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

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An effort has been made to calculate the water needs for various crops in different agro-ecological units (AEUs) of Kollam district (a humid tropical region of Kerala) using FAO-CROPWAT. The major cultivated crops are rice, coconut, rubber, pepper, banana, brinjal, tomato, tapioca, cardamom, tea, etc. The gross water required for these crops has been computed in various AEUs using meteorological parameters. Using evapotranspiration and effective rainfall in each unit, a water balance has been worked out. An overall water balance of the district has been attempted by considering irrigation, domestic and industrial demand of AEUs, under current scenario and future demand. The gross irrigation demand for the currently irrigated area in the district at 70% efficiency is 1045 mm^3, of which 920 mm^3 is supplied from surface water sources and 125 mm^3 from groundwater sources. The projected future total water demands for irrigation, drinking and industrial purposes will be 2667 mm^3. However, the utilizable water resource from all river basins of Kollam is only 1117 mm^3. The above data shows a deficit of 1550 mm^3 and it will be difficult to arrive at requirements with the existing water resources at a given point of time. We infer that if the total area is brought under irrigation, there will be water scarce years, and hence decreasing irrigation or the command area needs to be adopted to manage this shortfall and sustain production. We have also discussed several options/strategies for better water management under these changing climatic circumstances to provide water to meet the demands of all the users.

Keywords: Crop water requirement, CROPWAT, evapotranspiration, effective rainfall, irrigation demand.

SEVERE water scarcity occurs in many countries, particularly in India, and agricultural water use is progressively becoming more limited in the light of growing water demands of various sectors[1,2]. Any realistic policy planning for crop suitability needs a comprehensive understanding of the climate, particularly rainfall (its spatial and timely availability and their variability), demand for evaporation (solar radiation, wind speed and temperature) and existing water resources. Understanding these climatic parameters will be useful to know the risk levels in arable agriculture. Kerala experiences a humid tropical climate, characterized by heavy rainfall (3000 mm/year with the intensity up to 40 mm h^{-1}), high relative humidity, abundant sunshine and high ambient temperature. The wide range of agro-ecological conditions prevailing in Kerala facilitate cultivation of almost all crops apart from tropical suited crops. The production of most of these crops remains almost stagnant or declining, when compared with national and world average.

The mean annual rainfall in the state is 3000 mm. However, its distribution with respect to time and area is extremely irregular, resulting in extended dry spells of about 5–6 months. This unevenness in temporal and spatial distribution, causes a drought-like situation with water scarcity for 14–15 weeks in south Kerala and 18–21 weeks in north Kerala[3,4]. Rainfall analysis of historically longer data on Kerala illustrated that extended dry spell (as mentioned earlier) occurs in all seasons and exceptions are rare[5]. Due to uneven rainfall distribution pattern and low water retention capacity of soils, soil moisture deficit throughout summer season is one of the foremost limiting factors for higher yield in the state[6].

With irrigation, paddy yield can be enhanced by 500 kg per hectare to that of the non-irrigated conditions (averages about one-sixth of the total production per hectare) based on the assessment of the secondary data on the impact of irrigation on yield of paddy in Kerala under irrigated and non-irrigated conditions[7]. Irrigation not only improves crop productivity, but plays a major role in improving water availability in down streams as indicated by earlier studies[8]. However, the area which receives

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gross irrigation facility still hovers around 17% (2009–10) of the total cultivated area of Kerala state, which is very low from India's national average (38.7%)[9,10].

Lacunae of site-specific information on irrigation requirement for various crops, may be one main reason for adoption of irrigation and low irrigation efficiency in the state. Another is that although moisture deficit is present during summer, it is not reflected in the growth parameters of the crops, since most crops are perennial and adapted to drought. However, the reduction in yield gets unnoticed by farmers. The present recommendations for irrigation in Kerala are not based on different agro climates or for newly classified agro-ecological zones (AEZs), and are common in nature. There is need for regional scale information with respect to crop water needs to improve or sustain productivity. Regional planning of water resources could be achieved, only if we have more precise scientific data about the crop water requirements at different stages, quantity of water needed for producing targeted yields specific to crops and information on soil physical characteristics and weather conditions of specified regions. AEZs formed the basis for our study, since each zone has a related combination of problems and potentials for water resources, and hence recommendations can be suggested on a AEZ basis. Hence, an attempt was made to compute crop water requirements of major crops, in different AEZs of the humid tropical region of Kollam district, Kerala using FAO model CROPWAT 8.0 (ref. 11). It uses the FAO Penman-Monteith method[12] for calculating the reference crop evapotranspiration (ET_0), and gives values that matches with the actual need of the crop water use data worldwide, also being reproducible[13–18]. Besides, water balance assessments are also done for current requirement and future demand, which is essential for regional planning.

Materials and methods

Study location

The district selected for the present study is Kollam. It is situated in the southwest part of Kerala state and lies between 8°45′N–9°07′N and 76°29′–77°17′E (Figure 1). The geographical area is part of the Survey of India Toposheets 58C, D, G and H. The district has a geographical area of 2491 sq. km, which is about 6.48% of the total geographical area of the state.

