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Modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management: A case study in Palakkad district of humid tropical Kerala, India

U.Surendran*, C.M.Sushanth, George Mammen, and E.J.Joseph

Water Management (Agriculture) Division,Centre for Water Resources Development and Management, Kunnamangalam, Calicut-673571.

Abstract

Crop water requirements of crops in agro-ecological units (AEUs) of Palakkad district of humid tropical Kerala computed with CROPWAT 8.0 using the meteorological parameters.The major cultivated crops are rice, coconut, banana, arecanut, vegetables, pulses, rubber, tea, coffee, cotton etc. The total water requirement for these crops in various agro-ecological zones has been computed. Using the evapotranspiration (ET_0) and effective rainfall in each agro-ecological unit (AEU), a climatic water balance has been worked out. The net irrigation demand, the gross irrigation demand and irrigation interval for the various crops grown in different AEUs have been computed. The gross irrigation demand for the district is 1146 Mm^3, in which 981 Mm^3 is from surface water and 165 Mm^3 from groundwater sources. Water balance analysis was done for the current scenario and future demand for agriculture, domestic and industrial demand. The projected future total water demands for irrigation, drinking and industrial purpose will be 3841 Mm^3. However, the secondary data showed that utilizable water resources of Palakkad district is less and will create a deficit scenario. This deficit indicates that if the total area is brought under irrigation there will be deficit years and during such periods deficit irrigation or reduction in command area may have to be adopted. A wide spectrum of scenarios has been discussed in the paper along with the guidelines for future management of water resources.

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*Keywords:*CROPWAT; Crop water requirement; Evapotranspiration, Effective rainfall, Irrigation demand

* Corresponding author
E-mail address: u.surendran@gmail.com

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1. Introduction

Serious water shortages are developing in many countries particularly in India and water for agriculture is becoming increasingly scarce in the light of growing water demands from different sectors (IWMI 2010). Agriculture is the largest (81%) consumer of water in India and hence more efficient use of water in agriculture needs to be top most priority(Surendran et al. 2013). A better understanding of the intricate interactions between climate, water and crop growth needs to be a priority area in India. Water is an essential input for crop production. Even though the mean annual rainfall in the Kerala State is 3000mm, its temporal distribution is highly uneven, resulting in a long dry spell of about 5 to 6 months. Similarly, the unevenness in the spatial distribution causes a moisture stress period of 14 to 15 weeks in south Kerala and 18 to 21 weeks in north Kerala (Vardan 1996). Long term data on rainfall analysis of Kerala showed that intolerably long dry spells are the norm rather than the exception in all seasons (Krishnakumar et al. 2009). The productivity of most of the crops in the State remains almost static or lower when compared with the national average. The uneven rainfall distribution pattern and low water holding capacity of soils, soil moisture stress occurs during summer season and it is considered as one of the major limiting factors for higher productivity in the State.

