

# Farmer Irrigation Practices Exceed Crop Water Requirements in Brinjal Cultivation: Evidence from Northern Kerala

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## Abstract

Water is considered an inevitable component of crop production. Effective irrigation management is essential for maintaining sustainability in agriculture and controlling GHG emissions. The FAO CROPWAT model is a widely accepted tool for irrigation scheduling. In Kannur district of Kerala, small-scale vegetable farming is mainly practiced during the summer season. The reference evapotranspiration of the study area was recorded as higher during February to May (3.78- 4.18 mm/day). The current study conducted a field survey among the brinjal farmers of the study area. Irrigation and other cultivation practices were recorded. The recommended irrigation scheduling for brinjal was estimated using historic climatic data and standard cultivation practices recommended by KAU for the region. The average irrigation requirement for brinjal was 169.1 mm per decade (10 days). However, most of the farmers irrigated excessively, applying on average 776% more water than the recommended amount. Over-irrigation is also responsible for the high carbon footprint associated with irrigation in the area. This will also lead to water stress in the near future. The farmers' irrigation practices should be in accordance with the standard irrigation schedule for sustainable and low-emission agricultural practices in the area.

**Keywords:** Brinjal (*Solanum melongena* L.); irrigation scheduling; farmer irrigation practices; crop water requirement; water conservation; sustainable agriculture.

## 1. Introduction

The sufficient, safe and reliable water availability for human wellbeing, agricultural purposes, industrial needs and ecosystem health is referred as water security. 70% of available global freshwater is being used for agricultural purposes, making it the dominant water-demanding sector (FAO, 2017). India is vulnerable to high water stress. The country consists of 18% of world population with only 4% of global freshwater resources (CWC, 2029). The country based on agriculture economy and the agriculture sector consumes more than 80% of India's water use. It creates limited water for domestic and industrial purposes. The crop-water relationship is a critical component of agricultural system to ensure food security under increasing population pressure and climatic variability.

Crop growth and yield mainly relies on soil moisture and irrigation water. When water resources become scarce due to climate change and resource exploitation by population growth, the agricultural productivity become declined. It affects food security (Falkenmark, 2013). This scenario implicating the food security and water security are interrelated.

The crop water requirement is mainly determined by Evapotranspiration (ET), the combination of soil evaporation and plant transpiration processes (Allen et al., 1998). In this, evaporation from soil is a non-productive water loss, whereas transpiration supports plant's physiological needs and biomass production (Allen et al., 1998). ET mainly depends on climate, crop variety, growth phase and soil moisture. The climatic components of ET include temperature, solar radiation, humidity and wind. The reference evapotranspiration (ET<sub>o</sub>) or 'atmospheric thirst' quantifies this demand. The crop specific K<sub>c</sub> values (Crop coefficient) is based on the physiological and growth traits of the crops. The K<sub>c</sub> and ET<sub>o</sub> together forms the overall water demand which is ET<sub>c</sub> (crop evapotranspiration). The estimation of ET<sub>c</sub> for the crops is essential for calculating the water requirement of the crop. Proper water requirement estimation is very crucial in water scarce conditions.

Many methods are available and practicing for the estimation of evapotranspiration. Empirical methods calculate ET by climatic parameters and mathematical equations. The formulas related to climatic variables such as temperature, humidity, solar radiance, wind speed (Pereira et al., 2015). The common empirical methods are FAO Penman-Monteith method, Hargreaves method, Thornthwaite method and Blaney-Criddle method. In these methods, FAO Penman-Monteith method is considered as the most reliable and widely accepted for estimating reference evapotranspiration (ET<sub>o</sub>). It integrates multiple meteorological parameters and performs well under various climatic conditions. This method is widely accepted due to its simplicity and suitability for irrigation planning and water resource management (Allen et al., 1998).

The CROPWAT model by FAO has been widely used for irrigation planning and management (Smith, 1992). It estimates ET<sub>o</sub> based on FAO Penman-Monteith method, estimates effective rainfall, and computes ET<sub>c</sub> and

irrigation requirements for different crops. The simulation also considers various climatic and soil conditions for estimating irrigation schedules (Clarke et al., 2001). It also required crop inputs like Crop type, Length of growth stages (initial, development, mid-season, late season), Crop coefficient ( $K_c$ ) values for different growth stages, Rooting depth, Critical depletion fraction ( $p$ ) and Yield response factor ( $K_y$ ). The major soil data required are Soil texture, Total available soil moisture (TAW), Maximum infiltration rate and Initial soil moisture conditions.

The Kerala state is located in the humid tropics of southwest India. It receives annual precipitation of 3000 mm by two major monsoon stretches (Southwest and northeast). The dry spells during summer seasons demand supplementary irrigation (IMD, 2020). The state remains humid for most of the year due to the rainfall and warm temperature by monsoon and summer spells (Rajasekharan et al., 2014). Solanaceous vegetables such as tomato (*Solanum lycopersicum* L.), brinjal (*Solanum melongena* L.), and chilli (*Capsicum annuum* L.) are important to Kerala's diet and economy. These crops are cultivated across the coastal, midland, and high-range zones of Kannur district, each characterized by distinct rainfall, temperature, and soil conditions. The present study estimates crop water requirements of brinjal using the CROPWAT model based on the FAO Penman-Monteith method. The study also identified the gap between scientifically recommended irrigation schedules and actual field-level irrigation practices.

