



## Assessment of water footprint based on estimated crop evapotranspiration for paddy, sugarcane and banana under semi-arid climate

**J. Ramachandran** ✉

Department of Agricultural Engineering, Agricultural College and Research Institute, TNAU, Madurai-, Tamil Nadu, India.

**R. Lalitha**

Department of Soil and Water Conservation Engineering, Agricultural Engineering College and Research Institute, TNAU, Kumulur, Trichy, Tamil Nadu, India.

**S. Vallal Kannan**

Department of Irrigation and Drainage Engineering, Agricultural Engineering College and Research Institute, TNAU, Kumulur, Trichy, Tamil Nadu, India.

**K. Sivasubramanian**

Office of Controller of Examination, TNAU, Coimbatore, Tamil Nadu, India.

| ARTICLE INFO   | ABSTRACT  |
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| <p>Received : 02 August 2021<br/>                     Revised : 12 October 2021<br/>                     Accepted : 20 January 2022</p> <p>Available online: 17 April 2022</p> <p><b>Key Words:</b><br/>                     Banana<br/>                     Paddy<br/>                     Sugarcane<br/>                     Water Footprint</p> | <p><b>Climate change impact has adverse effects on water use in crop production. A better crop water use indicators to decide upon the water use policies of that region or country is necessary. Water footprint indicates relationship between water use and crop yield. Rice, sugarcane and banana are the major crops which require a significant amount of water in Lalgudi block of Trichy district in Tamil Nadu. This study analyzed the total water requirement, blue and green crop evapotranspiration, blue and green crop water use and blue, green and total water footprint for paddy, sugarcane and banana in Lalgudi block. The crop water footprint estimated by using FAO56-K<sub>c</sub> for paddy, sugarcane and banana was 2173 m<sup>3</sup> ton<sup>-1</sup>, 304 m<sup>3</sup>/ton and 501 m<sup>3</sup>/ton respectively. And by using ClimAdj-K<sub>c</sub>, the crop water footprint for paddy, sugarcane and banana was 2228 m<sup>3</sup> ton<sup>-1</sup>, 307 m<sup>3</sup>/ton and 503 m<sup>3</sup>/ton respectively. It was found that quantity of water used for producing per ton of yield was higher in paddy in comparison to banana and sugarcane.</b></p> |

### Introduction

A great stress occurs on water resources because of increasing consumptive use and non-consumptive use of water and changing climatic conditions (Jose *et al.*, 2010). The outcome in agricultural production is greatly affected by reduced supply of freshwater for irrigation in many river basins located in the semi-arid and arid regions. Burning problem of water scarcity is forcing the water managers to evolve a better crop water use indicators to decide upon the water use policies of that region or country. Water Footprint is a relatively new indicator that look in to the water use from production and consumption perspectives (Hoekstra and Hung, 2002). It is defined as the “total volume of freshwater used to produce the

*goods and services consumed by the individual or community or produced by the business”*. Crop water footprint is used for quantifying the crop water requirement based on the source of water and also addresses the amount of water used for producing a unit quantity of crop yield. For agricultural products, the water footprint is commonly expressed in terms of volume of water used per quantity of crop produced (m<sup>3</sup> ton<sup>-1</sup> or litres kg<sup>-1</sup>). Hoekstra *et al.* (2011) defined green water footprint as “*volume of rainwater consumed during the production process and is particularly relevant for agricultural and forestry products (products based on crops or wood), where it refers to the total rainwater evapotranspiration (from*

fields and plantations) plus the water incorporated into the harvested crop or wood". Blue water footprint is defined as "volume of surface and groundwater consumed as a result of the production of a good or service. Consumption refers to the volume of freshwater used and then evaporated or incorporated into a product".