Many studies conducted by various research institutions like Kerala Agricultural University, Central Plantation Crops Research Institute, Centre for Water Resources Development and Management etc. have shown that irrigation can enhance the productivity of the crops in the State. However, the area with a gross irrigation facility still hovers around 17.0 % (2009-10) of the gross cropped area of the State – a level far below the average for India (38.7%) (DoES 2012). Hence this needs to be improved to attain an improved productivity. Analyses of the secondary data on the yield of paddy in Kerala under irrigated and non-irrigated conditions confirmed that irrigation has a great effect on enhancing the yield levels by about one-sixth (about 500 kg per hectare) to that of the unirrigated level. One of the main reasons for the low irrigation efficiency in the State is the lack of location-specific scientific information on irrigation scheduling for different crops. The present irrigation recommendations for the State are of general nature and does not account for all the soil types and climate in different agro-ecological zones. While studies have identified the influence of one or more parameters on irrigation water requirements, there is a lack of information with respect to Kerala on these parameters when water requirements are to be aggregated at a regional scale. To achieve effective planning on water resources, accurate information is needed for crop water requirements, irrigation withdrawal as a function of crop, soil type and weather conditions. The rainfall and evapotranspiration ultimately determine water balance, crop water and irrigation requirements of different crops of the region. Studies of such climatic parameters are thus helpful in defining risk levels in arable agriculture. However, a detailed study by comprising all the data on water requirement and availability is also not available under humid tropical Kerala conditions. Keeping all this in background the study was carried out with the following objective to compute the agricultural water demand (crop water requirements) of major crops in different agro-ecological zones of Palakkad district of humid tropical Kerala with the long term climatic data by using CROPWAT 8.0 model (FAO 2009) .FAO Penman-Monteith method (FAO, 1998) is used in the present study for determining reference crop evapotranspiration (ET_0) since it is reported to provide values that are very consistent with actual crop water use data worldwide (Allen et al. 2006; Cai et al.2007; Lo´pez-Urrea et al., 2012).The irrigation schedule recommendations for various crops should be location-specific, considering the soil types and agro-ecological conditions. The scientific crop water requirements are required for efficient irrigation scheduling, water balance, canal design capacities, regional drainage, water resources planning, reservoir operation studies, and to assess the potential for crop production .There is a lack of information with respect to Kerala on crop water requirements in general and the shortfall of data at a regional scale. Hence, in this paper an attempt has been made to compute the crop water requirements of major crops in different agro-ecological zones of Palakkad district of humid tropical Kerala using CROPWAT 8.0 (FAO 2009) and comparing the same with the available water resources in that district to assess the current status and future demand, which is essential for planning.

2. Materials and methods

2.1 Study location

The study area is Palakkad district of humid tropical Kerala, which is the largest district in Kerala, having a total geographical area of 4480 km2. It is in the east-central part of the State between north latitudes 10º 19′ and 11º 15′

and east longitudes 76º 01′ and 76º 55′. The net cultivated area of the district is 221,999 ha, which is 49% of the geographical area of the district. The agro-ecological zones and units of Palakkad district delineated by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) based on slope, rainfall, soil depth, length of growing period (LPG) etc was used for the current study. These units formed the basis for the computation of crop water requirement (agricultural water demand), since each zone has a similar combination of constraints and potentials for land use, and serves as a focus for the targeting of recommendations. The district has been classified into three agro-ecological zones (AEZ) and eight agro-ecological units (AEU) (Nair et al. 2012) as given in Table 1.

Table 1.Agro-ecological zones (AEZ) and Agro-ecological units (AEU) of Palakkad district

Sl.No.	Agro-ecological zones (AEZ)	Agro-ecological units (AEU)
1	Northern hilly region	Three agro-ecological units (AEU-19, AEU-15 and AEU-18)
2	Central plains	Four agro-ecological units (AEU–23, AEU–22, AEU-10 and AEU-13)
3	Southern hilly region	One agroecological unit (AEU–14)

2.2 Crop water requirement

The reference evapotranspirationET0 of individual agro-ecological units are calculated by FAO Penman-Monteith method, using decision support software –CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56(FAO 1998). The FAO CROPWAT program (FAO, 2009) incorporates procedures for reference crop evapotranspiration and crop water requirements and allow the simulation of crop water use under various climate, crop and soil conditions (www.fao.org).

2.3 Meteorological data

Meteorological data collected from various agencies for different agro ecological units (AEUs) used in the calculations and the climatic characteristics of different AEUs are shown in Table 2. Meteorological parameters used for calculation of ET_o are latitude, longitude and altitude of the station, maximum and minimum temperature (^oC), maximum and minimum relative humidity (%), wind speed (km/day) and sunshine hours which was collected from various agencies for different agro ecological units (AEUs). In case of agro-ecological units for which data on relative humidity, wind speed and sunshine hours are not available; ET_0 was estimated using maximum and minimum temperature, and latitude, longitude and altitude of the place. In such cases, software estimates the relative humidity and sunshine hours based on known parameters. ET_0 was calculated for every ten days (defined as 'decade' by FAO) and then cumulated to monthly data. Soil characteristics considered for estimation of crop water requirement are available water content (mm/m) and depth of soil (cm).