## 2. Methodology of the study

### 2.1. Study area

The study was conducted in Dharmadam, Mannur, Payyannur and Kuthuparamba of Kannur district, Kerala (Fig. 1). Kannur district ( $11^{\circ}40'-12^{\circ}48'$  N,  $74^{\circ}52'-76^{\circ}07'$  E) is surrounded by the Western Ghats and Coorg district of Karnataka in the east, Kozhikode and Wayanad district in the south, the Lakshadweep Sea in the west, and Kasaragod district in the north side. It has three main agroecological regions: plantation dominated highlands, agriculturally intensive midland hills and valleys, and a narrow lowland strip of rivers and coast with coconut, paddy and seasonal vegetables. The climate is humid with a hot season (March-May), a dominant south west monsoon giving over 80% of the annual 3438 mm rainfall, and cooler months in December-January with temperatures near  $20^{\circ}\text{C}$  (IMD, 2020). Vegetation ranges from coastal psammophytes and mangroves to lateritic mixed deciduous-evergreen forests and high elevation forest-grassland mosaics over Archean gneiss and charnockite and younger laterite and alluvium. Brinjal cultivation is commonly practiced in different parts of the district. The soil of the study area including sandy loam and mixed type which influences water retention and irrigation requirement.

A total of 21 farmers were selected from different locations in Kannur district. The selection was done to ensure variation in irrigation practices, cultivated area, and management methods. Farmers were selected using random sampling from the study area.

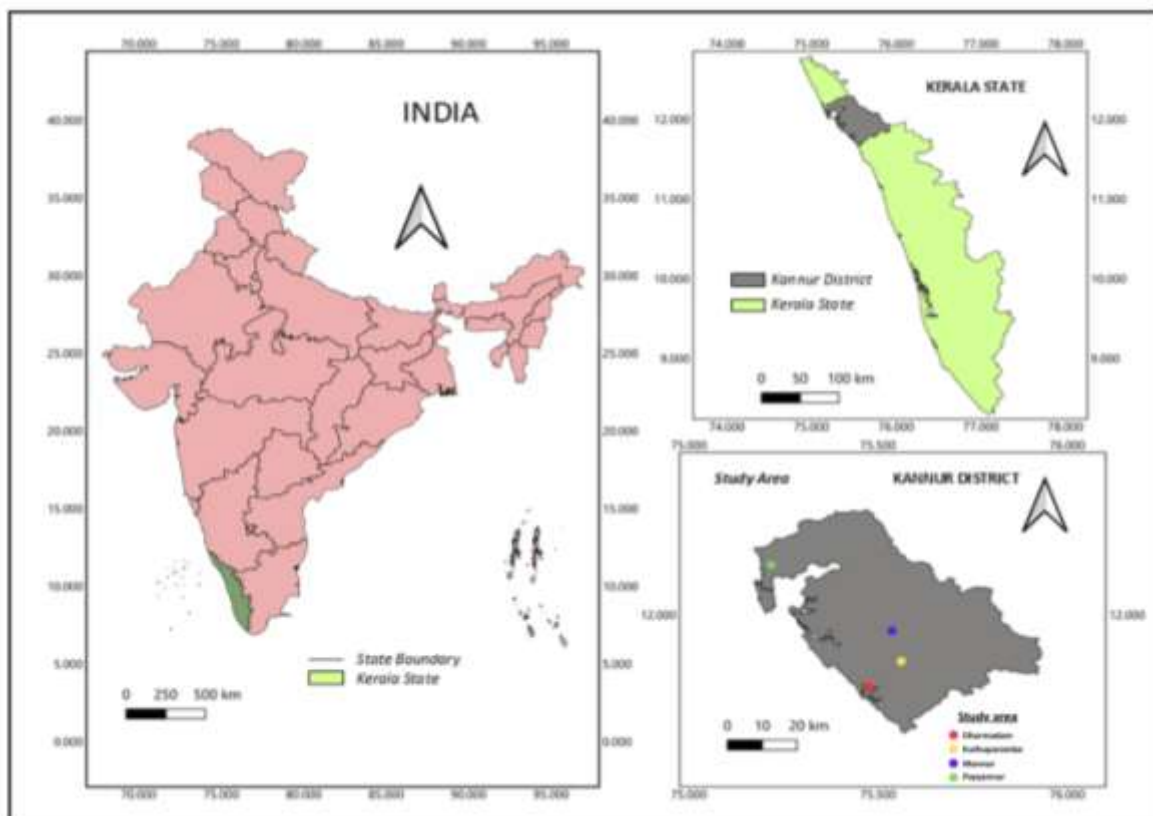


Fig 1: Study area

## 2.2. Data Collection

The field survey was conducted among brinjal farmers of the Kannur district for this study. The data were collected through direct interaction (Fig. 2). During the survey, data on cultivated area, crop type, daily irrigation quantity, irrigation frequency, crop duration, number of plants cultivated, and fertilizer application practices were collected.

Climatic data were collected from meteorological station at Kannur by IMD for the estimation of crop water requirements. The climatic parameters required for the analysis included maximum and minimum temperature, relative humidity, wind speed, sunshine hours, and radiation. These climatic data were used in the CROPWAT 8.0 software to calculate the reference evapotranspiration ( $ET_0$ ).