Maximizing the land productivity ( $\text{ton ha}^{-1}$ ) is the primary objective in agriculture when land is scarce and freshwater is abundant. Maximizing water productivity is more important when water is scarcer than land. Hence, less irrigation water (blue water) is applied in a smarter way and higher yield per cubic meter of water evaporated is obtained (Hoekstra *et al.*, 2011). Prasad *et al.* (2013) quantified the blue and green proportions of crop evapotranspiration of six important crops of Kothakunda sub watershed in Andra Pradesh. Kar *et al.* (2014) quantified field level water footprint of rice production in eastern India based on measured ETc. The measured values were compared with other three methods like Pan Evaporimeter, Bowen ratio and Penman Monteith methods. Mali *et al.* (2015) assessed blue and green components of evapotranspiration of 15 major crops grown in agricultural production units of Gomati basin. CROPWAT model was used for estimation of green and blue components of evapotranspiration. Veettil and Mishra (2016) indicated that due to changing pattern in climate variable and sectorial water demands, studies related to spatio-temporal variability of water footprints indicators is desirable for formulating water management practices. Zhao *et al.* (2016) investigated the scenario of blue and green water resources under various land use, irrigation and climate variability in spatial and temporal aspects.

In this paper, the total water requirement, blue and green crop evapotranspiration, blue and green crop water use and blue, green and total water footprint for paddy, sugarcane and banana was estimated in Lalgudi block Lalgudi block of Trichy district in Tamil Nadu.

## Material and Methods

### Study Area

Lalgudi block, located at Tiruchirapalli District, Tamil Nadu, India was selected for this study (Figure 1). Lalgudi block is situated at  $10^{\circ}52'27''$  N

and  $78^{\circ}48'57''$  E geo-coordinate and located 70 m above mean sea level. The total geographical area of the block is 20558 hectares. Lalgudi block has semi-arid climate with an average rainfall of 877 mm. Agriculture is the main occupation of Lalgudi block. Around 45 percent of area in Lalgudi block is used for agriculture. In Lalgudi block, 90 percent of the crop production is done by irrigation and the remaining 10 percent is under rainfed cropping. The major sources of irrigation are canals, bore wells, tanks and ponds. Paddy, sugarcane, banana and other vegetables are grown in the study area. In recent decades, water demand always exceeds rainfall and at the same time, exploitation of groundwater has increased greatly particularly for agriculture.

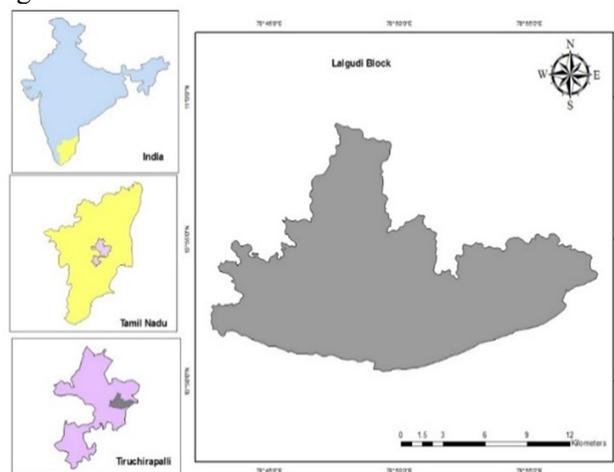


Figure 1: Location of study area – Lalgudi block (Trichy district)

### Meteorological Data

The daily maximum and minimum air temperature and relative humidity for the period 1995-2017 was collected from the meteorological observatory located at Agricultural Engineering College and Research Institute, Kumulur, Lalgudi Block of Trichy district.

### Estimation of Crop Water Requirement Using Cropwat

CROPWAT 8.0 was used to estimate the crop water requirement. Firstly, monthly reference evapotranspiration was estimated by FAO56 – Penman Monteith equation in CROPWAT from the meteorological data collected from the observatory.

The equation for estimating the daily grass-reference evapotranspiration is given by

$$ET_0 = \frac{0.408 * \Delta(R_n - G) + \gamma \frac{900}{[T + 273]} * u * (e_s - e_a)}{\Delta + \gamma(1 + 0.34 * u)} \quad (1)$$

Where  $ET_0$  reference evapotranspiration [ $\text{mm day}^{-1}$ ],  $\Delta$  is slope of vapour pressure curve [ $\text{kPa } ^\circ\text{C}^{-1}$ ],  $\gamma$  is psychrometric constant [ $\text{kPa } ^\circ\text{C}^{-1}$ ],  $R_n$  is net radiation at the crop surface [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],  $T$  is mean daily air temperature [ $^\circ\text{C}$ ],  $G$  is soil heat flux density [ $\text{MJ m}^{-2} \text{day}^{-1}$ ],  $u$  is wind speed at 2 m height [ $\text{m s}^{-1}$ ],  $e_s$  is saturation vapour pressure [ $\text{kPa}$ ],  $e_a$  is actual vapour pressure [ $\text{kPa}$ ], and  $e_s - e_a$  is saturation vapour pressure deficit [ $\text{kPa}$ ].

