkad district during 2020-21

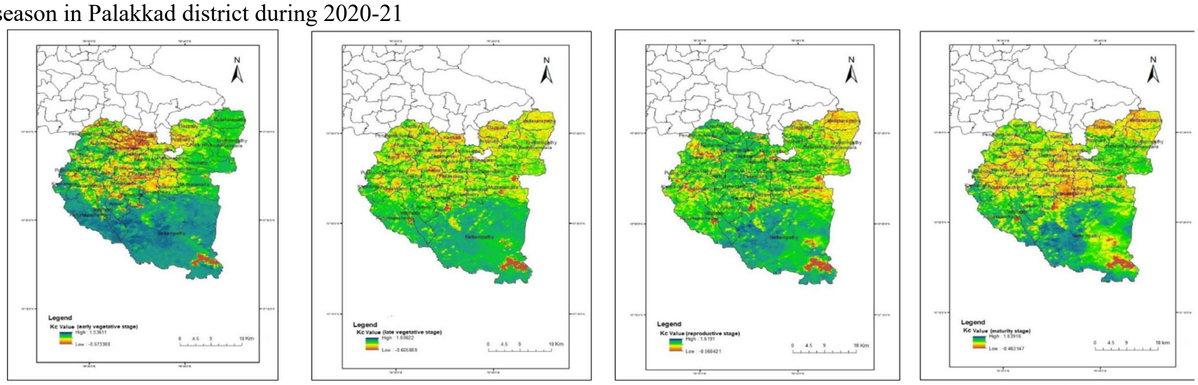

Fig. 6a. Fig. 6b. Fig. 6c. Fig. 6d.

Fig. 6: Kc mapsof rice during (a) early vegetative stage (b) late vegetative stage (c) reproductive stage (d) maturity stage of Mundakan season in Palakkad district during 2021-22

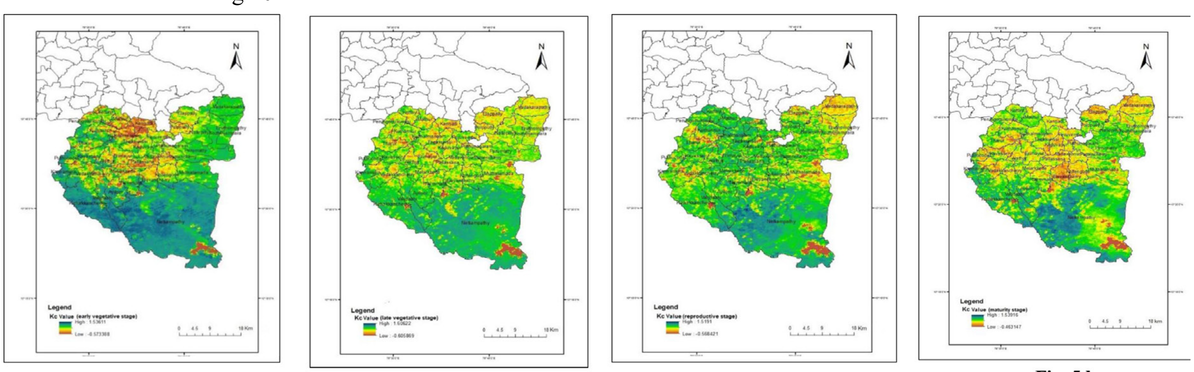

Fig. 5a. Fig. 5b. Fig. 5c. Fig. 5d.