For the estimation of crop water requirements, crop parameters brinjal were obtained from the KAU PoP and FAO Irrigation and Drainage Paper No.56. These parameters include crop coefficient ( $K_c$ ), growth stage duration, rooting depth, depletion fraction, and yield response factor. The soil type selected for the analysis was loamy soil, which represents the dominant soil condition in the study area. Soil parameters such as field capacity, permanent wilting point, and total available soil moisture from FAO-56 were used in the CROPWAT model to simulate soil water balance and irrigation requirements.

## 2.3. Estimation of Reference Evapotranspiration ( $ET_0$ ) and Crop Water Requirement (CWR)

Reference evapotranspiration ( $ET_0$ ) was calculated using the FAO Penman–Monteith method through the CROPWAT software developed by the FAO. Climatic data were entered into the software to compute monthly  $ET_0$  values. Minimum temperature, maximum temperature, humidity, wind speed, sun hours and radiation were provided to get monthly  $ET_0$  values. Based on these inputs, the CROPWAT model generated outputs such as crop

evapotranspiration ( $ET_c$ ), net irrigation requirement, gross irrigation requirement, irrigation intervals, and total seasonal water requirement.

## 2.4. Irrigation scheduling

The irrigation scheduling option in CROPWAT was used to estimate the optimal irrigation timing and quantity required during different crop growth stages, namely the initial, development, mid-season, and late-season stages. The model produced a detailed irrigation schedule indicating the net irrigation depth, gross irrigation depth, and irrigation timing for each stage. The schedule represents the scientifically recommended irrigation requirement for the crops under the climatic conditions of Kannur.

## 2.5. Comparison with farmer practice and estimation of irrigation gap

After estimating the recommended irrigation requirement using CROPWAT, it was compared with the actual irrigation practices followed by farmers. The irrigation water applied by farmers was recorded in litres per day (L/day). The FAO CROPWAT recommended irrigation requirement, expressed in mm/decade, was converted into litres per day for each farmer based on the cultivated area and crop duration. This conversion enabled direct comparison between the recommended irrigation requirement and the actual quantity of water applied by farmers under field conditions.

To identify the difference between recommended irrigation and farmers' practices, the irrigation gap was calculated. The irrigation gap represents the difference between farmer-applied irrigation and CROPWAT-estimated irrigation requirement. If the farmer irrigation value was higher than the recommended value, it was considered excess irrigation, whereas if it was lower, it was considered deficit irrigation. Based on the results, irrigation was categorized as Excess irrigation, Deficit irrigation and Optimal irrigation.

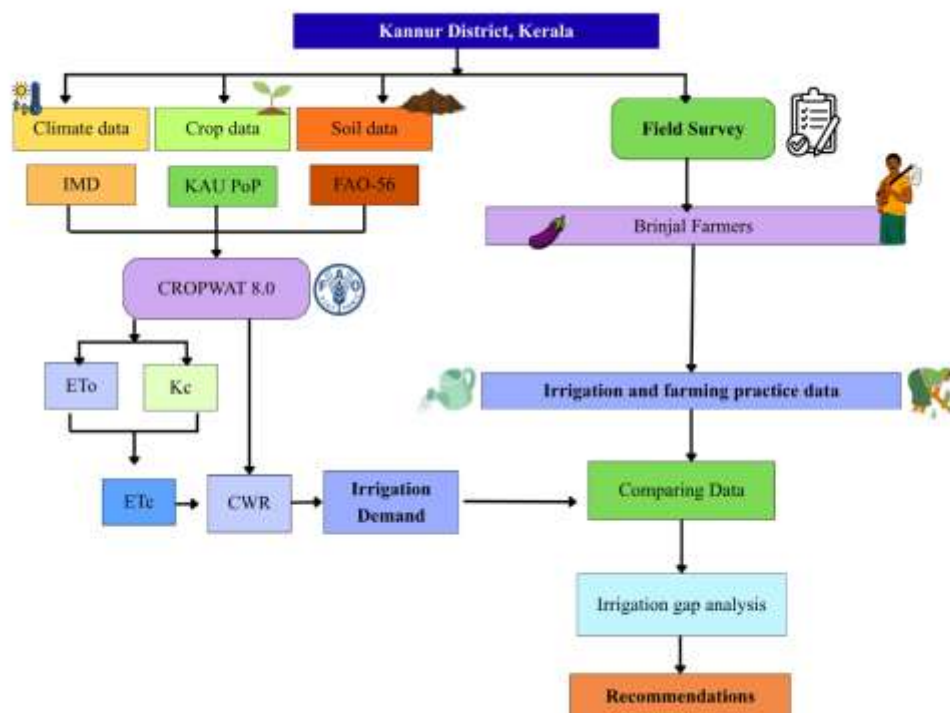


**Fig-2:** Methodology of the work

### 3. Results and Discussion

#### 3.1. Irrigation calculations

##### 3.1.1. Reference Evapotranspiration (ET<sub>0</sub>) estimation

The reference evapotranspiration (ET<sub>0</sub>) in Kannur district, Kerala, were calculated by using long-term climatic data analysis (1994-2024), based on the FAO-56 Penman–Monteith method implemented through CROPWAT (Table 1). The highest ET<sub>0</sub> were recorded in April (4.28 mm/day), which indicated the maximum crop water requirement during the pre-monsoon season. December showed the lowest ET<sub>0</sub> (3.42 mm/day), with a minimum irrigation demand. March exhibited the highest solar radiation (23.9 MJ/m<sup>2</sup>/day), which is accelerating ET. The highest relative

humidity (92%) was recorded in July and lowest maximum temperature (26.8°C), reflecting the influence of monsoon season. January experienced the lowest minimum temperature (17.5°C), whereas May had the highest minimum temperature (21.9°C). Sunshine duration was highest during January–February (9.9 hr/day) and lowest during monsoon months (6 hr/day). The average annual ET<sub>0</sub> of Kannur was estimated as 3.76 mm/day, indicating moderate atmospheric evaporative demand suitable for vegetable cultivation with supplemental irrigation. Seasonal variation in climatic parameters significantly influences irrigation scheduling and crop water requirement of vegetables in Kannur district.