Agro-ecological zones: The agro-ecological zones (AEZs) and units (AEUs) of Kollam district delineated by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), based on slope, rainfall, temperature, soil depth, length of growing period (LPG), etc. were taken for the current study[19,20]. The district has four AEZs and five AEUs (Figure 1). They are:

1. Coastal plain: Two AEUs (southern coastal plain – AEU 1 and Onattukara sandy plain – AEU 3) come under this zone.
2. Midland laterites: One AEU (south central laterite – AEU 9).
3. Foothills: One AEU (southern and central foothills – AEU 12).
4. Southern high hills: One AEU (southern high hills – AEU 14).

The above-mentioned AEUs are considered as base unit for calculating crop water requirement.

Methodology

Figure 2 is a flow diagram of steps involved in calculating crop water need, net and gross irrigation demand and water resources scenario. Reference crop evapotranspiration (ET_0) for selected AEUs was estimated using the FAO Penman–Monteith equations given in eq. (1). ET_0 of individual AEUs was calculated by a decision support system (Model CROPWAT 8.0 developed by FAO) based on Irrigation and Drainage Paper of FAO 56 (refs 11, 12, 21). Details of the decision support system CROPWAT's can be found in refs 2 and 11 and the secondary data used for calculating of crop water requirement is explained in subsequent sections.

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

where ET_0 is the reference crop evapotranspiration (mm day^{-1}); R_n the net radiation at the crop surface (MJ m^{-2} day^{-1}); G the soil heat flux density (MJ m^{-2} day^{-1}); T the mean daily air temperature at 2 m height (°C); u_2 the wind speed at 2 m height (ms^{-1}); e_s the saturation vapour pressure (kPa); e_a the actual vapour pressure; $e_s - e_a$ the saturation vapour pressure deficit (kPa); Δ the slope vapour pressure curve (kPa °C) and γ is the psychrometric constant (kPa (°C)).

Meteorological data: The different sets of data used for calculating various AEUs are given in Table 1. Broadly this includes meteorological data of different AEUs, climatic characteristics along with soil characteristics and crop parameters. The data used for calculation of ET_0 are geographical coordinates of the station (i.e. latitude, longitude and elevation above mean sea level), temperature maximum and minimum (°C), relative humidity maximum and minimum (%), wind speed (km/day) and sunshine hours. In case of AEUs for which data of some parameters like relative humidity, wind speed and sunshine hours are not available, ET_0 can be estimated from other parameters like temperature and geographical coordinates of the station. The software calculates the missing parameters based on available known parameters.

