Estimating Water Needs of Paddy and Finger Millet using NDVI and Empirical Models in the Hemavathi Command Area

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***Abstract* - Sustainable agriculture is needed for the adequate use of water during the present water scarcity scenario. In this aspect, crop water requirement plays a crucial role. In the present study, an attempt has been made for the estimation of crop water requirement of the two major crops grown in the Distributary 71 and 72 of Hemavathi Left Bank Canal which cover in Nagamangala taluk of Mandya district. CWR are estimated using empirical method and Normalized Difference Vegetation Index method and their comparison has been made. In empirical method, FAO Penman-Monteith equation model has been used to estimste ET_o. While in NDVI method, K_c has been estimated by NDVI using CROPWAT model. The crop water requirement for paddy is 624.06 mm/dec from empirical method and 503.80 mm/dec from NDVI method and for finger millet, it is 287.40 mm/dec and 285.13 mm/dec from empirical method and NDVI method respectively. The study demonstrates that ET_o of both the crops estimated from empirical and NDVI method are almost similar and does not show much variation. Also, the CROPWAT model is helpful in estimating crop water requirements of any irrigation project.**

***Keywords:* Crop Evapotranspiration, CROPWAT, Reference Evapotranspiration, Crop water requirement, NDVI, Hemavathi Command Area**

I. INTRODUCTION

Agriculture remains a cornerstone of India's economy, serving as the primary source of livelihood for nearly half of the country's population. Rapid population expansion and increasing water scarcity accelerate pressure on irrigation management to increase food production and productivity by utilizing water resources more proficiently for irrigation. So, the estimation of crop water requirement (CWR) and irrigation water requirement (IWR) plays a vital role for effective water management. Water is an important input for plants in many ways. To estimate evapotranspiration, empirical methods have been proposed because directly measuring of actual evapotranspiration is currently impossible for a particular location and characteristics of each land cover. Crop coefficient (K_c) based analysis of evapotranspiration is utilized for irrigation water management. Also, 70% of plant body constitute water. It helps in softening of seeds for rooting. Plants adsorb nutrients such as nitrogen, phosphate and potassium dissolved with water from the soil. Water is also important for photosynthesis. Nearly 95% of water is transpired through leaves and stems which help in cooling the plants in hot weather and without which plants wilt and die [1]. Due to the increase in water scarcity, there has been increased pressure on irrigation engineers for the efficient utilization of water resources for irrigation [2]. Kc is a key parameter for evaluating crop evapotranspiration. CWR is the quantity of water needed to compensate for the water loss by evapotranspiration (ETc) of a disease-free, healthy crop growing in vast fields with unrestricted soil conditions. Both CWR and ETc concepts can be put in an application to irrigated and rain-fed crops. To ensure the complete fulfillment of crop water requirements (CWR) for irrigated crops, it is essential to complement the CWR concept with the Irrigation Water Requirement (IWR) approach. Those fraction of CWR which is not satisfied by soil water storage, rainfall and groundwater contribution is considered as the IWR. The total evapotranspiration for the entire crop growing period is known as CWR. Reference evapotranspiration (ETo) and crop coefficient (Kc) values for specific crops are used to estimate crop evapotranspiration (ETc), which is a measure of crop water demand that is influenced by weather and crop circumstances [3].

An accurate, economical, and efficient method for determining agricultural water demand is satellite-based remote sensing. The integration of GIS and remote sensing technologies offers powerful tools for various aspects of agricultural monitoring and management. These tools enable accurate crop identification, assessment of crop health and cultivated area, estimation of crop evapotranspiration, analysis of soil and water conditions, and prediction of weather and climate change. Such insights are essential for precision farming, irrigation scheduling, and related agricultural practices. This information plays a vital role in smart irrigation planning and management, promoting efficient water use and increased food production. Among these tools, the Normalized Difference Vegetation Index (NDVI), which is closely linked to evapotranspiration, has been

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extensively utilized for evaluating crop yield, detecting drought conditions, and monitoring vegetation health. In the present study, an effort is put together to understand the association between NDVI and K_c value to estimate ET_c resulting in the computation of crop water requirement through empirical method, Normalized Difference Vegetation Index (NDVI) vegetation index and CROPWAT 8.0 software for two different crops specifically paddy and finger millet and comparison of these two crops.