**Table 1:** ET<sub>0</sub> estimation

| Month     | Min Temp (°C) | Max Temp (°C) | Humidity (%) | Wind (km/ day) | Sun hours | Radiation (MJ/m <sup>2</sup> / day) | ET <sub>0</sub> mm/ day |
|-----------|---------------|---------------|--------------|----------------|-----------|-------------------------------------|-------------------------|
| January   | 17.5          | 29.3          | 67           | 1              | 9.9       | 21.4                                | 3.44                    |
| February  | 18.4          | 30.5          | 61           | 1              | 9.9       | 22.9                                | 3.78                    |
| March     | 20.2          | 31.8          | 62           | 1              | 9.6       | 23.9                                | 4.23                    |
| April     | 21.8          | 32.1          | 71           | 1              | 8.2       | 22.2                                | 4.28                    |
| May       | 21.9          | 31            | 80           | 1              | 7.5       | 20.8                                | 4.16                    |
| June      | 20.3          | 28            | 88           | 1              | 6         | 18.2                                | 3.57                    |
| July      | 20.4          | 26.8          | 92           | 1              | 6         | 18.3                                | 3.51                    |
| August    | 20.4          | 27            | 91           | 1              | 6.5       | 19.3                                | 3.67                    |
| September | 20.4          | 27.9          | 89           | 1              | 6.7       | 19.4                                | 3.69                    |

|                 |              |              |              |             |             |              |             |
|-----------------|--------------|--------------|--------------|-------------|-------------|--------------|-------------|
| <b>October</b>  | 20.3         | 28.4         | 88           | 1           | 7.5         | 19.7         | 3.67        |
| <b>November</b> | 19.6         | 28.7         | 83           | 1           | 9.2         | 20.7         | 3.66        |
| <b>December</b> | 18.2         | 28.8         | 75           | 1           | 9.8         | 20.7         | 3.42        |
| <b>Average</b>  | <b>19.95</b> | <b>29.19</b> | <b>78.92</b> | <b>1.00</b> | <b>8.07</b> | <b>20.63</b> | <b>3.76</b> |

### 3.1.2. Crop Evapotranspiration (ETc) Estimation

Total ETc value for brinjal is 350.8 mm for a crop period, indicating the total crop water use for the whole season. This is the gross water demand of brinjal in Kannur for a period is represented in Table 2 and Fig. 3. Effective Rainfall was 254.6 mm that is, the rain that actually contributes to soil moisture. About 72.6% of ETc is met by rain. Total Irrigation Requirement value was 169.1 mm, which is the Net irrigation water needed to supply. The water need isn't constant. It follows the crop growth stages. In the Initial stage Kc = 0.15, ETc = 3.8-5.7 mm/dec. It shows low demand because the canopy is small. Irrigation is needed as effective rain is near zero. In

the development stage Kc rises from 0.18 to 0.83. ETc jumps from 7.4 to 35.2 mm/dec. This is when irrigation demand spikes. Decade 8 has the highest irrigation requirement (42.6 mm/dec). Upon Mid-season Kc peaks at 1.01. ETc is max at 42.6-42.7 mm/dec. This is the critical period. Decade 8 has zero effective rain, so full irrigation of 42.6 mm/dec is needed. Late stage shows Kc drops to 0.71. ETc falls, so effective rain exceeds ETc and the irrigation requirement becomes 0. In the dry period, effective rain is <5 mm/dec for most decades. Irrigation is mandatory. When effective rain jumps to 32.7-68.2 mm/dec, exceeding ETc, no irrigation needed. This shows brinjal in Kannur is feasible as a summer-early kharif crop.

**Table 2:** Crop water requirement estimated by CROPWAT for brinjal

| Decade       | Stage | Kc Coeff. | ETc (mm/day) | ETc (mm/dec) | Eff rain Mm/dec | Irrigation requirement (mm/dec) |
|--------------|-------|-----------|--------------|--------------|-----------------|---------------------------------|
| 1            | Init  | 0.15      | 0.55         | 3.8          | 0.1             | 3.8                             |
| 2            | Init  | 0.15      | 0.57         | 5.7          | 0.0             | 5.7                             |
| 3            | Init  | 0.15      | 0.59         | 4.7          | 0.2             | 4.5                             |
| 4            | Deve  | 0.18      | 0.74         | 7.4          | 3.2             | 4.2                             |
| 5            | Deve  | 0.38      | 1.59         | 15.9         | 4.8             | 11.0                            |
| 6            | Deve  | 0.60      | 2.55         | 28.0         | 4.7             | 23.3                            |
| 7            | Deve  | 0.83      | 3.52         | 35.2         | 1.2             | 34.0                            |
| 8            | Mid   | 1.00      | 4.26         | 42.6         | 0.0             | 42.6                            |
| 9            | Mid   | 1.01      | 4.27         | 42.7         | 12.3            | 30.4                            |
| 10           | Mid   | 1.01      | 4.23         | 42.3         | 32.7            | 9.6                             |
| 11           | Mid   | 1.01      | 4.19         | 41.9         | 46.9            | 0.0                             |
| 12           | Late  | 0.97      | 3.84         | 42.2         | 56.2            | 0.0                             |
| 13           | Late  | 0.81      | 3.06         | 30.6         | 68.2            | 0.0                             |
| 14           | Late  | 0.71      | 2.54         | 7.6          | 23.9            | 0.0                             |
| <b>Total</b> |       |           |              | <b>350.8</b> | <b>254.6</b>    | <b>169.1</b>                    |