The full dataset used in estimating reference evapotranspiration was collected from the meteorological observatory located at Agricultural Engineering College and Research Institute, Kumulur, Lalgudi Taluk, Trichy. The effective rainfall ( $P_{\text{eff}}$ ) was calculated by using Soil Conservation Service method. The rainfall data was also collected from the meteorological observatory located at Agricultural Engineering College and Research Institute, Kumulur, Lalgudi Taluk, Trichy. The crop evapotranspiration ( $ET_c$ ) under optimal conditions was estimated which is equal to crop water requirement (CWR).  $ET_c$  was estimated at a ten day time step throughout the total growing season.

The model calculates  $ET_c$  as follow as:

$$ET_c = ET_0 * K_c \quad (2)$$

Here,  $ET_0$  represents the reference evapotranspiration and  $K_c$  refers to the crop coefficient. The crop coefficient is calculated by two methods as explained below.

### Estimation of crop coefficients

Crop coefficients are used to estimate the crop water requirement. Generally, the value of crop coefficient is taken from the FAO56 Crop Evapotranspiration guidelines (Allen *et al.*, 1998) for different crops at different stages and the crop water requirement is calculated. There are numerous other methods to estimate the site-

specific crop coefficients. The following two methods were used in determination of  $K_c$  for paddy, sugarcane and banana.

### FAO56 Tabulated $K_c$

In this method, the value of  $K_c$  was taken from the tabulated  $K_c$  values (hereafter referred as FAO56- $K_c$ ) given in the FAO56 Crop Evapotranspiration guidelines (Allen *et al.*, 1998) for different crops at different stages, mean maximum plant height, non-stressed, well-managed crops in sub-humid climates.

### Adjusted $K_c$ for Local Climatic Conditions

The adjusted  $K_c$  values with respect to the local climatic effect (hereafter referred as ClimAdj- $K_c$ ) were estimated for mid and end stage for paddy, sugarcane and banana by using the following equations as given in FAO56 Crop Evapotranspiration guidelines (Allen *et al.*, 1998). For mid-season growth stage,  $K_c$  is given by:

$$K_{c\_mid} = K_{c\_mid(Tab)} + \left[ 0.04(u-2) - 0.004(RH_{\text{min}} - 45) \right] \left( \frac{h}{3} \right)^{0.3} \quad (3)$$

Where  $K_{c\_mid(Tab)}$  is crop coefficient value tabulated in FAO56 Crop Evapotranspiration guidelines (Allen *et al.*, 1998) for midseason growth stage;  $u$  is as indicated in equation 1,  $RH_{\text{min}}$  is average daily minimum relative humidity and  $h$  is the mean plant height during the mid-season stage. Similarly, for end-season growth stage, the adjusted  $K_c$  value is obtained by using the following equation:

$$K_{c\_end} = K_{c\_end(Tab)} + \left[ 0.04(u-2) - 0.004(RH_{\text{min}} - 45) \right] \left( \frac{h}{3} \right)^{0.3} \quad (4)$$

Where  $K_{c\_end(Tab)}$  is crop coefficient value tabulated in FAO56 Crop Evapotranspiration guidelines (Allen *et al.*, 1998) for end season growth stage and  $u$ ,  $RH_{\text{min}}$  and  $h$  are as indicated in equation 3. Allen *et al.* (1998) suggested that in planning studies, the typical value for initial crop coefficient ( $K_{c\_ini}$ ) given in FAO56 Crop Evapotranspiration guidelines can be used in estimation of crop evapotranspiration. Hence for initial stage alone the crop coefficients given in FAO56 Crop Evapotranspiration guidelines was used.