II. STUDY AREA AND DATA USED

Hemavathi river origin at Western Ghats at an elevation of 1,219 m above mean sea level near Ballala Rayana Durga in Chikmangalur District, Karnataka. Hemavathi Left Bank Canal (HLBC) off takes from Gorur dam constructed across Hemavathi river in Hassan District at 76º03’0” E longitude and 12º45’0” N latitude with live storage of 32.731 TMC. The Hemavathi command area has covered four districts i.e., Hassan, Mandya, Mysuru and Tumkuru. The land use is distinguished by agricultural lands, plantation and forests. In the study area, the cultivation of large variety of crops is achievable due to the presence of loamy structured red soils. Mandya district in Karnataka which is a part of the Cauvery river basin is usually falls under the semi-arid region. Annual rainfall in the district has fluctuated over the last few decades, with some years seeing as little as 298 mm and others seeing as much as 1,192.9 mm (Arpitha et al., 2023). In certain years, this unpredictability has resulted in moderate drought seriously affecting water availability and crop production. Thus, the estimation of Crop Water Requirement (CWR) and Net Irrigation Requirement (NIR) is crucial for effective irrigation and water management (Chandra et al., 2019). The location map of the study area is displayed in the Figure 1.

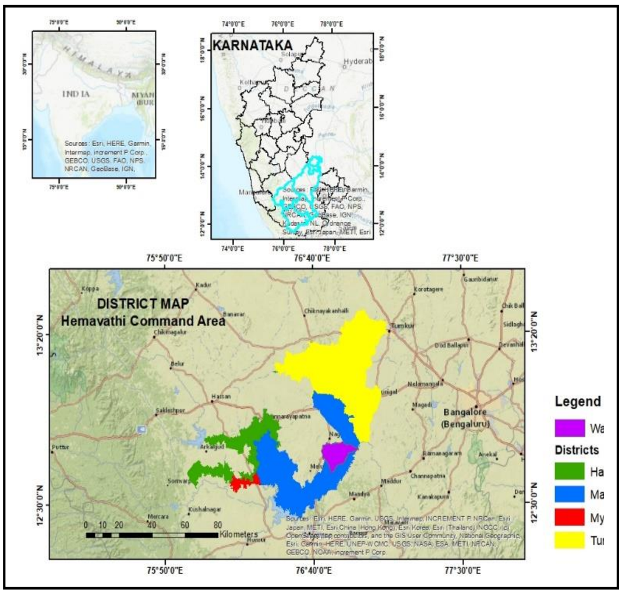

Fig. 1. Location map of Hemavathi Command Area

Hemavathi river has two canal namely Hemavathi Right Bank Canal (HRBC) and Hemavathi Left Bank Canal (HLBC). In the HLBC, there are 72 distributaries. For the present study, distributary 71 and 72 have been considered because they irrigate a large area and comes under one watershed. The distributaries D71 and D72 of the HLBC comes under Nagamangala taluk, Mandya district.

