Original Research Article

Quantifying water use efficiency in paddy production for different regions of Thenpennaiyaru river basin (TRB) of Tamil Nadu

Abstract

Agriculture is the world's greatest user and consumer of water. Crop irrigation accounts for two-thirds of all world water withdrawals and 85 per cent of total global water consumption. Today we face major issues on water scarcity which is closely related to "water stress" or "water crisis" is the lack of fresh water resources to meet the standard water demand. Irrigated cropping faces some issues on, decreasing water supply owing to increasing extraction and fewer inflows, as well as increased competition from other users in this context the current study focused on the estimation of crop water use efficiency and irrigation efficiency in the different regions of Thenpennaiyaru river basin (TRB) of Tamil Nadu. As per the Central Water Commission's Basin Report, Thenpennaiyar Basin is the second largest interstate flowing river basin among the 12 basins lying between pennar and Cauvery basins. The river is the main source for irrigating over 38,000 acres in Krishnagiri district; 6250 acres in Dharmapuri district; 17,980 acres in Tiruvannamalai district and 25000 acres in Villupuram district and majority of population depend on this river for agricultural and allied activities. So, this river basin was purposefully selected for the present study with the sample size of (320), to access the efficiency in water usage. As per the result CWUE is better in the head region due to consistent water supply, which is directly dependent on effective management practices, which ultimately have higher efficiency. Irrigation efficiency is most similarly in all three regions. The CWUE is a better indicator when quantifying the efficiency of a crop production system because it directly reflects the amount of grain yield produced per amount of water used rather than per depth of water applied, which is the case with the IWUE.

Key words: Agriculture, Crop water use efficiency, Irrigation water use efficiency, Thenpennaiyar river basin.

1. Introduction

The agricultural, industrial, and domestic sectors all need water. Agriculture is the world's greatest user and consumer of water. Crop irrigation accounts for two-thirds of all world water withdrawals and 85 per cent of total global consumption [13]. Groundwater, lakes, and rivers provide the majority of the water supply. When rain or snow falls as precipitation on the ground, part of the water condenses and becomes surface runoff, which travels horizontally under gravity toward the nearest body of water, such as a stream or lake. Surface runoff is the most major source of water resources. The remainder runs vertically into the earth, filling aquifers, which are pores in soil, sand, clay, or rocks. Groundwater is a kind of water that is becoming increasingly important as a supply of water, albeit it may need pumping to reach the surface.

Water scarcity closely related to “water stress” or “water crisis” is the lack of fresh water resources to meet the standard water demand [9]. Two types of water scarcity have been defined: physical or economic water scarcity. Physical water scarcity is where there is not enough water to meet all demands, including that needed for ecosystems to function effectively. Arid areas (for example Central and West Asia, and North Africa) often suffer from physical water scarcity. On the other hand, economic water scarcity is caused by a lack of investment in infrastructure or technology to draw water from rivers, aquifers, or other water sources, or insufficient human capacity to satisfy the demand for water [10]. Much of Sub-Saharan Africa is characterized by economic water scarcity. The essence of global water scarcity is the geographic and temporal mismatch between fresh water demand and availability [5]. The main driving forces for the rising global demand for water are the increasing world population, improving living standards, changing consumption pattern (for example a dietary shift toward more animal products), and expansion of irrigated agriculture.

Irrigated cropping has additional issues, including decreasing water supply owing to increasing extraction and fewer inflows, as well as increased competition from other users [6]. Water use efficiency can be defined in a variety of ways, depending on the scale of interest (for example, from stomata to catchment) or time scale over which WUE is monitored (for example, from instantaneous gas exchange of leaves to crop season results). Crop WUE is defined as the quantity of harvested commodity generated per unit water made accessible to the crop for the purposes of this evaluation [2]. Improving crop WUE has been a study priority for at least a century [1], with early researchers focusing on "water requirement," or the quantity of water consumed per unit product created. This ratio is the inverse of WUE and may be a more logical explanation of the problem. Agriculture's response to climate change will include the development of new crop varieties to supplement shifting farming techniques. This breeding should be sped up by identifying and deploying relevant target features that increase crop WUE. The physiology and genetics of plant processes and characteristics with the potential to impact crop WUE are continuously growing. With this context the main focus of the study is to estimate crop water use efficiency and irrigation efficiency in the Thenpennaiyaru river basin (TRB) of Tamil Nadu.