Table 2. Climatic characteristics of different agroecological units in Palakkad district

Agro-ecological Unit	Range of annual Rainfall (mm)	Temperature (oC)		Length of growing period (days)
		Maximum (oC)	Minimum (oC)	
19	700-1000	35.5 (Apr)	21.0 (Dec)	105
15	1000-1500	31.7 (Apr)	18.6 (Dec)	245
18	2000-3000	33.1 (Mar)	18.6 (Jan)	238
23	1500-2000	37.7 (Mar- Apr)	20.3 (Jan)	181
22	2000-2500	36.9 (Mar)	21.9 (Jan)	203
10	2500-3000	36.2 (Mar)	20.0 (Jan)	203
14	2500-3500	29.1 (Apr)	16.4 (Dec)	252
13	2500-3000	33.4 (May)	20.2 (Nov-Dec)	203

Source: NBSS &LUP, IMD and KAU

2.4 Crop data

The major cultivated crops in study area are rice, coconut, banana, rubber, arecanut, brinjal, tomato, gourds, pumpkin, groundnut, sugarcane, sweet potato, tapioca, maize, ragi, sorghum, red gram, black gram, green gram, horse gram, black pepper, nutmeg, cardamom, tea, coffee, cotton etc. The salient details of crops considered for the study are as per FAO and package of practices of KAU. Crop coefficient values (Kc) are taken from available published data. Kc values for initial, mid and late growth stages of annual and seasonal crops are used. In the case of perennial crops, same Kc value is used for the whole year.

2.5 Crop evapotranspiration (ETc)

ET_0 is multiplied by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration (ETc), as in Eq. (2),

$$ETc = Kc \times ETo \qquad (2)$$

2.6 Water balance computations

Water availability in the district computed earlier by CWRDM (CWRDM, 1999) was used in the present study. In these, one hydrological year (June to May) is divided into three seasons viz., *kharif, rabi and summer* and all water resource information are estimated on an annual as well as seasonal basis Available ground water is estimated on the basis of Ground water Estimation Methodology-1999 of Ministry of Water Resources, Government of India. Salient features/data on the irrigation projects have been extracted from the Irrigation Projects of Kerala by PWD (1974) and Farm Guide (2010). Block wise list of cultivable command area, irrigated area has been derived from report of Economics and Statistics department of Government of Kerala. Irrigated area under minor irrigation schemes has been taken from the report of Minor irrigation census 2000-01. These available data from different sources have been grouped into agro ecological zone wise data based on the list of blocks. Based on the gross irrigated area statistics, the net irrigation demand for each of the AEUs has been worked out both for major/medium and minor irrigation schemes. The major crop in the district which is irrigated is paddy followed by coconut. Paddy is mainly irrigated by government canals. While calculating the irrigation demand for the uplands, coconut or coconut based cropping systems are found to be the major ones and hence the irrigation demand is worked out based on the demand for coconut. Recommendations on the irrigation schedule for important crops of Palakkad are presented assuming that the irrigation method will be surface irrigation.

3. Results and discussion

3.1. Reference Evapotranspiration (ET_0)

The ET0 of different agro-ecological units ranged from 1164 to 1757 mm / year. AEU 2 showed the lowest ET0 and the highest was observed in AEU 15 (data not shown). This indicates the differences observed in the meteorological parameters within the study area and stress the need for having scientific water requirement (Gunter et al. 2009). The results are in accordance with Adeniran et al. 2010, which showed that ET_0 was lowest during the peak of the rainy season to highest during the peak of the dry season for the respective AEUs.

3.2. Total water requirement (ETc)

The total water requirements for different crops in various agro-ecological zones are given in Fig1. The total water requirement for Paddy ranged from 1377 to 1668 mm. The lowest water requirement of Paddy is recorded in *Viruppu* season (Kharif) in all the zones.The results showed that reference and crop evapotranspiration (ET_0 and ET_C) were higher for crops with longer growing seasons than for those with shorter ones. Also ET_C were more during the dry season than the rainy season. This is similar to the FAO (2009) report, in that crops grown in the dry season needs more water than those grown during the rainy season. In short-term crop, the range of water requirement for lowland rice was particularly high in Mundakkan season, because the meteorological parameters were very high with less or no rainfall. It can be inferred from the table that there are differences in the case of total water requirement for crops if AEUs are considered within the district and hence it is essential to plan a scientific water requirement, so that the high productivity can be achieved with optimum quantity of water, if all other agronomic practices are followed (Vishal et al., 2013).