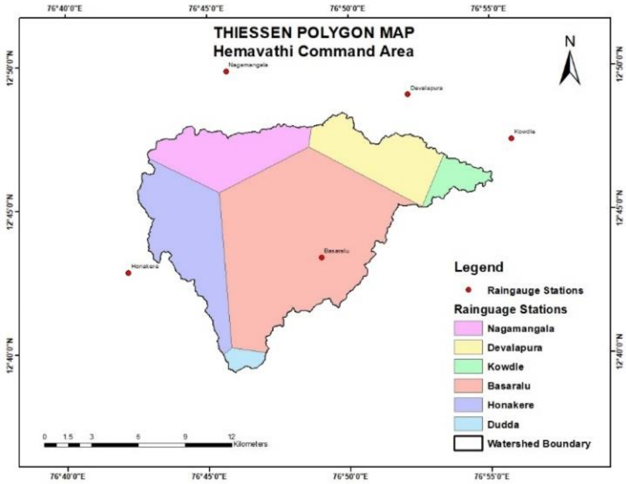

Fig. 2. Thiessen Polygon Map of the study area

Thiessen polygon is drawn to find out the influencing rain gauge stations. Thiessen Polygon Map of the study area is displayed in Fig.2. Basaralu, Devalapura, Honakere, Kowdle and Nagamangala raingauge stations are influencing the study area. Among these, Basaralu, Devalapura, Honakere and Nagamangala are weather stations. Geographical location of the influencing rainguage stations are shown in Table 1. The Thiessen weights of these stations within the area of influence are shown in Table 2.

Table 1 Geographical location of influencing Rainguage Stations of Hemavathi Command Area under Nagamangla Taluk

Sl.No.	Name of the Rain Guage Stations	Geographical Location	
		Latitude (N)	*Longitude (E)*
1	Basaralu	12°43'16.74"	76°49'0.07"
2	Devalapura	12°48'55.31"	76°52'5.41"
3	Honakere	12°42'47.62"	76°42'9.19"
4	Kowdle	12°47'23.61"	76°55'46.44"
5	Nagamangala	12°49'47.67"	76°45'38.63"

The details of data products used in the present study are displayed in Table 3.

Table 3 Details of data products

S.No.	Data	Details
1	SOI Toposheets on 1:50,000 scale	No.- 57C/16, 57C/15, 57C/11, 57C/8, 57C/12, 57C/16, 57D/5, 57D/1, 57D/9, 57D/14, 57D/13, 57D/11, 57D/10, 57D/7, 57D/6, 57D/2, 57G/4, 57G/3, 57H/1, 48P/13, 48P/14.
2	Satellite Data	Sentinel -2 (10 m resolution)
3	Meteorological/ Climate Data	Minimum & Maximum temperature, Wind speed, Humidity, and Sunshine hours
4	Rainfall Data	Daily Rainfall Data from 2000 to 2022
5	Soil Data	Maximum rooting depth, maximum rain infiltration rate, and total soil moisture availability
6	Crop Data	Values of the crop coefficient (Kc) for various stages

For the present study, Arc GIS 10.4 software which is developed by ESRI, ERDAS Imagine 9.1 and Google Earth Pro are used.

Table 2 Thiessen weights of Hemavathi Command Area

Sl.No.	Rainguage Station Name	Area of Thiessen polygon (km^2)	Area (%)	Thiessen Weights
1	Basaralu	43.64	8.29	0.0829
2	Devalapura	106.27	20.20	0.2019
3	Honakere	40.15	7.63	0.0763
4	Kowdle	19.75	3.75	0.0375
5	Nagamangala	61.68	11.72	0.1172

III. METHODOLOGY

The methodology which is considered for evaluation of ETo and CWR through NDVI and empirical method for comparative study are displayed as flowchart Fig.3.