2. Materials and Methods

As per the Central Water Commission's Basin Report, Thenpennaiyar Basin is the second largest interstate flowing river basin among the 12 basins lying between pennar and Cauvery basins. Thenpennaiyar river basin lies within the tropical monsoon zone. Based on the hydrometeorological features of the basin, it is divided into two periods (i.e.,) 1) Monsoon period spanning from June to December and 2) Non-monsoon period spanning from January to May. The monsoon period is further sub-divided into Southwest monsoon period spanning from June to September (4 months) and Northeast monsoon period spanning from October to December (3 months). Similarly, the non-monsoon period is further sub-divided into winter period spanning from January & February (2 months) and summer period spanning from March to May (3 months). The monsoon period is hydrological significant for water resources analysis. The River is the main source for irrigating over 38,000 acres in Krishnagiri district; 6250 acres in Dharmapuri district; 17,980 acres in Tiruvannamalai district and 25000 acres in Villupuram district and majority of population depend on this river for agricultural and allied activities. It is also the main source of drinking water to more than 100 villages along its route. So this river basin was purposefully selected for the present study to access the efficiency in water usage.

The study area is shown in Figure 1. To estimate irrigation efficiency and crop water use efficiency in Thenpennaiyaru river basin which was classified as head, middle and tail regions. Taking into consideration the purpose and data requirement of the study, the period of study was fixed i.e. the agricultural year 2021 - 2022. The field enquiry was made during the months of January to May 2021.