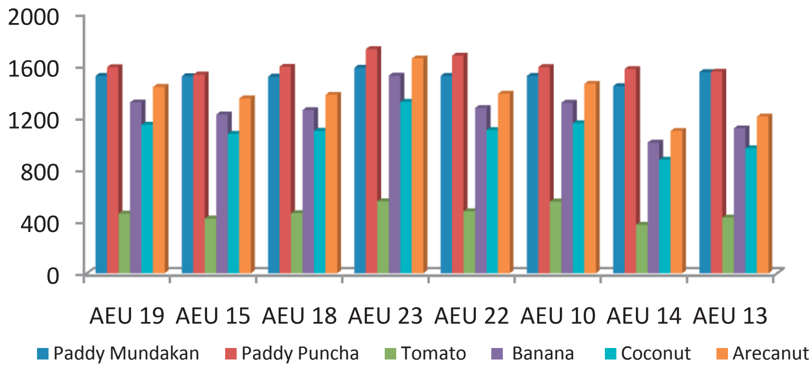

Fig.1 Total water requirement of different crops in AEUs of Palakkad district

3.3 Seasonal Climatic Water Balance

Seasonal climatic water balance has been worked out based on the ET_0 and effective rainfall in each agro-climatic unit. The model calculated effective rainfall was higher in less rainfall decade i.e. rainfall is 100 % effective when it is very low as 1.0 mm/decade and it is less in high intensity rainy decades i.e. only 26 % of the rainfall is effective when it is very high as 328 mm/ decade. For instance, in the case of AEU-19, except for the month of November and December, the potential evaporation is more than the effective rainfall and hence need irrigation during other 10 months. For AEU -18 and 13, except for the month of June, July, August, September and October, the potential evaporation is more than the effective rainfall and hence need irrigation for the rest of 7 months.

3.4. Net Irrigation requirement (NIR)

The NIR of different crops in different agro-ecological units are given in the Table 3. The net irrigation requirement for Paddy ranged from 442 to 1483 mm. The lowest requirement is recorded in the *Kharif (Viruppu)* season for all the AEUs and the highest is recorded in the *Summer (Puncha)* season invariably for all he AEUs. This is because of the occurrence of rainfall during *Kharif*(*Viruppu)* rainy season (May–September) was high, whereas during the growing period of *Summer* (*Puncha)* rice, rainfall was very less, as a result, the irrigation requirement was very high (Kar and Verma, 2005). Among the AEUs, AEU 15 recorded the lowest NIR of 442 mm for *Viruppu* season and AEU 7 recorded the highest NIR of 552 mm for the same season. This indicates the differences in water requirement even within a single district for the same period and hence it shows the significance of requirement of scientific planning for irrigation. The difference in the NIR in AEUs might be due to the combined effect of the changes in temperature, sunshine hour percentage and wind and the decrease in effective rainfall as outlined earlier by Tempa and Sung (2012).

Table 3. Net Irrigation Requirement (mm) of different crops in various AEUs in Palakkad district

No.	Crops	AEU 10	AEU 13	AEU 14	AEU 15	AEU 18	AEU 19	AEU 22	AEU 23
1	Paddy*								
	Viruppu	464	442	505	554	582	641	458	513
	Mundakan	906	741	819	786	1084	1125	1052	1302
	Puncha	1465	1290	1290	1331	1213	1202	1406	1461
2	Cowpea	384	244	245	324	274	280	368	430
3	Tapioca								
	Sept to May	467	247	260	347	250	357	463	522
	Feb to oct	89	45	48	82	108	326	142	235
4	Sweet Potato	318	163	176	212	131	123	284	299
5	Brinjal								
	Sept to Jan	167	72	76	94	59	41	173	194
	May to Sept	6.5	5.4	5.3	6.7	71	264	34	56
6	Tomato								
	Oct to Mar	324	170	180	230	145	140	291	296
	Mar to Jul	177	7.9	18	142	191	366	227	358
7	Chilli	163	69	73	92	57	40	173	194
8	Banana								
	Sept to Aug	616	348	360	475	463	650	639	836
	May to Aprl	730	430	435	567	526	821	738	923
9	Coconut	458	235	247	326	310	588	497	644
10	Arecanut	609	330	333	450	481	776	628	846