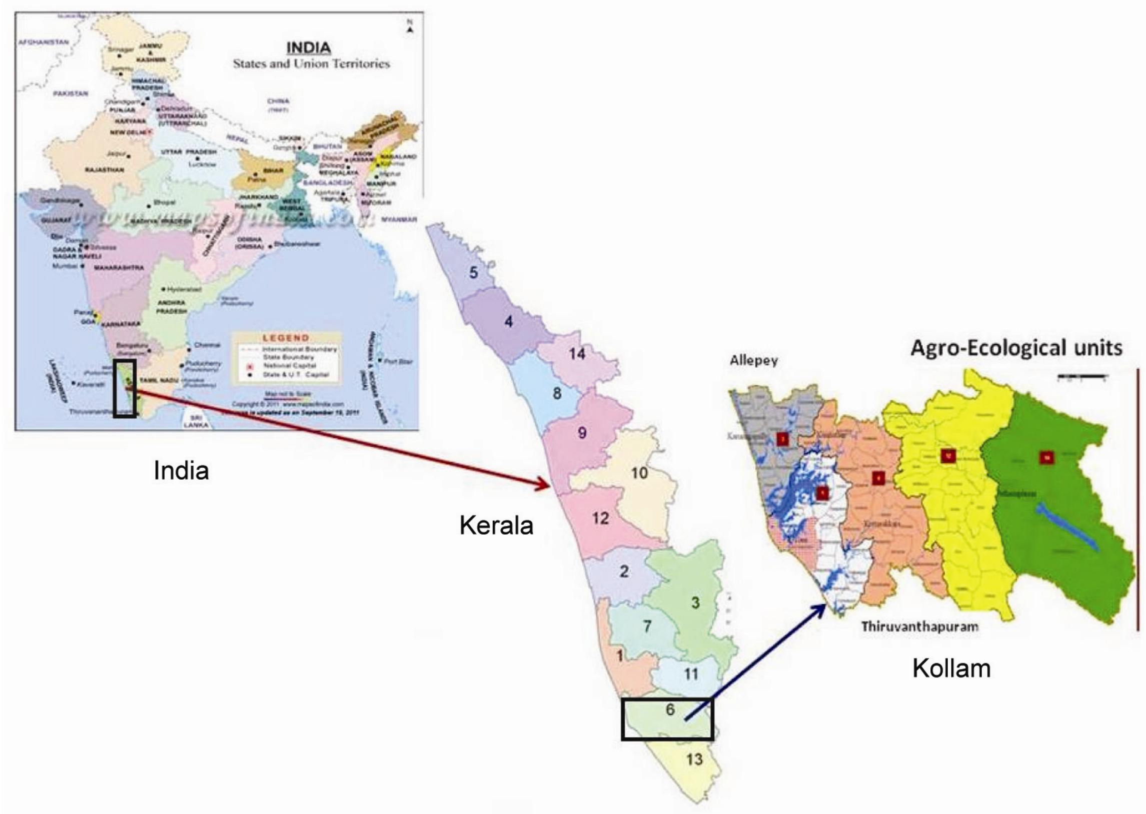

Figure 1. Geographic location of the study area along with the agro-ecological units of Kollam district.

ET_0 for each month was calculated for a 'decade' (every ten days) as defined by FAO. Available soil water content (mm/m) and depth of soil (cm) are the soil characteristics utilized to estimate crop water requirement (Table 1).

Effective rainfall: Effective rainfall is calculated based on rainfall data available from various stations within these AEUs, using the inbuilt formula (eqs (2) and (3)) of USDA Soil Conservation Service (SCS) in CROPWAT model.

$$P_{eff}(\text{dec}) = (P_{dec} * (125 - 0.6 * P_{dec}))/125 \text{ for } P_{dec} \leq (250/3) \text{ mm}, \quad (2)$$

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

where P_{eff} is the effective rainfall and P_{dec} is the rainfall for 10 days.

Crop data: The important crops grown in Kollam district are coconut, rice, rubber, pepper, banana, brinjal, tomato, gourds, pumpkin, tapioca, cardamom, tea, etc. Details such as planting season, crop duration, depth of active root zone, canopy coverage as a percentage of spacing of various crops are based on earlier studies[2,22]. Crop coefficient values (K_c) used in our study are given in Table 2. We used specific K_c values for specific stages of annual and seasonal crops (i.e. planting, mid- and late-growth stages). For perennial nature crops, K_c value of late growth stage-maturity, was used for the whole year.

Total water requirement: From the calculated ET_0, total water requirement/crop evapotranspiration (ET_c) was worked out for specific crops according to eq. (4).

$$ET_c = K_c * ET_0. \quad (4)$$

Net irrigation requirement: The irrigation requirement is calculated for the specific period, and it is the variation between the concerned crop evapotranspiration (ET_c) under standard conditions, without any pest and disease impact and the effective rainfall contributions over the same time step (mm) (see eq. (5)).

$$\text{NIR} = \text{TWR} - \text{ER} - \text{Ge}, \quad (5)$$

where TWR is the total water requirement, ER the effective rainfall and Ge is the groundwater contribution from the water table (not considered in the calculation as this is negligible).

Water resources scenario: Water resource information derived for the whole year as well as on seasonal basis by

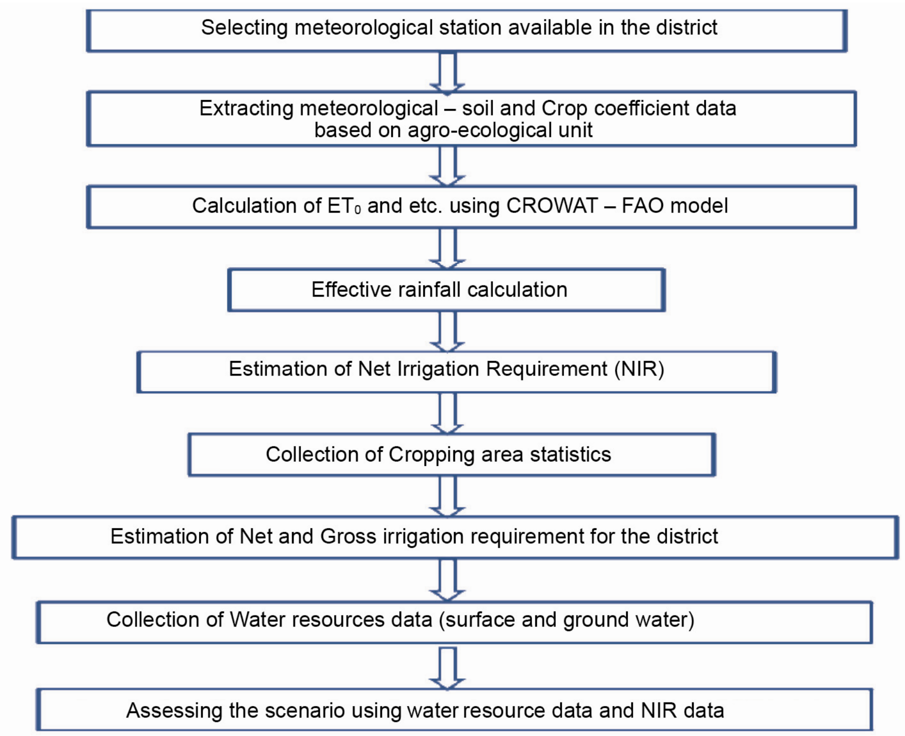

Figure 2. A flowchart diagram about the methodology adopted.