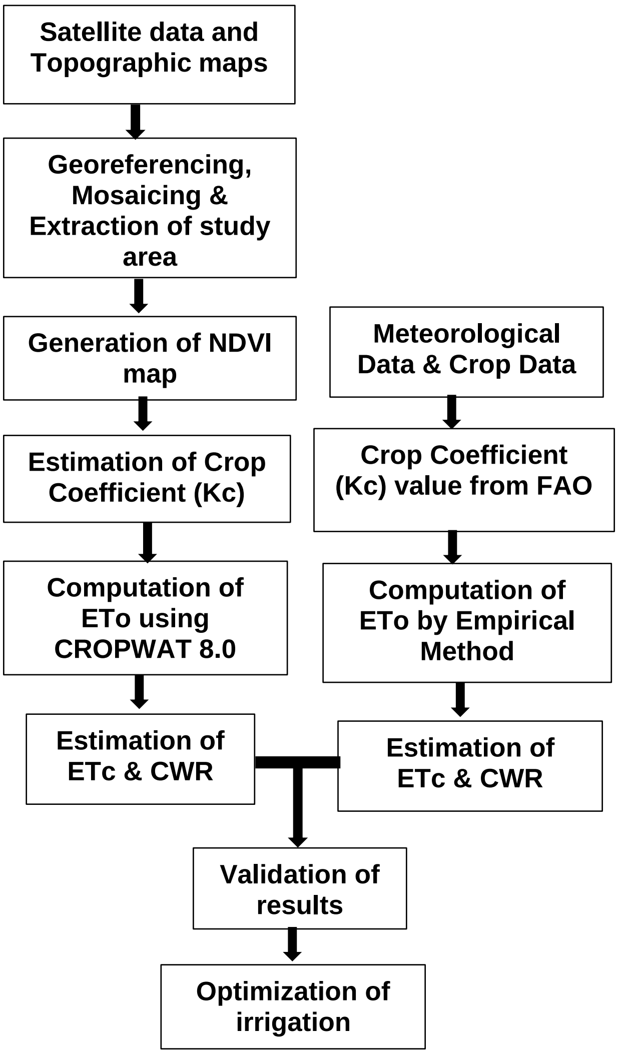

Fig. 3. Methodology for evaluation of CWR and optimization of irrigation

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A. Reference Evapotranspiration (Et_o)

The daily meteorological/climate data which includes minimum & maximum temperature, wind speed, humidity and sunshine hours are collected from KSNDMC, Bangalore for 2022 year. After that, these data are used for estimating reference evapotranspiration (ET_o) empirically by FAO,56 Penman-Monteith equation and by CROPWAT 8.0 for 2022 [4]. The FAO Penman-Monteith equation is given as,

$$ETo = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U2\ (es-ea)}{\Delta+\gamma(1+0.34u2)} \tag{1}$$

where ET_o = reference evapotranspiration [mm day-1],Rn = net radiation at the crop surface [MJ m-2 day-1],G = soil heat flux density [MJ m-2 day-1],T = mean daily air temperature at 2 m height [°C],es = saturation vapour pressure [kPa],ea = actual vapour pressure [kPa],(es–ea) = saturation vapour pressure deficit [kPa],Δ= slope vapour pressure curve [kPa °C-1],γ = psychrometric constant [kPa °C-1].

B. Calculation of Crop coefficient (K_c)

The crop coefficients of both paddy and finger millet are estimated from FAO,56 and also from the remote sensing acquired vegetation index which is demonstrated as follows:

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \tag{2}$$

The Normalized Difference Vegetation Index (NDVI) is widely used to assess vegetation health and density. It ranges from -1 to 1, where values near 1 indicate dense, healthy vegetation, and negative values correspond to non-vegetated surfaces. Higher NDVI values reflect greater vegetation greenness and cover.

For Sentinel 2 satellite data NDVI is as follows,

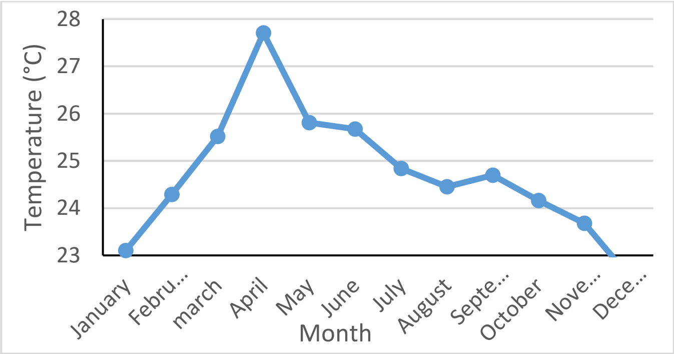
$$NDVI = \frac{(B8 - B4)}{(B8 + B4)} \tag{3}$$