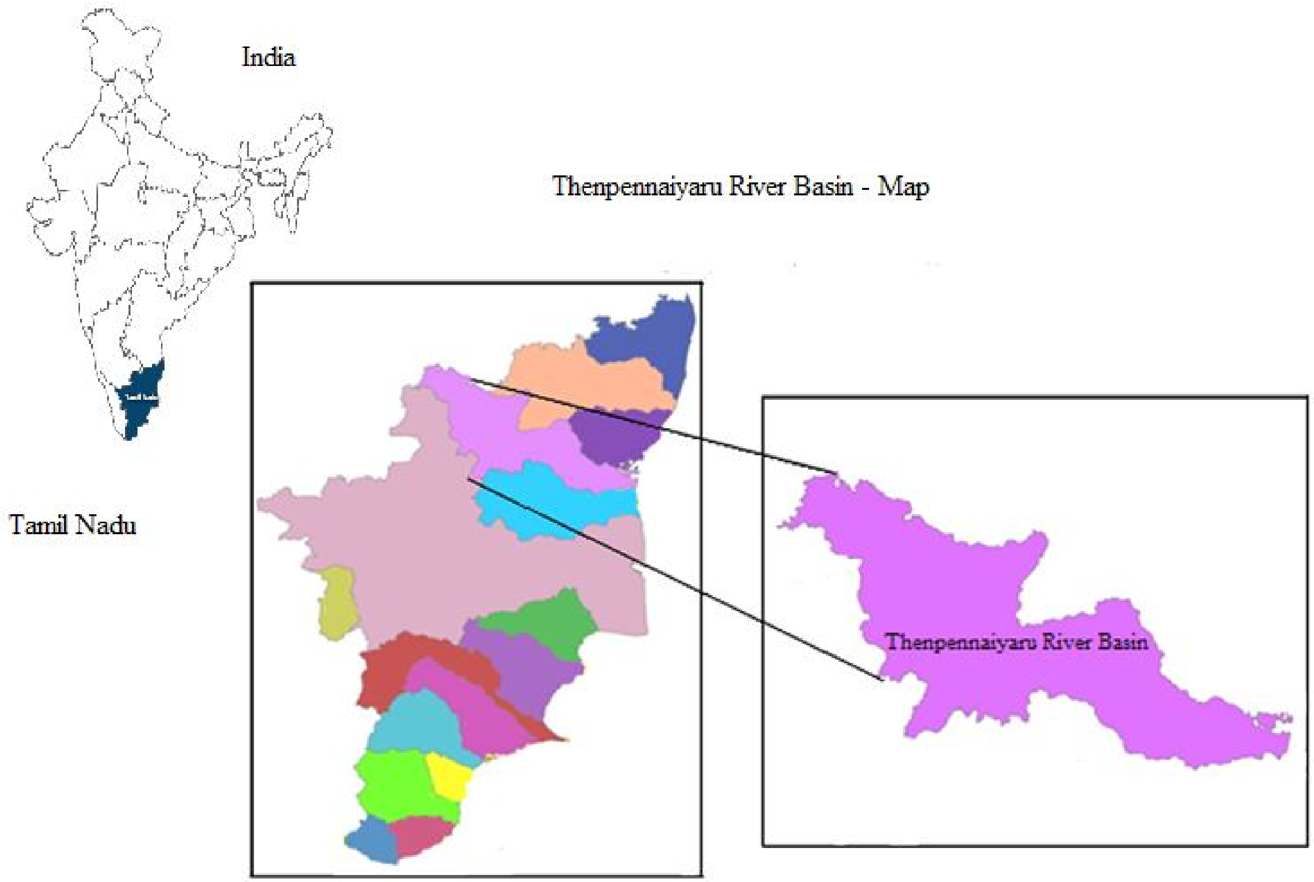

Figure.1. Study area Thenpennaiyaru river basin of Tamil Nadu

2.1 Design of interview schedule

A reconnaissance survey was taken before shaping the research problem and the researchers met the farm households in person to collect some issues about the varying water supply on the river basin and their water demand for and groundwater dependency for irrigation, and additional information gathered and personal observation were made during the preliminary survey formed the basis for developing hypotheses. Based on the preliminary survey, interview schedule was prepared and pretested to evaluate its field applicability with some selected respondents and the final version of the questionnaire was prepared to perform the inquiry with sample respondents size (N=360).

2.2 Methods of inquiry

Efforts were made to obtain realistic data from the sample by convincing them that the study was undertaken for research purpose. Cross verification of data was done then and there through crosscheck questions to ascertain the reliability and validity of data collected from farmers.

2.3 Sources and nature of data

2.3.1 Primary Data

The detailed information was collected from the respondents involved in water usage from river basin with the aid of structured and pre tested schedules, covering the following aspects. General information, information regarding size of the land holdings, sources of irrigation, details of wells, crop wise particulars of well command, number of bore well in command area, cropping pattern under rain fed condition, river basin water use, ground water use, number of stress days, number of irrigation and irrigation duration.

2.3.2 Secondary Data

Besides primary data the general information were collected through secondary data source related to geographic location, cropping pattern, rainfall, Max-Min temperature, wind velocity, sunshine, sources of irrigation, distribution of tube wells, capacity of reservoir, classification of area, available groundwater resources and other related details were obtained from the following departments - Directorate of Economics and Statistics, Department of Agriculture, Tamil Nadu State Groundwater Authority and Central Groundwater Board, Government of India.

2.4 Tools

2.4.1 Cropping Intensity

It is the ratio of gross cropped area to net cropped area and is expressed in percentage.

$$\text{Cropping Intensity (CI)} = \frac{\text{Gross cropped area}}{\text{Net cropped area}} \text{ X } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2.4.2 Irrigation Intensity

It is the ratio of gross irrigated area to net irrigated area and expressed in percentage.

$$\text{Irrigation Intensity (II)} = \frac{\text{Gross irrigated area}}{\text{Net irrigated area}} \text{ X } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

2.5 Economic Analysis

2.5.1 Crop Water Use Efficiency (CWUE)

Crop water use efficiency (CWUE) is used to characterize crop yield in relation to total depth of water applied for irrigation [4]. Crop WUE is mostly used to define irrigation effectiveness as a ratio of biomass accumulation expressed as total crop biomass yield or economic yield to consumed water expressed as ET or total water use [12]. It is expressed as follows:

$$\mathbf{CWUE} = \frac{\mathbf{Y}}{\mathbf{ET}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{3})$$