Table 1. Climatic and soil characteristics of different agroecological units in Kollam district

Agro-ecological unit	Location of meteorological stations	Range of annual rainfall (mm)	Temperature (°C) Maximum	Temperature (°C) Minimum	Data source	Available water content (AWC; mm/m)	Depth of soil (cm)
1.1	Kollam	1982–3066	35.6 (March)	20.3 (December)	IMD	125	130
1.3	Sooranadu	1797–3193	35.6 (March)	20.3 (December)	IMD	68	150
2.2	Kottarakkara	1987–2768	35.6 (March)	20.3 (December)	KAU	101	80
3.1	Punalur and Anchal	2394–3564	36.1 (March)	20.7 (January)	IMD, DAF	100	200
4.1	Thenmala, Kulathupazha and Aryankavu	2386–3806	36.1 (March)	20.7 (January)	IMD	117	130

IMD, India Meteorological Department; DAF, Department of Agriculture Farm; KAU, Kerala Agricultural University.

CWRDM was used in the present study[23,24]. The method adopted is as follows: Computations for one year (hydrological year, i.e. months from June to May) are divided into three seasons, viz. *kharif* (*Viruppu*), *rabi* (*Mundakkan*) and *summer* (*Puncha*). The available data on rainfall, stream flow, evaporation, transpiration and various hydrogeological features were considered for estimating the existing water resources of the district. The CWRDM estimate is conservative considering the practical limitations in the district for storage structures, environmental flows required especially during the lean period in these rivers and a high reliability needed for planning purposes[25]. Available ground water for the district is extracted from the CGWB report, which was calculated based on the basis of groundwater estimation methodology (1999) of the Ministry of Water Resources, Government of India[26].

Water balance computations: Details of the data on irrigation projects available in the district were compiled from the statistical details of irrigation projects of Kerala by Public Works Department, Water Resources Department and Farm Information Bureau[27,28]. The list of available cultivable command area and area irrigated was derived from the report of agricultural statistics – a glance[9]. From the report of minor irrigation census 2000–01, the area that receives water through minor irrigation schemes was compiled. Most of these data sets were available according to administrative boundary, i.e. on block basis; they were grouped into AEUs and AEZs based on area covered by each block. Similarly, the gross irrigated area statistics of Economics and Statistics Department of Government of Kerala, were used for calculating and comparing the net irrigation demand for

Table 2. Crop coefficient (K_c) of annual/seasonal crops

Crops	K_c Initial	K_c Middle	K_c Late	Reference
Annual/seasonal crops				
Rice	1.1	1.20	1.05	12
Cowpea	0.50	1.15	0.30	
Tapioca	0.30	0.80	0.30	
Bittergourd	0.50	1.00	0.8	
Brinjal	0.60	1.05	0.90	
Banana	0.50	1.10	1.00	
Crops			**K_c**	**Source**
Perennial crops alone and in mixed cropping system				
Coconut			0.75	8
Coconut (coconut–arecanut–pepper)			0.78	
Arecanut (coconut–arecanut–pepper)			0.36	
Pepper (coconut–arecanut–pepper)			0.07	
Nutmeg (coconut–nutmeg)			0.87	
Coconut (coconut–nutmeg)			0.83	

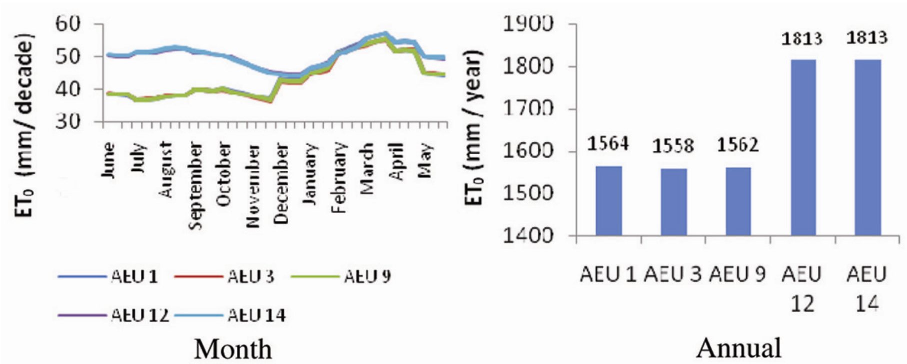

Figure 3. Reference crop evapotranspiration (ET_0 – mm) for different agro-ecological units on monthly and annual basis of Kollam district.

each of the AEUs from major, medium and minor irrigation schemes. The major crops, which receives irrigation is paddy and coconut, and paddy is mostly irrigated by government canals of major and medium irrigation schemes. Hence, for lowlands and wetlands, irrigation demand was calculated based on water need of paddy. However, the irrigation requirement for garden lands/uplands, was worked out based on the irrigation requirement of coconut or coconut-based cropping systems (major cropping systems). Another assumption made is that irrigation will be through surface method and hence respective efficiency factors have been considered while making recommendations on the irrigation schedule for important crops of Kollam.