Kc Coeff – Crop coefficient

Init – Initial stage of crop growth

ETc – Crop evapotranspiration

Deve – Development stage of crop growth

Eff rain – Effective rainfall

Mid – Mid season stage of crop growth

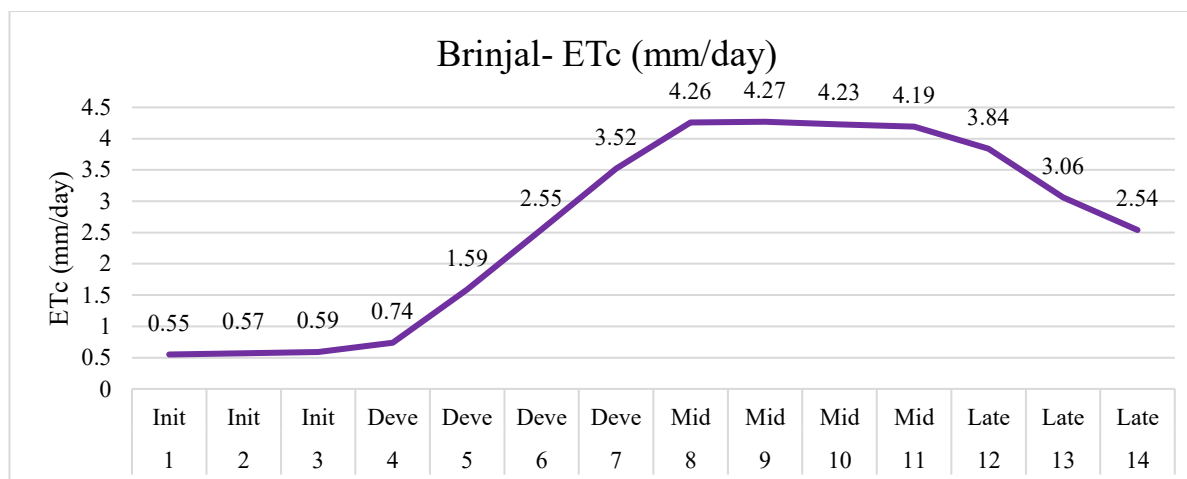


**Fig. 3:** Crop evapotranspiration (ETc) of brinjal across different decades of crop growth period.

### 3.2. Irrigation Schedule

The CROPWAT output indicates irrigation requirement, crop water use, rainfall contribution, irrigation efficiency and expected yield reduction in Table 3. Total gross irrigation is 405.9 mm, and the total net irrigation is 284.2 mm. Irrigation requirement was highest during the initial establishment stage. Water demand increased again during the mid-growth stage, probably due to flowering and fruit development. Brinjal cultivated under loamy soil in Kannur requires approximately 348 mm total crop water, indicating moderate water demand. Actual crop water use (348.0 mm) was nearly equal to the potential crop water requirement (348.3 mm), showing minimal crop water stress. Actual irrigation requirement was only 183.2 mm, suggesting reduced dependence on irrigation due to

effective rainfall contribution. Rainfall efficiency was 24.0%, demonstrating better utilization of rainfall compared to crops with lower rainfall efficiency. Approximately one-fourth of total rainfall contributed effectively to crop growth, reducing irrigation dependence. Irrigation scheduling showed 100% efficiency with only 0.1% deficiency, indicating optimum irrigation management. No moisture deficit occurred at harvest (0.0 mm), suggesting adequate soil moisture throughout the cropping period. Seasonal yield reduction due to water stress was only 0.3%, indicating that proper irrigation management maintained near-maximum yield potential. Higher irrigation demand was observed during initial growth and mid-growth stages, identifying critical periods for irrigation application.

**Table 3:** Crop irrigation schedule for brinjal cultivation

| Day | Stage | Rain (mm) | Ks (fract.) | ETa (%) | Deple (%) | Net irr. (mm) | Gr. Irr (mm) | Flow (l/s/ha) |
|-----|-------|-----------|-------------|---------|-----------|---------------|--------------|---------------|
| 1   | Init  | 0.0       | 0.45        | 45      | 75        | 79.3          | 113.3        | 13.12         |
| 54  | Dev   | 0.0       | 1.00        | 100     | 50        | 63.9          | 91.3         | 0.20          |
| 72  | Mid   | 0.0       | 1.00        | 100     | 52        | 69.9          | 99.8         | 0.64          |
| 98  | Mid   | 0.0       | 1.00        | 100     | 53        | 71.0          | 101.5        | 0.45          |
| END | End   | 0.0       | 1.00        | 0       | 0         |               |              |               |