CWUE = Crop Water Use Efficiency

Y = Economic Yield

ET = Evapotranspiration

It is expressed in kg/ha/mm

2.5.2 Irrigation Water Use Efficiency (IWUE)

Irrigation water use efficiency (IWUE) is used to characterize crop yield in relation to total depth of water applied for irrigation. It is expressed as follows:

$$\mathbf{IWUE} = \frac{\mathbf{Y}}{\mathbf{IR}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{4})$$

IWUE = irrigation water use efficiency (bu/acre-inch)

Y = Economic yield of the irrigation level crop (bu/acre)

IR = Depth of irrigation water applied for irrigation (inch)

3. Result and Discussion

3.1 Cropping pattern and cropping intensity

Paddy (55.04 per cent) is high water-consuming crop cultivated dominantly in the head of the river basin, which is cultivated more than half of the gross cropped area. It is followed by the cultivation of tomatoes (25.53 per cent) and groundnut (7.63 per cent).

Sugarcane (27.13 per cent) is cultivated in nearly half of the area in the Middle region and water-loving paddy (37.04 per cent). Like the head region, paddy (34.98 per cent) is cultivated dominantly in the tail region, followed by sugarcane cultivation (29.23 per cent).

A significant proportion of the area under water-loving crops forces the farmer to invest more in wells. Table 1 shows that paddy is cultivated dominantly in the all three region which is the reason for high demand for irrigation water. The cropping intensity is 119.96, 145.81 and 132.79 in the head, middle and tail regions.

Table 1. Cropping pattern and cropped area of the sample farmers

(Hectares)

Region/ Crops	Head region (n=120)	Middle region (n=120)	Tail region (n=120)
Paddy	377.89 (55.04)	233.57 (37.04)	320.59 (34.98)
Tomato	206.65 (25.53)	.. ..	.. ..
Tapioca	.. ..	128.68 (25.87)	93.75 (14.87)
Cotton	.. ..	100 (10.01)	17.65 (2.57)
Groundnut	52.35 (7.63)	108.39 (17.00)	82.69 (13.11)
Sugar crop	.. ..	200.48 (27.13)	132.30 (29.23)
Gross Cropped Area	636.89	771.12	646.98
Net Sown area	572.54	437.23	474.89
Cropping intensity (per cent)	119.96	145.81	132.79

Source: Primary data collection (2021)

Note: Cropping intensity is the ratio of gross cropped area to the net sown area and is expressed in percentage.

3.2 Methods of irrigations

The method of irrigation explains the reason for the high consumption of water. Adoption of water management practices reduces water consumption [8]. The gross irrigated area is higher in the head regions followed by the middle region and tail regions. Large farmers have more gross cropped area (206.91 ha, 233.77 ha, and 219.15 ha) respectively in head region, middle region and tail region). In the head region, large farmers are adopting drip irrigation for (9.45 ha), while medium farmers for (16.63 ha). The area under flood irrigation (421.65 ha) is higher than basin (121.89 ha) and drip irrigation (34.02 ha) in the head region. In the middle region, basin irrigation was adopted for 286.17 ha of land followed by drip irrigation (152.59 ha) presented in (Table 2). The area under basin irrigation is higher in the tail region.

The large farmers of tail region have large areas under drip irrigation than large farmers of other regions. These values explain the reason for decreased water flow.

Table 2. Methods of irrigations across the study area

(Area in ha)