Results and discussion

Reference evapotranspiration

The ET_0 values of different AEUs (Figure 3) ranged from 1558 to 1814 mm/year. Among AEUs, lower ET_0 was observed on AEU 3 and the maximum was noticed in AEU 12. Among different months, AEU 1, AEU 3 and AEU 9 showed lesser ET_0 values in July and higher ET_0 values in March respectively. However, this is different in the case of AEU 12 and AEU 14, in which December showed the least ET_0 value. Nevertheless, maximum ET_0 was observed in March, which is similar to that of other zones. This points out the distinction observed in the meteorological parameters, i.e. reference evapotranspiration within the district and emulating the need for having scientific water management[29]. The results agree with earlier studies, which also showed that ET_0 was minimum during the peak of rainy season to maximum during the peak of summer/dry season for the respective AEUs[30].

Total water requirement

The total requirement of water for various crops in different AEZs is given in Table 3. The quantity of total water needed for paddy ranged from 1418 to 1726 mm. The lowest water requirement of paddy is recorded in *Viruppu*

Table 3. Total water requirement (TWR) and net irrigation requirement (NIR) in mm of crops in agro-ecological units (AEUs) of Kollam district

	AEU 1		AEU 3		AEU 9		AEU 12		AEU 14	
Crops	TWR	NIR	TWR	NIR	TWR	NIR	TWR	NIR	TWR	NIR
Paddy[a]										
Viruppu	1418	585	1420	539	1418	581	1544	519	1546	477
Mundakkan	1662	1195	1655	1174	1660	1180	1726	1137	1724	1161
Puncha	1492	1442	1488	1413	1491	1446	1504	1401	1503	1423
Cowpea										
January to May[b]	445	196	445	166	445	198	476	120	477	170
September to December[c]	356	155	352	161	354	128	419	140	418	137
Tapioca										
September to May	761	405	758	373	760	372	835	334	835	376
February to October[d]	644	78	645	49	645	75	832	38	834	47
Bittergourd										
January to May	509	323	508	296	509	323	534	250	534	292
September to December	644	205	400	211	403	184	468	197	467	185
Brinjal										
September to January	484	358	477	355	481	332	521	341	519	339
May to September[e]	414	10	416	3	415	14	581	18	564	8
Banana										
September to August	1376	562	1373	538	1375	557	1624	488	1625	550
May to April	1402	684	1394	660	1399	657	1603	604	1603	649
Coconut	1125	434	1154	411	1157	424	1338	376	1351	397

[a]In paddy, the values are inclusive of percolation losses @ 6 mm/day and 300 mm towards land preparation (puddling); [b]January planting; [c]September planting; [d]February planting; [e]May planting.

Table 4. Total water potential of Kollam district*

Description of item (mm^3)	*Kharif* June–September	*Rabi* October–January	*Summer* February–May	Annual
Available water resources				
Surface water runoff	2339	769	96	3204
Ground water potential	79	79	105	263
Total water resources	2418	848	202	3468
Maximum utilizable water resources (for meeting all consumptive uses)				
Utilizable surface water	657	231	29	920
Utilizable ground water	59	59	79	198
Utilizable total water resources	716	290	108	1117

*Comprises Ithikkara, Pallickal, Kallada and Achenkoil rivers.

season (*Kharif*-rainy) for AEU 1, 3 and 9, whereas it is *Puncha* (*summer*) in the case of AEU 12 and 14. The results showed that reference and crop evapotranspiration (ET_0 and ET_c) were higher for crops with longer duration than for those with shorter ones. Also ET_c was more during the summer/dry season than rainy season which is similar to the FAO report. Crops grown in the summer/dry season need more water than those grown during monsoon (rainy) season. In short-term crops, the range of water requirement for lowland rice was particularly high in *Mundakkan* season, because climate parameters (temperature/humidity/sun shine hours) were very high with less or no rainfall. This data confirms that there are variations in the case of quantity of total water required for different crops within the district, and it is mainly because of the difference observed in climate parameters and existing soil types. This shows that it is indispensable to adopt scientific water management based on the need of the crop, so that higher crop yield and water productivity can be attained with optimal quantity of water, provided all other management practices are adopted[2,22,31].