C. K_c- NDVI RELATIONSHIP

An equation for obtaining from NDVI is proposed by Akdim et al. [7], is given as:

$$Kc = 1.25 * NDVI + 0.2 \tag{4}$$

where the value of spectral crop coefficient K_c ranges from 0.15 – 1.20 and it can be assimilated to the FAO 56 crop coefficient and NDVI is calculated from sentinel-2 bands. The hydrometeorological data including mean temperature, relative humidity, wind speed and sunshine hours for Basaralu, Devalapura, Honakere and Nagamangala weather stations for the year 2022 are shown in Fig. 4,5,6 and 7.



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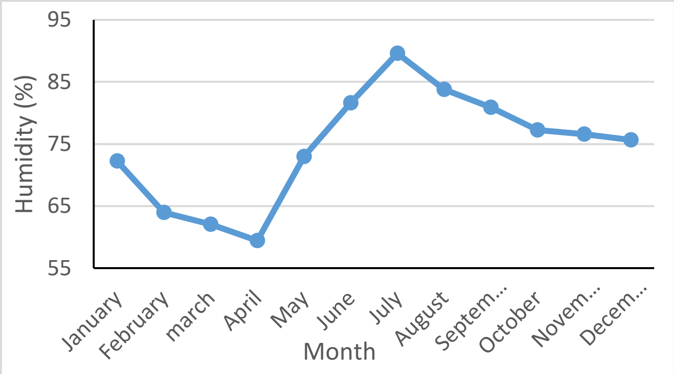

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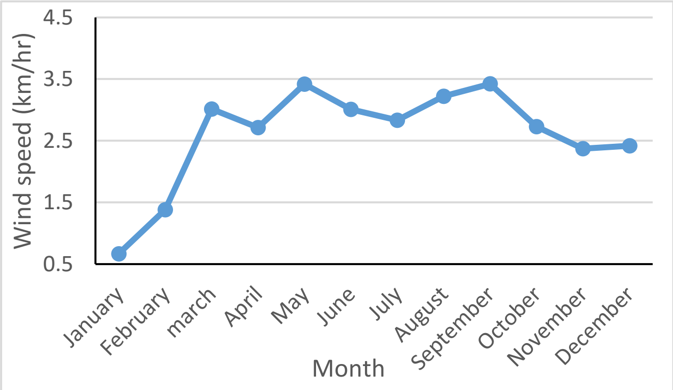

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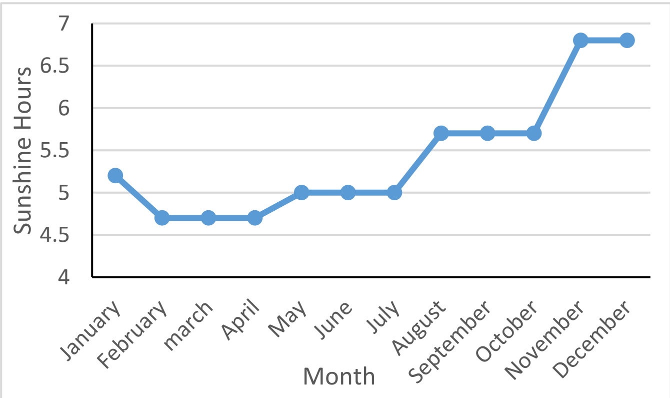

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Fig. 4 Hydrometeorological data of Basaralu for year 2022