Region/ Landholding size in ha	**Head region**				**Middle region**				**Tail region**			
	Basin	Flood	Drip	GIA	Basin	Flood	Drip	GIA	Basin	Flood	Drip	GIA
Marginal (<1 ha)	28.45 (23.34)	34.23 (8.12)	2.42 (7.11)	65.10 (11.67)	29.36 (10.26)	11.25 (9.88)	10.35 (8.24)	50.96 (9.22)	25.26 (10.79)	9.56 (8.91)	25.53 (12.78)	60.35 (11.15)
Small (1-2 ha)	50.25 (41.23)	78.27 (18.56)	5.52 (16.23)	134.04 (23.21)	45.97 (16.06)	12.39 (10.88)	39.01 (31.06)	97.37 (17.62)	35.26 (15.07)	23.87 (22.25)	36.92 (18.48)	96.05 (17.75)
Medium (2-4 ha)	29.56 (24.25)	125.32 (29.72)	16.63 (48.88)	171.51 (29.70)	96.21 (33.62)	45.63 (40.06)	28.74 (22.88)	170.58 (30.87)	76.25 (32.58)	31.24 (29.13)	57.98 (29.03)	165.47 (30.58)
Large (>4 ha)	13.63 (11.18)	183.83 (43.60)	9.45 (27.78)	206.91 (35.82)	114.63 (40.06)	44.65 (39.20)	74.49 (59.31)	233.77 (42.30)	97.26 (41.56)	42.59 (39.71)	79.30 (39.70)	219.15 (40.51)
All categories	121.89 (100)	421.65 (100)	34.02 (100)	577.56 (100)	286.17 (100)	113.89 (100)	152.59 (100)	552.65 (100)	234.03 (100)	107.26 (100)	199.73 (100)	541.02 (100)

Source: Primary data collection (2021)

Note: Figures in the parentheses indicate the percentage of the total area.

Irrigation intensity

The intensity of irrigation is defined as the per cent of annually irrigated area and the irrigation intensity per farm is defined as about the per cent of irrigated area per farm annually [3]. The irrigation intensity is (128.67 per cent) per well and 130.30 per cent per farm for the head region. The irrigation intensity per well is higher for large farmers (14 per cent) but the irrigation intensity per farm is higher for marginal farmers (187.67 per cent). Medium farmers (152 per cent) have higher irrigation intensity per well and the marginal farmers (214.50 per cent) have higher irrigation intensity per farm in the middle region which is similar to the tail region (Table 3).

Table 3. Irrigation intensity

Regions/ Landholding size in ha	Head region						Middle region						Tail region					
	GIA		NIA		Irrigation intensity (per cent)		GIA		NIA		Irrigation intensity (per cent)		GIA		NIA		Irrigation intensity (per cent)	
	Per well	Per farm	Per well	Per farm	Per well	Per farm	Per well	Per farm	Per well	Per farm	Per well	Per farm	Per well	Per farm	Per well	Per farm	Per well	Per farm
Marginal (<1 ha)	0.73	1.37	0.75	0.73	97.33	187.67	0.91	1.33	0.75	0.62	121.33	214.52	0.51	0.73	0.50	0.43	100	167.77
Small (1-2 ha)	1.15	2.33	1.50	1.47	76.67	164.29	1.48	2.51	1.00	1.46	148.00	171.91	1.12	1.42	0.75	1.12	157.14	126.79
Medium (2-4 ha)	1.79	4.11	1.50	3.12	119.33	132.25	1.52	4.06	1.00	2.43	152.00	167.08	1.02	2.64	0.75	2.28	142.86	115.79
Large (>4 ha)	2.86	8.60	2.00	7.24	143.00	119.44	2.17	6.50	1.50	4.96	144.67	131.05	2.14	6.43	1.00	5.38	210.00	121.37
All categories	1.84	4.30	1.43	3.32	128.67	130.30	1.55	3.36	1.06	2.11	146.23	159.24	0.90	1.59	0.75	1.23	128.57	129.27

Source: Primary data collection (2021)

3.3 Crop Water Use Efficiency (CWUE)

Crop WUE is mostly used to define irrigation effectiveness as a ratio of total crop biomass yield or economic yield to consumed water expressed as ET or total water use [12]. Crop production is affected by a variety of inputs and management factors. The most important input is irrigation water, which is directly related to crop management; hence, crop yield varies among regions due to differences in the water supply.

Variables used in crop yield

The inputs used in Rice yield varied significantly between the head, middle, and tail regions of the command area (Table 4), with the head region producing 50.62 quintals per heater, which is comparable to the tail region's 49.37 quintals per heater, and the middle region producing 47.30 quintals per heater, which is less than the other two regions due to its reliance on ground water.