Seasonal water balance

Climatic water balance for all the months (seasonal) has been computed based on the ET_0 and effective rainfall in

Table 5. Status of irrigation in different AEUs

Unit	Block	Net cropped area (ha)		Gross irrigated area (ha)	
		Garden land	Wetland	Major/medium	Minor
AEU-1	Anchalumood	4,541	39	321	55
	Chittumala	7,341	112	1,605	1615
	Mukhathala	7,270	214	1,820	581
	Ithikkara	8,845	216	4,368	974
	Sasthamkotta	6,457	134	189	175
AEU-3	Chavara	8,763	33	3,030	810
	Karunagappally	6,907	180	2,888	671
	Oachira	4,790	48	4,807	209
	Sasthamkotta	5,051	277	2,225	497
AEU-9	Chadayamangalam	9,474	315	227	1,654
	Ithikkara	4,058	283	1,492	603
	Kottarakkara	13,162	459	4,760	912
	Sasthamkotta	9,313	173	2,850	1,319
	Vettikkavala	10,114	253	3,340	227
AEU-12	Anchal	11,159	340	812	2,652
	Chadayamangalam	11,996	344	0	1,171
	Pathanapuram	11,921	224	1,527	656
	Vettikkavala	6,948	74	1,025	1,377
AEU-14	Anchal	9,131	72	0	518
Total		157,242	3,789	37,285	16,676

Table 6. Net irrigation demand (mm^3) in Kollam district

Unit	Blocks	Net irrigation requirement (mm^3)				Grand total
		Major/medium	Surface	Minor ground	Total	
AEU-1	Anchalumood	4.6	1.5	4.3	5.8	10.4
	Chittumala	23.2	12.1	7.4	19.4	42.6
	Mukhathala	26.3	2.4	14.4	16.8	43.1
AEU-1	Ithikkara	84.7	16.8	8.3	25.1	109.8
AEU-1, 3	Sasthamkotta	76.1	0.9	13.1	14.0	90.1
AEU-3	Chavara	42.9	4.2	6.4	10.6	53.5
	Karunagappally	40.9	0.4	9.1	9.5	50.4
	Oachira	68.1	1.4	4.9	6.3	74.4
AEU-9	Kottarakkara	67.4	10.9	11.2	22.1	89.5
	Vettikkavala	61.3	3.1	17.4	20.5	81.8
AEU-9 and 12	Chadayamangalam	3.2	5.3	12.4	17.7	20.9
AEU-12	Pathanapuram	21.8	35.9	6.8	42.7	64.5
AEU-12 and 14	Anchal	11.6	17.3	9.7	27.0	38.6
Total		532.1	112.0	125.3	237.5	769.6
Gross @ 70% efficiency		760.0	160.0	125.0	285.0	1045.0

each AEUs. The effective rainfall (EF) for the individual AEUs against the total rainfall received is shown in Figure 4 *a*. The computed EF was maximum in less rainfall decade, i.e. 100% EF is achieved when the rain is as low as 1.0 mm/decade. Similarly, EF is low in high intensity rainy period, i.e. a meagre 23% of the total rainfall is only effective (72.8 mm) when the rainfall is as heavy as 312 mm in the first 10 days of June (Figure 4 *b*). This monthly climatic water balance gives a clear idea about the months which require irrigation (period of irrigation demand) in each AEZs. For instance, in AEU 1, the months from November to April, evapotranspiration is more than EF and hence the crop requires water in the form of irrigation for these six months. The irrigation requirement for zones, AEU 3, 12 and 14 based on potential evapotranspiration and effective rainfall worked out to be for 5 months (December–April). In the case of AEU 9, except for the months June–October, evapotranspiration is greater than EF and hence requires water for irrigation for the rest of 7 months. Generally based on the climatic water balance, AEU 9 needs 7 months irrigation in a year followed by AEU 1 for 6 months. This shows

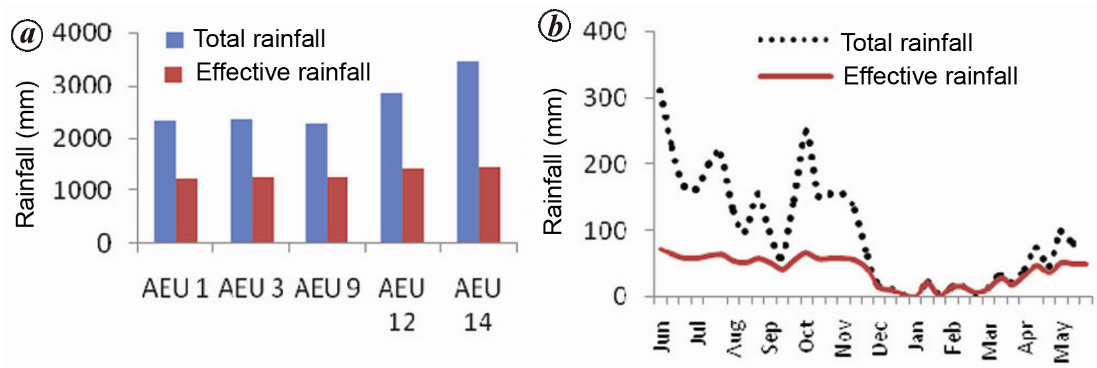

Figure 4. ***a***, Effective rainfall (mm/year) of (mm/decade) different AEUs of Kollam district. ***b***, Example of effective rainfall compared with total rainfall.

that it is essential to scientifically plan release of irrigation water from canals, so that farmers get enough water when required.