Total gross irrigation: 405.9 mm

Total net irrigation: 284.2 mm

Total irrigation losses: 0.0 mm

Actual water uses by the crop: 348.0 mm

Potential water uses by the crop: 348.3 mm

Efficiency irrigation schedule: 100.0 %

Deficiency irrigation schedule: 0.1 %

Total rainfall : 688.8 mm

Effective rainfall : 165.1 mm

Total rain loss : 523.7 mm

Moist deficit at harvest : 0.0 mm

Actual irrigation requirement: 183.2 mm

Efficiency rain : 24.0 %

- \*  $K_s$  (fract.) – Soil moisture stress coefficient (fraction)
- \*  $ET_a$  (%) – Actual crop evapotranspiration as a percentage of potential  $ET_c$
- \*  $Deple$  (%) – Soil moisture depletion percentage – the amount of available soil moisture that has been used by the crop
- \*  $Net\ irr.$  (mm) – Net irrigation requirement in millimeters – the amount of water that needs to reach the crop root zone
- \*  $Gr.\ Irr$  (mm) – Gross irrigation requirement in millimeters – the total amount of water to be applied, including losses from efficiency
- \*  $Flow$  (l/s/ha) – Flow rate in liters per second per hectare

The maximum cultivated area (404.70 m<sup>2</sup>) used for brinjal cultivation by Farmer 21, Payyannur, on mixed soil type. Minimum area used is 12.00 m<sup>2</sup> by Farmer 18 from Velloor, Payyannur, using sandy soil. The average area can be seen from the data is 83.56 m<sup>2</sup>, and the total area covered is 1754.85 m<sup>2</sup>. Most farmers operate on small plots. 14 out of 21 farmers cultivate  $\leq 80.94$  m<sup>2</sup>, showing brinjal is mostly a smallholder crop in the study area. 67% of farmers cultivate  $< 100$  m<sup>2</sup>. Brinjal is a subsistence/commercial crop for small landholdings in Kannur. Maximum yield (400 kg) contributed by Farmer 1 and Farmer 21, and the Minimum yield is 10 kg by Farmer 4 and 5, Dharmadam. The Average yield is 91.19 kg, and the Yield range is 10 to 400 kg per reported plot. Higher yield per unit area is achieved by smallholders with intensive management, not just by scaling area. Sandy soil used by 9 farmers with both low (Farmer 2: 60 kg) and high (Farmer 1: 400 kg) yields. Mixed soil used by 11 farmers with a slightly higher average. Only 1 farmer (Farmer 14) cultivated in clay soil, and the yield was 10 kg.

Sandy and mixed soils dominate brinjal cultivation here, likely due to better drainage.

Brinjal white long, *Elle komban*, Mahy 11, Haritha KAU show yields from 10 to 400 kg. Farmer 1 using 'Brinjal white long' got 9.88 kg/m<sup>2</sup>, the highest productivity. Oct-Feb/Dec-Feb is the cropping period selected by most farmers (8 farmers). Peak during winter-early summer. Dec-April/Dec-May (6 farmers) Matches the CROPWAT data, where peak water demand was Feb-April. The May-Aug period is favoured by 2 farmers as an Off-season crop, possibly relying on irrigation. Most farmers avoid the monsoon season (June-Sept). This aligns with brinjal's sensitivity to waterlogging.

Hose pipe is the dominant method used by 17 farmers, but it's also the most inefficient. This leads to non-uniform

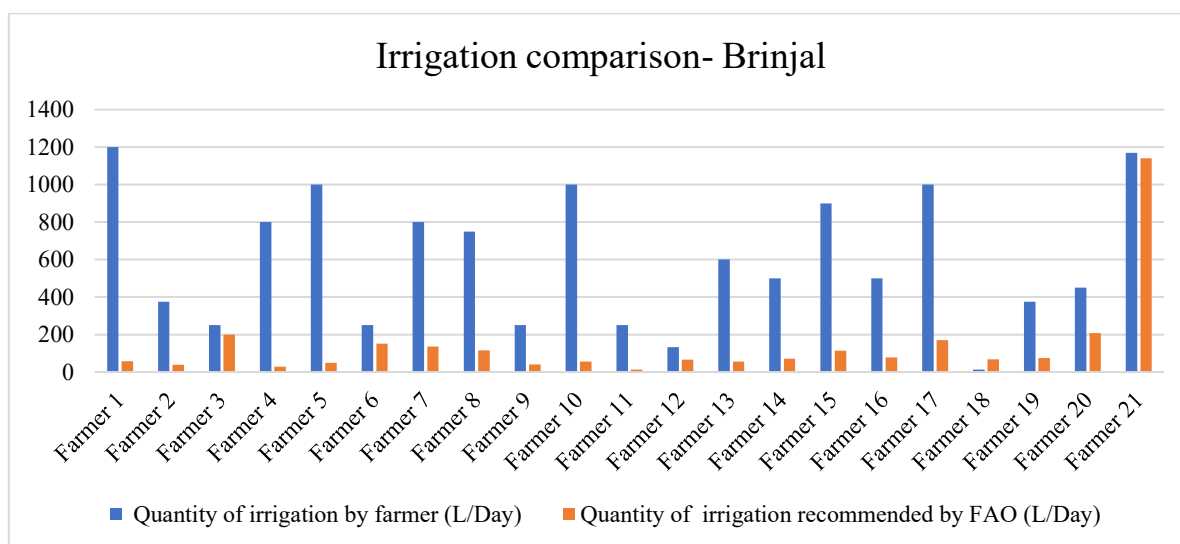
application, runoff, and waterlogging in parts of the field. 4 farmers adopted drip irrigation method, even though it's promoted for water saving. Only one farmer, relying mainly on rain, used 12.5 L/day for the first 30 days. They under-irrigate by 12.5 L/day. This farmer likely depends on monsoon onset and risks yield loss if the rains are delayed. The maximum duration was 250 days by Farmers 9 and 11, and the Minimum 30 days irrigated by Farmer 18. The maximum water used was 1200 L/day (Farmer 1, Hose pipe). The Minimum 12.5 L/day used by Farmer 18. The average duration of days lies between 120 and 138 days.