*In Paddy, the values are inclusive of percolation losses @6mm/day and 300 mm towards land preparation (puddling)

3.5 Water resources assessment and Irrigation Scenario

The surface water resources of the Palakkad district comprise rivers, streams and ponds. About 75.56% of the area in the district falls within Bharathapuzha basin and the remaining 13.33%, 8.89% and 2.22% fall in Bhavani, Chalakkudy and Kadalundy river basins, respectively. Total water potential (available) of Palakkad district is 6602 MCM and Utilizable surface flow in the district as per CWRDM report is 1579 MCM (CWRDM, 1999).Seven major/ medium irrigation projects are catering to the irrigation needs of Palakkad district. The irrigation projects in this region are mainly intended for rice crop. Out of the gross cultivated area an area of 59,643 ha is under the command of major/medium irrigation projects. Block wise list of irrigated area under minor irrigation schemes are collected and it includes dug wells, bore wells and diversion structures. The net area irrigated by these schemes in the district works out to 41,305ha. The data on the ayacut details collected from Irrigation Department and data available from the Minor irrigation Census (2001) have been used for arriving at the area under irrigation in the AEUs. The status of irrigation combining both major and minor irrigation in the different AEUs is given in Fig.2.

Based on the gross irrigated area statistics given above, the net irrigation demand for each of the AEUs has been worked out both for major/medium and minor irrigation schemes. It has to be noted that third season paddy is cultivated only in a small area in the whole of the district and hence its distribution in the AEUs have been assumed as negligible compared to the overall irrigated area and demand. The major crop in the district which is irrigated is paddy followed by coconut. Paddy is mainly irrigated by government canals. While calculating the irrigation demand for the uplands, coconut or coconut based cropping systems are found to be the major ones and hence the irrigation demand is worked out based on the demand for coconut. Table 4 gives the net irrigation requirement in different AEUs based on the current irrigated area. The gross demand at 70% efficiency works to 1146 MCM.As per the Central Ground Water Board (CGWB) estimate (2007) the groundwater draft for irrigation in Palakkad is 165 MCM. Thus the surface water utilization for irrigation by both major and minor irrigation projects in the district works to 981 MCM.

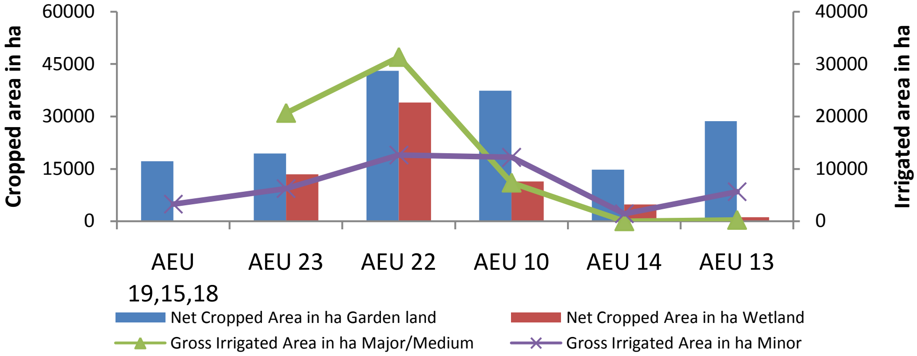

Fig.2. Net cropped area and Gross irrigated area of Palakkad District

Table 4. Net and gross irrigation demand in different AEUs

Unit	Net Irrigation requirement in Mm3				Total
	Major/medium	Minor			
		Surface	Ground	Total	
AEU – 19, 15 and 18		20	4	24	24
AEU – 23	220	28	40	68	288
AEU – 22	277	25	65	90	367
AEU – 10	78	19	43	62	140
AEU – 14		2	4	6	6
AEU – 13	1	16	11	27	28
Total	576	111	165	276	852
Gross @ 70% efficiency	823	158	165	323	1146