Net irrigation requirement

The net irrigation requirement of various crops in different AEUs is given in Table 3. The net irrigation requirement for paddy ranged from 477 to 1446 mm. The lowest requirement is recorded in the *Kharif* (*Viruppu*) season for all AEUs and highest requirement in *Summer* (Puncha) invariably for all AEUs. This is because *Kharif* (*Viruppu*) is a rainy season (May–September) having high rainfall, whereas the availability of water through rainfall is very low during the growing period of *Summer* (*Puncha*) rice; as a result, the quantity of water required for irrigation was very high[32]. Among AEUs, AEU 14 recorded the lowest NIR of 477 mm for *Viruppu* season and AEU 1 recorded the highest NIR of 585 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 NIR in AEUs might be due to differences in climatic parameters such as changes in temperature (maximum and minimum), solar radiation and wind speed and percentage change in effective rainfall[33].

Water resources assessment

The district has four west flowing rivers, viz. Achenkovil, Pallickal, Kallada and Ithikkara, beginning in the eastern hilly region and draining within Kollam district. These rivers jointly with their tributaries show dendritic pattern of drainage. Total water potential (available and utilizable) of Ithikkara, Pallickal, Kallada and Achenkoil rivers is pooled (Table 4) for Kollam district as a whole. Utilizable water resources in Kollam district are 1117 mm (ref. 25).

Irrigation scenario – major and minor irrigation schemes: The net cultivated area of Kollam district is 1,45,701 ha, which is 58% of the total area of the district. The area irrigated by the Kallada Irrigation project in Kollam district is about 37,285 ha. Irrigation through wells, borewells and diversion structures (minor irrigation schemes) is from individual blocks. In Kollam, the net area irrigated by all irrigation schemes totals 16,676 ha. The position of irrigation including major and minor irrigation schemes in different AEUs is shown in Table 5.

Gross irrigation demand: The demand for net irrigation for all AEUs has been worked out by considering all schemes (major and minor irrigation; Table 6), based on the statistics of irrigated area. At 70% efficiency, the gross water required (irrigation demand) is 1045 mm^3. As per the CGWB estimate, the draft for irrigation from groundwater sources in Kollam is 125 mm^3. Thus the water requirement from surface resources for irrigation is about 920 mm^3.

Future irrigation demands: The total water requirements for consumption in a region include water required for agricultural crops, for domestic purposes and for industrial needs. From the total (gross) cropped area of the district, the non-irrigated area was worked out assuming that if the entire cultivated area except rubber is to be irrigated, then what will be the net irrigation requirement. The future demand considering that the current non-irrigated crops (gross) will be irrigated is given in Table 7. The net demand if the current non-irrigated area is also irrigated works to 484 mm^3. Net irrigation requirement was 769.6 mm^3 for the existing irrigated area (Table 6) and thus the total net demand for irrigation in Kollam district will be 1254 mm^3. If efficiency of 70% is considered it comes out to 1791 mm^3.

The per capita requirement as per IS 1172: 1993 of Indian Standards for the current population was utilized for calculating the water requirement for domestic needs.

Table 7. Net irrigation demand for currently non-irrigated areas in different AEUs

		Non-irrigated area (ha)		Net irrigation requirement for the currently non-irrigated area (mm^3)	
Unit	Block	Garden land	Wetland	Garden land	Wetland
AEU 1	Anchalumood	4,126	39	17.9	0.6
	Chittumala	4,010	112	17.4	1.6
	Mukhathala	4,655	214	20.2	3.1
	Ithikkara	3,288	216	14.3	3.1
	Sasthamkotta	5,959	134	25.9	1.9
AEU 3	Chavara	4,890	33	19.0	0.5
	Karunagappally	3,167	180	13.0	2.5
	Oachira	274	48	1.1	0.7
	Sasthamkotta	2,052	277	8.4	3.9
AEU 9	Chadayamangalam	7,279	315	37.1	4.5
	Ithikkara	1,680	283	8.6	4.1
	Kottarakkara	7,031	459	35.9	6.6
	Sasthamkotta	4,971	173	25.4	2.5
	Vettikkavala	6,294	253	32.1	3.6
AEU 12	Anchal	7,355	340	27.7	4.8
	Chadayamangalam	10,481	344	39.4	4.8
	Pathanapuram	9,515	224	35.8	3.1
	Vettikkavala	4,472	74	16.8	1.0
AEU 14	Anchal	8,541	72	33.9	1.0
Total		99,492	3,789	429.8	54.1