### Estimation of blue and green water evapotranspiration

Green water evapotranspiration ( $ET_{green}$ ) was calculated as the minimum of total crop evapotranspiration ( $ET_c$ ) and effective rainfall ( $P_{eff}$ ) at ten day time step.

$$ET_{green} = \min(ET_c, P_{eff}) \quad (5)$$

The blue water evapotranspiration ( $ET_{blue}$ ) was calculated as the difference between the total crop evapotranspiration ( $ET_c$ ) and the total effective rainfall ( $P_{eff}$ ) and if the effective rainfall is greater than total crop evapotranspiration  $ET_{blue}$  is equal to zero..

$$ET_{blue} = \max(0, ET_c - P_{eff}) \quad (6)$$

Adding  $ET_{blue}$  over the whole growing period, total  $ET_{blue}$  is obtained. Also, percolation loss of 5 mm  $day^{-1}$  was included with total crop evapotranspiration for paddy (except during the end stage). For banana and sugarcane, other water losses of 1 mm  $day^{-1}$  was included with total crop evapotranspiration.

### Estimation of crop water footprint

First, the estimated crop evapotranspiration in mm is converted to  $m^3 ha^{-1}$  by applying a factor 10 which is called as crop water use.

$$CWU_{green} = 10 * ET_{green} \quad (7)$$

$$CWU_{blue} = 10 * ET_{blue} \quad (8)$$

The green component of water footprint ( $WF_{proc,green}$ ,  $m^3 ton^{-1}$ ) was calculated as the green component in crop water use ( $CWU_{green}$ ,  $m^3 ha^{-1}$ ) divided by the crop yield  $Y$  ( $ton ha^{-1}$ ). The blue component of water footprint ( $WF_{proc,blue}$ ,  $m^3 ton^{-1}$ ) was calculated from blue component in crop water use ( $CWU_{blue}$ ,  $m^3 ha^{-1}$ ) in the similar way. The equations used are listed below:

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \quad (9)$$

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \quad (10)$$

Thus the methodology adopted to achieve the framed objectives is clearly presented in the above section.

## Results and Discussion

### FAO56 tabulated $K_c$

The FAO56- $K_c$  for paddy, sugarcane and banana at different stages are presented in Table 2. The number of days in Initial (Ini), Development (Dev), Middle (Mid) and End stages during the crop period was taken from FAO56 Crop Evapotranspiration guidelines (Allen *et al.*, 1998) and shown in Table 1. The  $K_c$  coefficient incorporates crop characteristics and averaged effects of evaporation from the soil.

### Adjusted $K_c$ for local climatic conditions

The ClimAdj- $K_c$  values with respect to the local climatic effect estimated for mid and end stage for paddy, sugarcane and banana by using the FAO56 Crop Evapotranspiration guidelines is presented in the following table 2. (Allen *et al.*, (1998)) suggested that in planning studies, the typical value for initial crop coefficient ( $K_{c\_ini}$ ) given in FAO56 Crop Evapotranspiration guidelines can be used in estimation of crop evapotranspiration. Hence, for initial stage alone the crop coefficients given in given in FAO56 Crop Evapotranspiration guidelines was used and presented in table 2. The ClimAdj- $K_c$  values of sugarcane obtained in this study is comparable to the values determined by Dingre and Gorantiwar (2020) during grand growth and maturity stages of sugarcane (1.20 and 0.78, respectively). Dingre and Gorantiwar (2020) also determined the  $K_c$  value for sugarcane in a semi-arid region of India.

### Crop water footprint

The crop water requirement was estimated in CROPWAT 8.0, by using the  $K_c$  values obtained by the two methods as discussed in the previous section. The total water requirement, blue and green

crop evapotranspiration, blue and green crop water use and blue, green and total water footprint for paddy, sugarcane and banana is presented in Table 3-5 respectively. The total water requirement estimated by ClimAdj-Kc was higher for paddy, sugarcane and banana compared to FAO56-Kc. Since ClimAdj-Kc considers the local climatic and agronomic conditions of crops, the total water requirement estimated with ClimAdj-Kc values is high.