Fig. 7: Crop water demand maps of rice during ((a) early vegetative stage (b) late vegetative stage (c) reproductive stage (d) maturity stage of Mundakan season in Palakkad district during 2020-21

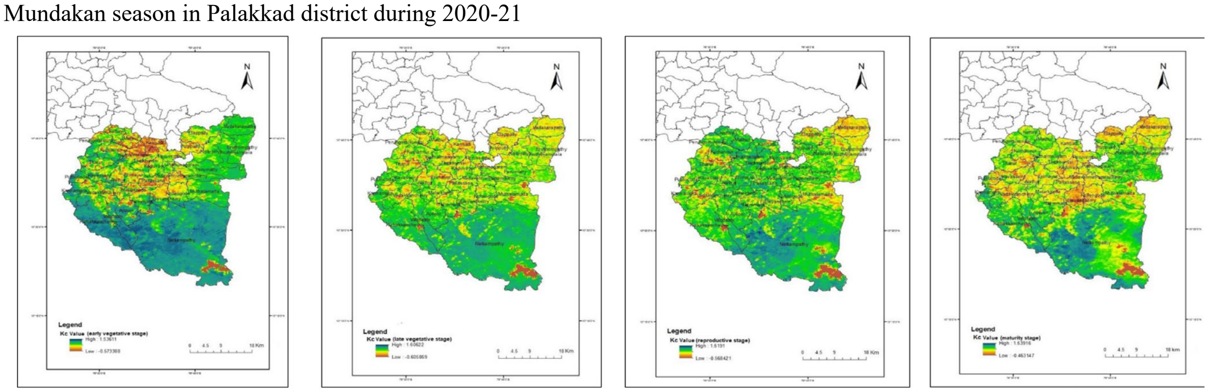

Fig. 6a. Fig. 6b. Fig. 6c. Fig. 6d.

Fig. 8: Crop water demand mapsof rice during (a) early vegetative stage (b) late vegetative stage (c) reproductive stage (d) maturity stage of Mundakan season in Palakkad district during 2021-22

stage of crop growth in crop season 2020-21, while in 2021-22 maximum irrigation requirement was observed in reproductive stage of the crop. Similarly, stage wise and total irrigation requirement during the crop period was estimated for the ground truth locations in remaining four blocks. Kollengode, Chittur and Kuzhalmannam blocks showed maximum irrigation requirement during the late vegetative stage of the crop, whereas, in Nenmara block maximum irrigation requirement was observed in the reproductive stage of the crop in 2020-21.

In majority of locations, the rainfall during the initial stage is sufficient to meet successful crop growth. But as the crop growth advances the rainfall received is less compared to the water demand of the crop and the irrigation requirement increases. High wind, low relative humidity due to a lack of rain, and high temperatures all contribute to increased evapotranspiration during the dry months of the season. When the hottest time with the highest temperature prevailed, high evaporation occurred with a quick reduction in soil moisture, meaning more irrigation water requirement, according to Shouqin *et al.* (2014).

Crop coefficient (K_c) maps created at a regional scale provided K_c values during various stages of crop growth, allowing for a more accurate estimation of crop evapotranspiration for the research area. The K_c maps corresponding to the early vegetative stage, late vegetative stage reproductive stage and maturity stage of the crop for *Mundakan* season corresponding to the year 2020-21 and 2021-22 are presented in Fig.5 and 6 respectively. Similarly, crop water demand maps were generated for the early vegetative stage, late vegetative, reproductive stage and maturity stage for *Mundakan* season corresponding to the year 2020-21 and 2021-22 and depicted in Fig. 7 and 8 respectively. They depict the spatial and temporal distribution of irrigation requirements. If the geographical coordinates of the place are known, these maps make estimates of the crop water requirement of a rice field much easier. Nonetheless, the findings of this study make more precise and accurate spatial data on water requirements of the existing cropping area available to future hydrological modelling operations than those often used in similar planning studies (Capelli *et al.,* 2005).

CONCLUSIONS

Global warming and climate change may lead to increased frequency of irrigation in the near future. This in turn causes increased demand of water for irrigation purposes. Information regarding crop-specific areas under irrigated agriculture and crop growing season are important for the efficient use of available water resources. The irrigation requirement map prepared for the study area covering 5 blocks of Palakkad district can be used for water resource planning and management. This is particularly useful for understanding inter-seasonal variations in irrigation water demand at different geographical and temporal dimensions.

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***Data availability*:** To be provided on reasonable request.

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