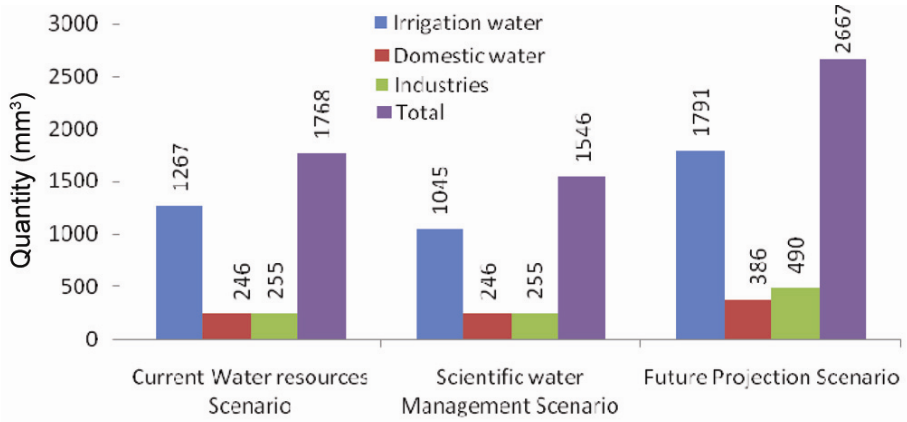

Figure 5. Water demand for various water use sectors: current scenario, scientific water management and future projection scenario.

Based on secondary data, the current domestic demand per annum is 244 mm^3. The projected requirement for 2021 by a water atlas of Kerala is 386 mm^3 (ref. 23).

Industrial demand was worked out based on data available from establishments and manufacturing units in this region. It totals approximately 255 mm^3 for 2000 and the projected future requirement for 2021 by the Water Atlas of Kerala is 490 mm^3. Figure 5 shows the condition of current and future water requirement based on scientific crop water requirement calculations using FAO model for agricultural sector in comparison with other sectors like industrial and domestic demand of Kollam district.

The current utilization of water resources for irrigation from both surface and groundwater sources on scientific basis works out to 1045 mm^3. This shows that if irrigation is done based on scientific crop water requirement using proper planning based on our study, it may be possible to save up to 72 mm^3 of water. In other words, more area can be brought under irrigation or the water can be effectively used in other sectors. With respect to future, projected gross irrigation demand for the district is 2667 mm^3. The above data shows the deficit of 1550 mm^3 and it will be virtually difficult to congregate the estimated requirements with these existing water resources at a given point of time.

This study highlights that if the total area needs to be brought under irrigation, there will be water deficit years and during such periods, deficit irrigation or decreasing the command area needs to be adopted, to manage the crop production. Several strategies for better water management under these changing climatic circumstances have been discussed below in order to satisfy the demands of agricultural water use.

In general, there will be excess water available during rainy season (monsoon), even after fulfilling all the needs of user sectors and then will be shorter during non-monsoon seasons which may be reduced only through long-term storage structures. As more and more large-scale storage structures have limitations due to the recent enforcement of environmental clearances, a realistic approach to fulfil this total water demand will be through scientific approaches of water management and soil and water conservation practices. First and foremost, water use efficiency needs to be improved by adopting scientific irrigation management practices in the area. This available surplus water conserved through scientific management during monsoon season can be utilized for fulfilling the scarcity during non-monsoon season.

Our study showed that it may not be possible to bring the entire cultivable area under irrigation, and hence policy makers, planners in irrigation department, agriculture department officials and agricultural scientists should promote water saving methods/techniques. This includes adoption of microirrigation techniques such as drip, sprinkler and microsprinklers[34], crop varieties resistant to drought/water deficit, re-adjustment of cropping and nutrient application patterns[35], planting period adjustment (moving the planting window depending on the rainfall), prioritization of areas/crops to be brought under irrigation and following the practice of deficit irrigation. Besides, sophisticated tillage operations (laser levelling) and traditional mulching techniques could also decrease water use by limiting soil evaporation and plant transpiration, and more area can be brought under irrigation. Even though the water use efficiency has increased since 1980s, adoption of water saving technologies in agriculture is limited[8]. Hence, water saving techniques for agricultural sector, in combination with optimized water reallocation, are prerequisites for comprehensively addressing the worsening water shortage problems in Kerala, especially during summer season.

Conclusions

The crop water demand of major crops, viz. rice, coconut, rubber, pepper, banana, brinjal, tomato, gourds, pumpkin, tapioca, cardamom, tea, etc. in various AEUs of Kollam was computed using FAO model CROPWAT 8.0. Using the ET_0 and EF (effective rainfall) in each agro-climatic unit, a monthly water balance has been worked out. Based on the above, the net irrigation demand, the gross irrigation demand and irrigation interval for various crops grown in different AEUs have been computed. The status of irrigation from various sources in each of the AEUs has also been computed from the secondary data available. Based on these data the current and future irrigation demand in each of these AEUs has been computed. An overall water balance of the district for the future scenario, showed the deficit of 1550 mm^3 and it will be virtually difficult to congregate the estimated requirements with these existing water resources at a given point of time. This confirms that there will be water scarce years and during such periods, either decreasing the command area or the strategies discussed in this article have to be adopted for sustaining agricultural production.

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