Irrigation in cm/crop is greater in the head region because surface water availability is greater in the head, where more than 90 per cent of the water used is surface water. In the tail region, 85 per cent of irrigation comes from surface water, but in the middle region, more than 30 per cent of irrigation is from ground water.

The average nitrogen application rates in all three regions were identical (142 kg/ha). In fact, it would be desirable to use lower N-rates in water-deficient regions due to their substantial negative impact on rice yield [14].

Similarly, labour contributions varied somewhat among these three regions. This is likely owing to the fact that farmers overuse labour in the head area relative to the middle and tail regions, without substituting water for labour, particularly in weeding operations.

The level of crop management was significantly higher in head region (18/20), indicating that water is a complementary factor to management.

Evapotranspiration is the amount of water lost due to evaporation and transpiration; this data is computed using Cropwat 8.0 and data on maximum and minimum temperature, wind velocity, and sunlight were acquired from a nearby weather station shown in Table 5. The monthly Evapotranspiration rate in mm is presented as chart in Figure 2. Crop water use efficiency is represented as kg/ha/mm.

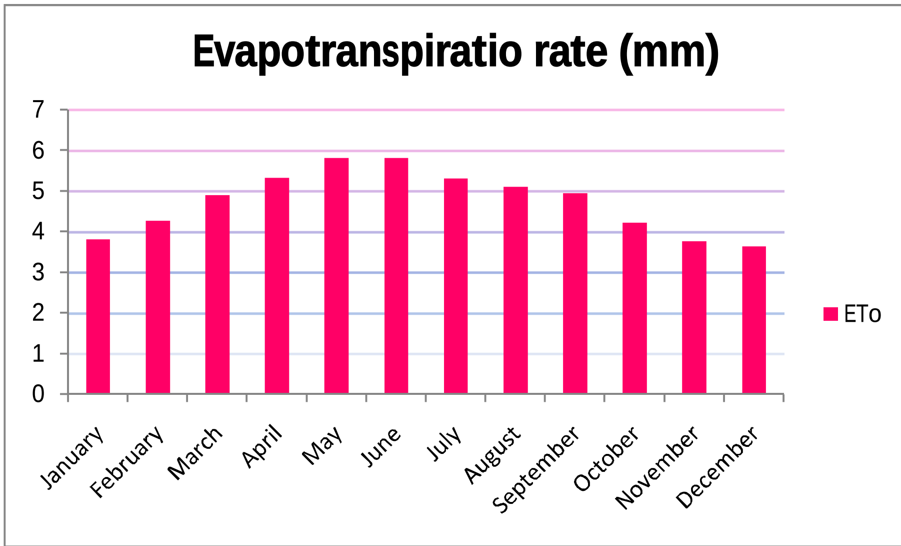

Figure 2. Monthly Evapotranspiration ETo Chart

The Crop water use efficiency (CWUE) is higher in the head region 12.34 followed by the tail region 10.41 and in the middle region we have significantly less which is 8.15 presented in Figure 3. Crop water use efficiency is better in the head region due to consistent water supply, which is directly dependent on effective management practices, which ultimately have higher efficiency. Irrigation efficiency is most similarly in all three regions shown in Table 6.