3.6 Water Demands

The consumptive use requirements consist of irrigation for agricultural crops, domestic water demand and industrial needs. Total net irrigation demand for the district will be 852 MCM. At 70% efficiency, this works out to 1146 MCM (Table 4).The domestic water requirements of the river basin are calculated considering the present population with the per capita demand as per the Indian standards on code of basic requirements for water supply, drainage and sanitation (IS 1172 : 1993). The gross water demand inclusive of irrigation, domestic and industries will be 1496 MCM. The maximum utilizable water resources available in the district is only 1579 MCM. The projected requirement by Water Atlas of Kerala (1995) of the river basins of Palakkad is 338 MCM. Based on the industrial growth and other financial growth, Water Atlas of Kerala (1995) report projected the demand as 240 MCM. The status of future water demands (after 2025) calculated based on the crop water requirement calculations for the entire cropped area for irrigation and for the other sectors viz., domestic and industrial of Palakkad district works out to be 3841 MCM , shows a large deficit in water resources, when compared to the available water resources. Hence better water management specially focusing on improving the irrigation efficiency has to be adopted to cater to the demands of the user sectors. It will be practically difficult to meet the requirements under probable climate change scenario, with these available resources at a specified point of time even if reliability factor is considered.

This deficit indicates that if the current area under irrigation is irrigated there will be deficit years and during such periods deficit irrigation or reduction in command area may have to be adopted. More over it emphasises the need for improving the water use efficiency by adopting scientific irrigation practices in the area. In general there will be surplus water during the monsoon period after meeting all the needs of the user sectors and there will be deficit during non monsoon periods which can be bridged only through long term storage. As more large scale storage has limitations a practical approach to meet this total demand will be through scientific water management and conservation practices. Hence better water management specially focusing on improving the irrigation efficiency has to be adopted to cater to the demands of the user sectors. In a nutshell, adoption of scientific water management practices will have to be undertaken to achieve long term sustainability in the water resources sector of the district under probable climate change scenario. The findings of this study have some important points for farmers, extension services and future studies. In the humid tropical climate of Kerala, with more than adequate rainfall, moisture stress is noticed for 14 to 21 weeks.

In general the following points needs to be considered,

- ✓ To ease water constraints and enhance productivity, there is need to consider improving crop patterns and cultivate crops with less water requirements.
- ✓ There is need to improve the irrigation efficiency by changing traditional irrigation system to more efficient systems such as drip, sprinkler and pipe irrigation.
- ✓ There is need to mount an effort to integrate small farms into big units to increase the irrigation efficiency.

4. Conclusions

An attempt has been madeto compute the crop water requirements of major crops in different agro-ecological zones of Palakkad using CROPWAT 8.0 model of FAO and comparing the same with the available water resources of the district.The major cultivated crops are rice, coconut, banana, arecanut, vegetables, pulses, rubber, tea, coffee, cotton etc. The total water requirement for these crops in various agro-ecological zones has been computed. Using the evapo transpiration (ET_0) and effective rainfall in each agro-ecological unit (AEU), a climatic water balance has been worked out. The net irrigation demand, the gross irrigation demand and irrigation interval for the various crops grown in different AEUs have been computed. The gross irrigation demand for the district is 1146 Mm^3, in which 981 Mm^3 is from surface water and 165 Mm^3 from groundwater sources. Water balance analysis was done for the current scenario and future demand for agriculture, domestic and industrial demand. The projected future total water demands for irrigation, drinking and industrial purpose will be 3841 Mm^3. However, the secondary data showed that utilizable water resources of Palakkad district is less and will create a deficit scenario. This deficit indicates that if the total area is brought under irrigation there will be deficit years and during such periods deficit irrigation or reduction in command area may have to be adopted. A wide spectrum of scenarios has been discussed in the paper along with the guidelines for future management of water resources.

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