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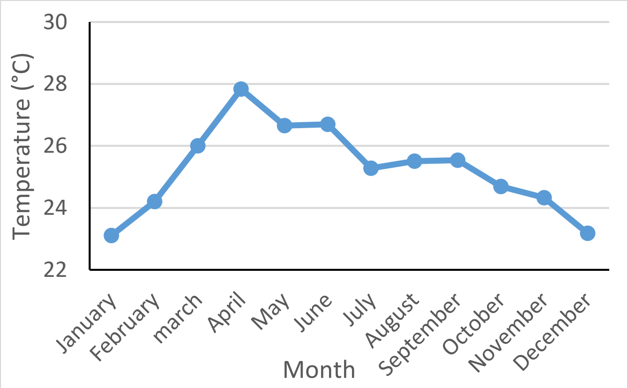

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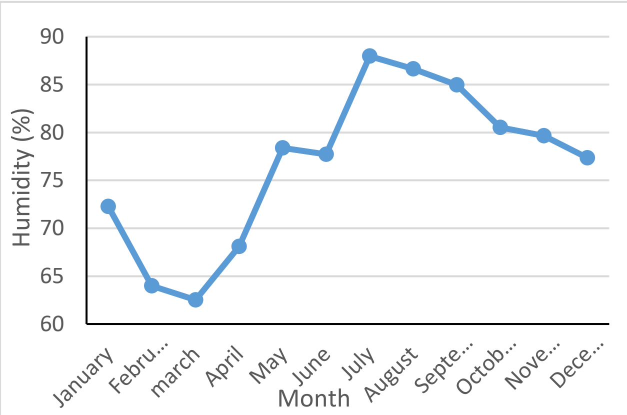

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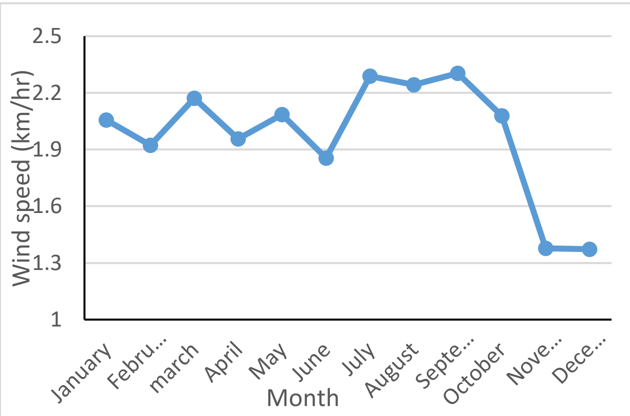

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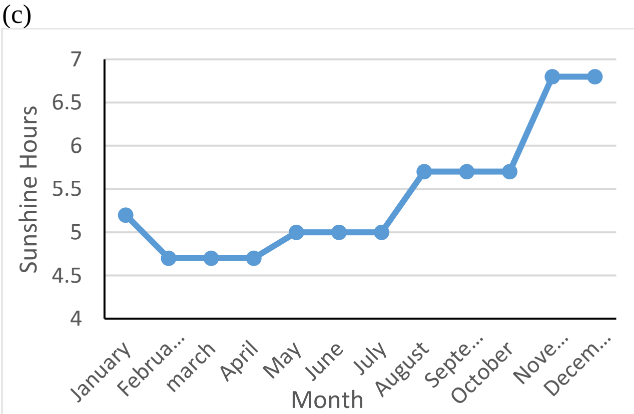

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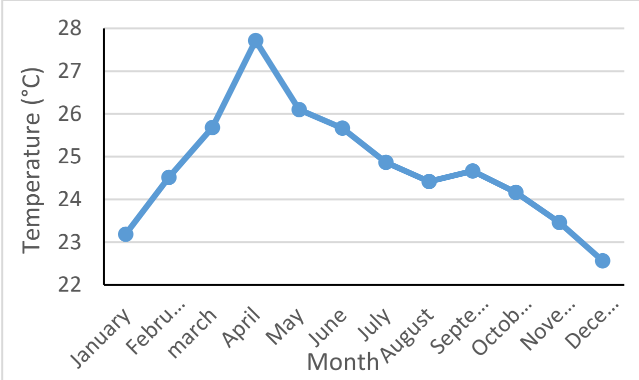
Fig. 5 Hydrometeorological data of Devalapura for year 2022