### 3.3. Comparison with Farmer Irrigation Practice and Estimation of Irrigation Gap

From Table 4, out of 21 brinjal farmers, 20 applied excess irrigation than the FAO recommended rate. It showing that over-irrigation is the dominant practice in the study area (Fig. 4). The excess irrigation ranged from a minimum of 29.4 L/day for Farmer 21 to a maximum of 1142.97 L/day for Farmer 1, indicating wide variability in farmer practices. Farmer 18 was the only farmer who under-irrigated, applying 12.5 L/day instead of the recommended 67.6 L/day, resulting in a deficit of 55.1 L/day. The highest over-irrigation was observed in Farmer 1, who applied 1200 L/day compared to the recommended 57.03 L/day, which is 21 times more than required. Farmers using hose pipe irrigation, such as Farmers 1, 5, and 10, showed the greatest excess, often exceeding 900 L/day above the recommended rate. Drip irrigation users like Farmers 12 and 16 still applied 2 to 6 times more water than needed, suggesting that technology alone did not improve efficiency without proper scheduling. Farmer 21 had the lowest excess of 29.4 L/day, but this was due to a larger plot size, and the per m<sup>2</sup> application was still above optimal levels. The widespread over-irrigation indicates low water use efficiency, with nearly 75% of applied water likely lost through runoff, evaporation, or deep percolation. The pattern shows that farmers are irrigating based on habit and visual judgment rather than crop water requirement or  $ET_c$ -based scheduling.

**Table 4:** Comparison of brinjal farmer's irrigation practice with FAO recommendation

| Farmer ID      | Quantity of irrigation by farmer (L/Day) | Quantity of irrigation recommended by FAO (L/Day) | Remark  | Difference (Quantity in L/Day) | Percentage of Excess/deficit irrigation |
|----------------|------------------------------------------|---------------------------------------------------|---------|--------------------------------|-----------------------------------------|
| Farmer 1       | 1200                                     | 57.029                                            | Excess  | 1142.97                        | 2004.19                                 |
| Farmer 2       | 375                                      | 38.019                                            | Excess  | 336.981                        | 886.349                                 |
| Farmer 3       | 250                                      | 198.938                                           | Excess  | 51.062                         | 25.6673                                 |
| Farmer 4       | 800                                      | 28.991                                            | Excess  | 771.009                        | 2659.48                                 |
| Farmer 5       | 1000                                     | 49.59                                             | Excess  | 950.41                         | 1916.54                                 |
| Farmer 6       | 250                                      | 152.077                                           | Excess  | 97.923                         | 64.3904                                 |
| Farmer 7       | 800                                      | 135.28                                            | Excess  | 664.72                         | 491.366                                 |
| Farmer 8       | 750                                      | 115.991                                           | Excess  | 634.009                        | 546.602                                 |
| Farmer 9       | 250                                      | 41.057                                            | Excess  | 208.943                        | 508.91                                  |
| Farmer 10      | 1000                                     | 56.558                                            | Excess  | 943.442                        | 1668.1                                  |
| Farmer 11      | 250                                      | 13.687                                            | Excess  | 236.313                        | 1726.55                                 |
| Farmer 12      | 133                                      | 66.89                                             | Excess  | 66.11                          | 98.8339                                 |
| Farmer 13      | 600                                      | 56.558                                            | Excess  | 543.442                        | 960.858                                 |
| Farmer 14      | 500                                      | 71.286                                            | Excess  | 428.714                        | 601.4                                   |
| Farmer 15      | 900                                      | 114.058                                           | Excess  | 785.942                        | 689.072                                 |
| Farmer 16      | 500                                      | 78.729                                            | Excess  | 421.271                        | 535.09                                  |
| Farmer 17      | 1000                                     | 171.087                                           | Excess  | 828.913                        | 484.498                                 |
| Farmer 18      | 12.5                                     | 67.64                                             | Deficit | -55.14                         | -81.52                                  |
| Farmer 19      | 375                                      | 74.792                                            | Excess  | 300.208                        | 401.391                                 |
| Farmer 20      | 450                                      | 207.378                                           | Excess  | 242.622                        | 116.995                                 |
| Farmer 21      | 1170                                     | 1140.58                                           | Excess  | 29.421                         | 2.57939                                 |
| <b>Average</b> | <b>598.357</b>                           | <b>139.82</b>                                     |         | <b>458.537</b>                 | <b>776.54</b>                           |


**Fig 4:** comparison of the actual irrigation applied by brinjal farmers with the FAO recommended rate

The findings align with established literature and the Kerala Agricultural University Package of Practices. The peak water demand during flowering and fruiting for brinjal matches the Kc values of 1.0-1.1 recommended by FAO-56 and KAU. The field data show a gap between recommended and actual practices.