**Water footprint for paddy**

The water footprint in paddy by using FAO56-Kc and ClimAdj-Kc was 2173 and 2228 m<sup>3</sup> ton<sup>-1</sup> respectively. The water footprint for paddy is high compared to banana and sugarcane. But when

compared to banana and sugarcane, the total water requirement for paddy is low. Kar *et al.* (2014) also reported that the water footprint for two varieties of paddy (varieties: ‘Lalat’ and ‘Gayatri’) was 2470 and 2704 m<sup>3</sup> ton<sup>-1</sup> respectively in Puri, Odisha. In paddy only 12 % of total water requirement is satisfied by green water (effective rainfall) whereas remaining amount of water is satisfied by blue water resources like groundwater, canals, wells and lake. The following strategies may be adopted to reduce the water footprint without affecting the yield and income of the farmers. The practice of deficit irrigation strategy instead of full irrigation helps in reducing water consumption while having

**Table 1: Tabulated Kc values and crop parameters**

| Crop      | Stages (Days) |     |     |     | K <sub>c</sub> |      |      |
|-----------|---------------|-----|-----|-----|----------------|------|------|
|           | Ini           | Dev | Mid | End | Ini            | Mid  | End  |
| Paddy     | 30            | 30  | 60  | 30  | 1.05           | 1.2  | 0.85 |
| Sugarcane | 40            | 70  | 170 | 30  | 0.45           | 1.25 | 0.75 |
| Banana    | 120           | 90  | 120 | 60  | 0.50           | 1.10 | 1.00 |

Source: FAO56 Crop Evapotranspiration guidelines (Allen *et al.*, 1998)

**Table 2: ClimAdj-Kc value for different crops in Lalgudi Block**

| SN | Crop      | Ini  | Mid  | End  |
|----|-----------|------|------|------|
| 1  | Paddy     | 1.15 | 1.23 | 0.90 |
| 2  | Banana    | 0.50 | 1.11 | 1.00 |
| 3  | Sugarcane | 0.45 | 1.26 | 0.80 |

**Table 3: Crop water footprint for paddy crop**

| Approach    | Total Water Requirement (mm) | ET <sub>Green</sub> (mm) | ET <sub>Blue</sub> (mm) | CWU <sub>Green</sub> (m <sup>3</sup> ha <sup>-1</sup> ) | CWU <sub>Blue</sub> (m <sup>3</sup> ha <sup>-1</sup> ) | WF <sub>Green</sub> (m <sup>3</sup> ton <sup>-1</sup> ) | WF <sub>Blue</sub> (m <sup>3</sup> ton <sup>-1</sup> ) | Total Water Footprint (m <sup>3</sup> ton <sup>-1</sup> ) |
|-------------|------------------------------|--------------------------|-------------------------|---|--|---|--|---|
| FAO56 Kc    | 1304                         | 165                      | 1139                    | 1651  | 11389  | 275   | 1898   | 2173  |
| Adjusted Kc | 1337                         | 165                      | 1172                    | 1651  | 11718  | 275   | 1953   | 2228  |

**Table 4: Crop water footprint for sugarcane crop**

| Approach    | Total Water Requirement (mm) | ET <sub>Green</sub> (mm) | ET <sub>Blue</sub> (mm) | CWU <sub>Green</sub> (m <sup>3</sup> ha <sup>-1</sup> ) | CWU <sub>Blue</sub> (m <sup>3</sup> ha <sup>-1</sup> ) | WF <sub>Green</sub> (m <sup>3</sup> ton <sup>-1</sup> ) | WF <sub>Blue</sub> (m <sup>3</sup> ton <sup>-1</sup> ) | Total Water Footprint (m <sup>3</sup> ton <sup>-1</sup> ) |
|-------------|------------------------------|--------------------------|-------------------------|---|--|---|--|---|
| FAO56 Kc    | 1825                         | 605                      | 1220                    | 6050  | 12199  | 101   | 203  | 304   |
| Adjusted Kc | 1839                         | 605                      | 1234                    | 6050  | 12337  | 101   | 206  | 307   |