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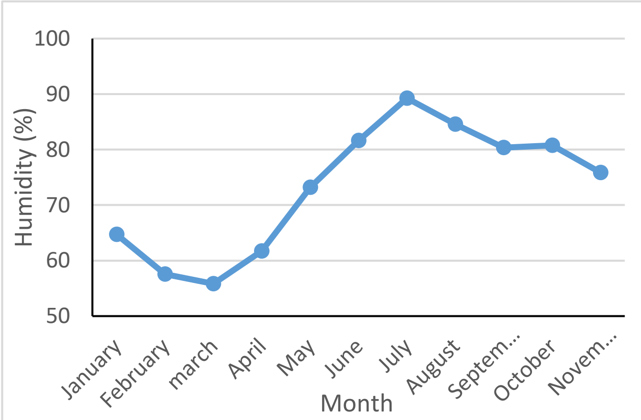

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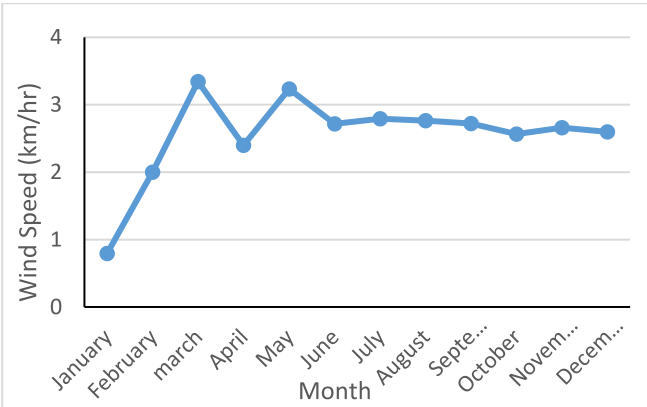

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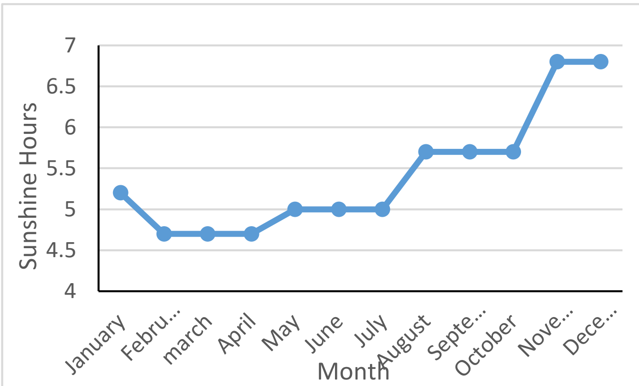

(d)