The present study revealed a substantial gap between the irrigation volumes applied by farmers and the

scientifically recommended irrigation requirements for brinjal cultivation in Kannur district. In all scenarios examined, farmers applied irrigation in excess of crop water requirements, indicating a tendency towards precautionary over-irrigation. Similar farmer behaviour has been reported in several irrigated production systems, where the perception that "more water ensures higher yields" often overrides scientific irrigation recommendations. However, evidence increasingly

suggests that irrigation beyond crop evapotranspiration requirements provides limited agronomic benefits while generating considerable environmental costs (Prinz & Malik, 2004).

Although Kerala receives high annual rainfall, water scarcity during the dry season has become increasingly evident due to changing rainfall patterns, rising demand across sectors, and declining availability of local water resources (Surendran et al., 2014). Under such conditions, inefficient irrigation practices may intensify pressure on already stressed freshwater systems. The World Bank's comprehensive review of irrigation impacts emphasized that irrigation-related environmental consequences, including groundwater depletion, alterations in hydrological regimes, and off-site ecological effects, often offset some of the gains achieved through enhanced agricultural production (Giordano et al., 2023). The review further highlighted that negative impacts are highly context-specific and tend to become more pronounced where irrigation management is suboptimal.

The excess irrigation observed in the present study may contribute to reduced water productivity, defined as the amount of crop produced per unit of water consumed. In water-limited environments, maximizing water productivity is increasingly recognized as a central objective of sustainable agricultural intensification (Yang et al., 2023). Application of water beyond crop requirements not only represents a direct loss of valuable freshwater resources but may also increase deep percolation losses and nutrient leaching. Prolonged over-irrigation has been associated with waterlogging, soil structural degradation, and salinity development in poorly drained environments, ultimately affecting long-term soil health and agricultural sustainability (Giordano et al., 2023).

From a regional perspective, the implications of over-irrigation extend beyond individual farms. Agricultural water use constitutes the largest share of freshwater withdrawals worldwide, and unsustainable irrigation practices are increasingly recognized as major drivers of water resource depletion. Studies have shown that improvements in irrigation efficiency can substantially alleviate water stress; however, increasing agricultural demands may outpace these gains if inefficient practices persist. For instance, Multsch et al. (2017) demonstrated that although improved irrigation efficiency could reduce pressure on water resources in the Nile Basin, efficiency gains alone would be insufficient to meet future water demands under scenarios of expanding irrigation. Their findings underscore the importance of demand-side management and adherence to crop-based irrigation scheduling. In the context of Kannur district, where competing domestic, agricultural, and ecological water demands coexist during the dry season, reducing unnecessary irrigation applications could contribute significantly to local water conservation efforts.

Another important implication of excessive irrigation is its contribution to agricultural greenhouse gas emissions. Irrigation itself is an energy-intensive activity, particularly where water is lifted using electric or diesel-powered pumps. Applying irrigation volumes beyond crop requirements increases energy consumption without corresponding yield benefits, thereby increasing the carbon footprint associated with crop production (Sapkota et al., 2020). Additional emissions may arise indirectly through enhanced nitrogen losses from irrigated soils. Excess soil moisture can accelerate nitrogen transformations and nutrient losses, necessitate higher fertilizer inputs and increase the environmental burden of production systems.

Recent assessments of agricultural sustainability increasingly advocate integrating water-use efficiency with climate mitigation objectives. Therefore, optimizing irrigation scheduling in vegetable production systems can generate dual benefits by simultaneously conserving freshwater resources and reducing energy-related carbon emissions. Given the growing emphasis on climate-smart agriculture, adoption of scientifically derived irrigation schedules may represent a practical strategy for improving both resource-use efficiency and environmental performance in brinjal cultivation.

The findings of this study highlight the need for targeted interventions aimed at bridging the gap between recommended and actual irrigation practices. Farmer awareness programmes emphasizing crop water requirements, demonstration trials showcasing the benefits of optimized irrigation scheduling, and the promotion of simple decision-support tools could facilitate behavioural change. Furthermore, strengthening extension services to disseminate location-specific irrigation recommendations may help improve water stewardship among vegetable growers in northern Kerala.

Overall, while irrigation remains indispensable for ensuring stable vegetable production during dry periods, the present findings suggest that current farmer practices may undermine long-term water security and increase the environmental footprint of production systems. Transitioning from experience-based irrigation to evidence-based scheduling has the potential to enhance water productivity, reduce unnecessary energy consumption, and support the broader goals of sustainable and climate-resilient agriculture in Kerala.

#### 4. Conclusion

The present study demonstrated that brinjal farmers in Kannur district consistently applied irrigation volumes exceeding scientifically recommended requirements. Although intended to safeguard crop productivity, such over-irrigation may lead to inefficient water use, increased energy consumption, and a higher environmental footprint. In regions experiencing seasonal water stress, these practices could undermine long-term water security and agricultural sustainability.

The findings highlight the need for wider adoption of crop water requirement-based irrigation scheduling to improve water productivity and reduce unnecessary resource use. Strengthening extension support and enhancing farmer awareness regarding efficient irrigation practices could facilitate the transition towards more sustainable vegetable production systems. Optimizing irrigation management offers a practical pathway to conserving freshwater resources while simultaneously contributing to climate-smart agriculture through reductions in irrigation-related carbon emissions.

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