**Table 5: Crop water footprint for banana crop**

| Approach    | Total Water Requirement (mm) | ET <sub>Green</sub> (mm) | ET <sub>Blue</sub> (mm) | CWU <sub>Green</sub> (m <sup>3</sup> ha <sup>-1</sup> ) | CWU <sub>Blue</sub> (m <sup>3</sup> ha <sup>-1</sup> ) | WF <sub>Green</sub> (m <sup>3</sup> ton <sup>-1</sup> ) | WF <sub>Blue</sub> (m <sup>3</sup> ton <sup>-1</sup> ) | Total Water Footprint (m <sup>3</sup> ton <sup>-1</sup> ) |
|-------------|------------------------------|--------------------------|-------------------------|---|--|---|--|---|
| FAO56 Kc    | 2105                         | 698                      | 1408                    | 6977  | 14077  | 166   | 335  | 501   |
| Adjusted Kc | 2116                         | 698                      | 1417                    | 6977  | 14175  | 166   | 337  | 503   |

negligible effects on yield. The irrigation interval recommended in this study may be prolonged one day so that total water footprint of crops will be reduced. Alternate wetting and drying in paddy cultivation may be practiced to save water which additionally reduces greenhouse gas emissions by maintaining yields. Kar *et al.* (2014) suggested that better rainwater management and efficient application methods will reduce the blue water footprint. Higher percolation need in the first phase of the land preparation can be reduced by water saving seeding/planting methods of rice like direct dry seeding, System of Rice Intensification (SRI).

### Water footprint for sugarcane

The water footprint in sugarcane by using FAO56-K<sub>c</sub> and ClimAdj-K<sub>c</sub> was 304 and 307 m<sup>3</sup> ton<sup>-1</sup> respectively. In sugarcane, around 33% of total water requirement was satisfied by green component and the remaining was given through irrigation in Lalgudi block. The results are on par with that of total water requirement of sugarcane obtained by Dingre and Gorantiwar (2020). Dingre and Gorantiwar (2020) reported that, for sugarcane irrigation water requirement and effective rainfall was 991 mm year<sup>-1</sup> and 424 mm year<sup>-1</sup> respectively in semiarid India. When drip or subsurface drip irrigation for sugarcane is recommended, it will reduce the water footprint, but at a significant cost.

### Water footprint for banana

The estimated total water requirement for banana by using FAO56-K<sub>c</sub> and ClimAdj-K<sub>c</sub> was 2105 and 2116 mm respectively. While compared to paddy and sugarcane, the total water requirement for banana is high. The water footprint in banana by using FAO56-K<sub>c</sub> and ClimAdj-K<sub>c</sub> was 501 and 503 m<sup>3</sup> ton<sup>-1</sup> respectively. While comparing banana and sugarcane, the water footprint of banana was higher. Around 33% of total water requirement was satisfied by green component and the remaining was given through irrigation in Lalgudi block. For

banana crop, the use of organic mulching can significantly reduce the water footprint at a relatively low cost. Paul *et al.* (2008) also reported that use of drip, either alone or in combination with mulching, can increase the banana yield up to 33% over basin irrigation along with a saving of 20% of irrigation water. Besides high yielding banana varieties like Poovan, Rasthali and Elarasi which starts yielding at seven months may be cultivated.

### Conclusion

The total, water requirement, blue and green crop evapotranspiration, blue and green crop water use and blue, green and total water footprint for paddy, sugarcane and banana were estimated. The crop water requirement was estimated using CROPWAT 8.0. The crop water footprint of paddy was higher compared to sugarcane and banana. It means that quantity of water used of producing per ton of yield was higher in paddy compared to banana and sugarcane since paddy is water loving crop. In paddy, only 12 % of total water requirement is satisfied by green water (effective rainfall) whereas remaining amount of water in satisfied by blue water resources like groundwater, canals, wells and lake. Similarly for sugarcane and banana, around 33% of total water requirement was satisfied by green component and the remaining was given through irrigation. The water footprint of paddy was 86 percent higher than sugarcane and 76 percent higher than banana water footprint. Hence water footprint is necessarily to be reduced to alleviate overexploitation of groundwater and increase national food security. The results will be useful for water management and effective operation of water supply system. It can be applied in establishing long-term policies for agricultural water resources.

### Conflict of interest

The authors declare that they have no conflict of interest.

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