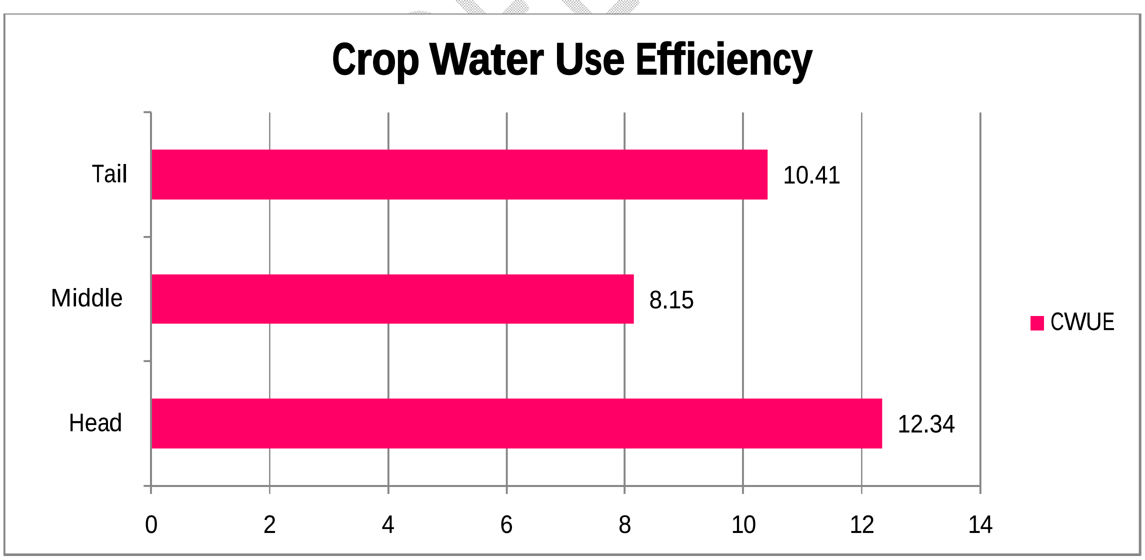

Figure 3. Crop Water Use Efficiency in the head, middle and tail region of Thenpennaiyaru River Basin (TRB)

Table 4. Input used and rice yield in Head, Middle & Tail region

Inputs	units	Head		Middle		Tail	
		quantise	cv	quantise	cv	quantise	cv
Tank water	cm	113	0.0035	88.3	0.0038	95.15	0.0056
Well water	cm	9.80	0.0263	27.15	0.0123	23.75	0.0188
Nitrogen use	kg/ha	145.95	0.0039	144.5	0.0027	139.75	0.0087
Labour use	days/ha	130.6	0.0049	124.55	0.0051	129.7	0.0090
Crop management	index	18	0.0121	16.07	0.0152	17.95	0.0118
Rice yield	q/ha	50.625	0.0055	47.30	0.0095	49.37	0.0221

Source: Primary data collection (2021)

Table 5. Monthly ETo Penman-Monteith Data

Month	Min °C	Max °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	20.8	27.9	77	173	8	18.8	3.8
February	21.2	29	75	164	8.5	20.8	4.26
March	22.9	30.8	74	156	9.1	23.1	4.9
April	25.7	32.8	74	181	8.7	23	5.32
May	27.1	35.7	69	199	8.3	21.9	5.8
June	27	36.9	61	181	7.2	19.9	5.82
July	26.1	35.4	63	173	6.1	18.4	5.31
August	25.4	34.5	67	156	6.6	19.5	5.1
September	25.1	33.8	70	138	7.1	20	4.94
October	24.3	31.5	76	112	6.8	18.7	4.21
November	22.8	29	79	164	6.8	17.2	3.75
December	21.5	27.9	77	181	7.2	17.2	3.64
Average	24.2	32.1	72	165	7.5	19.9	4.74

Source: Penman-Monteith Data (2021)

Table 6. Crop Water Use Efficiency and Irrigation Efficiency in different region of Thenpennaiyaru River Basin (TRB)

Particulars	**Head**	**Middle**	**Tail**
CWUE (quintals/ha/mm)	12.3475	8.1551	10.4156
IWUE (percentage)	0.4122	0.4097	0.4152

4. Conclusion

As available water resources become more limited, greater emphasis is placed on effective irrigation water usage for optimal economic return and water resource sustainability [11]**.** Crop water stress and yield decrease come from insufficient irrigation application. Excessive irrigation can pollute water sources owing to the loss of plant nutrients through leaching, runoff, and soil erosion [7]. The CWUE is a better indicator when quantifying the efficiency of a crop production system because it directly reflects the amount of grain yield produced per amount of water used rather than per depth of water applied, which is the case with the IWUE [4]. This is because not all irrigation water applied to the field is used for crop ET. Thus, IWUE does not account for the irrigation application losses and actual water used by the crop.

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