Fig. 6 Hydrometeorological data of Honakere for year 2022

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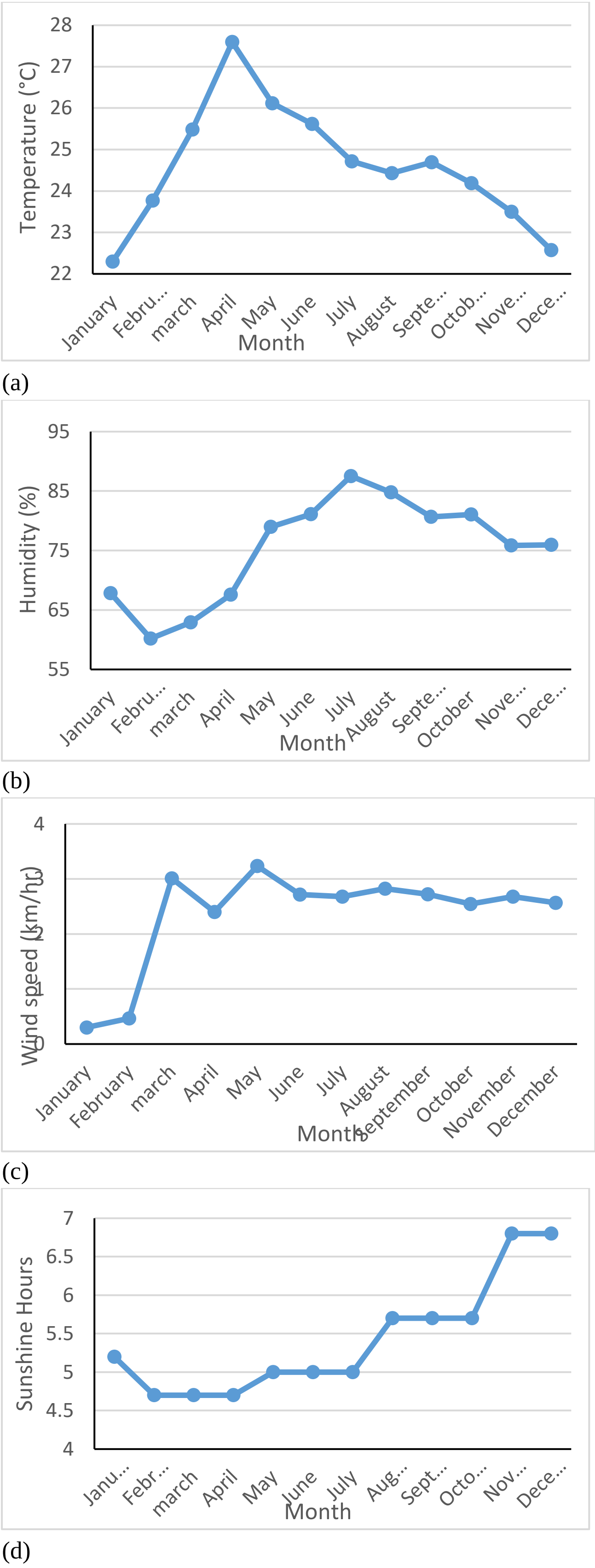

Fig. 7 Hydrometeorological data of Nagamangala for year 2022

D. Crop Evapotranspiration (Et_c)

Crop water requirement is the total quantity of water needed to mature an adequately irrigated crop to meet up with the losses mostly due to evapotranspiration.

$$CWR = ETc = \sum (ETo * Kc) \quad (5)$$

CWR or ET_c for both the crops is obtained by,

$$ETc = Kc \times ETo \quad (6)$$

IV. RESULTS AND DISCUSSIONS

A. Generation of Crop coefficient (K_c) curve

Crop coefficient (K_c) gives the relationship between ET_o and ET_c. The outcome of crop characteristics like type of crop, duration, growing season, stage of crop growth, depth of rooting, method of irrigation, plant population, fertilization, weed control, tillage, plant protection, etc., on CWR is accounted by crop coefficients. The Kc value represents ET of a crop growth under optimum conditions producing maximum yields. Kc values are identical for any given crop but the values are unstable for the entire crop period and change with the stage of the crop. Crop coefficient values are low during the crop growth early stages and increase as the plant approaches the growth period and are constant for some time and then decline gradually. The NDVI maps for June, July, August, September, October and November months of 2022 area are generated and are shown as Fig.8.

The crop coefficient curve of paddy and finger millet obtained from empirical method and NDVI is shown in Fig. 9 and10.

B. Calculation of Reference evapotranspiration (ET_o)

Evapotranspiration (ET) refers to the combined loss of water from the soil through evaporation and from plants through transpiration. Reference evapotranspiration (ETo) is a key parameter indicating the amount of water required to sustain healthy crops, lawns, gardens, and trees. Estimating ETo is essential for effective water resource management and understanding soil water balance in a given region. It plays a critical role in agricultural planning, irrigation scheduling, water transfer decisions, system design, and other water-related activities. Table 4 presents the monthly mean ETo (mm/day) values for the year 2022 at different stations using an empirical method.

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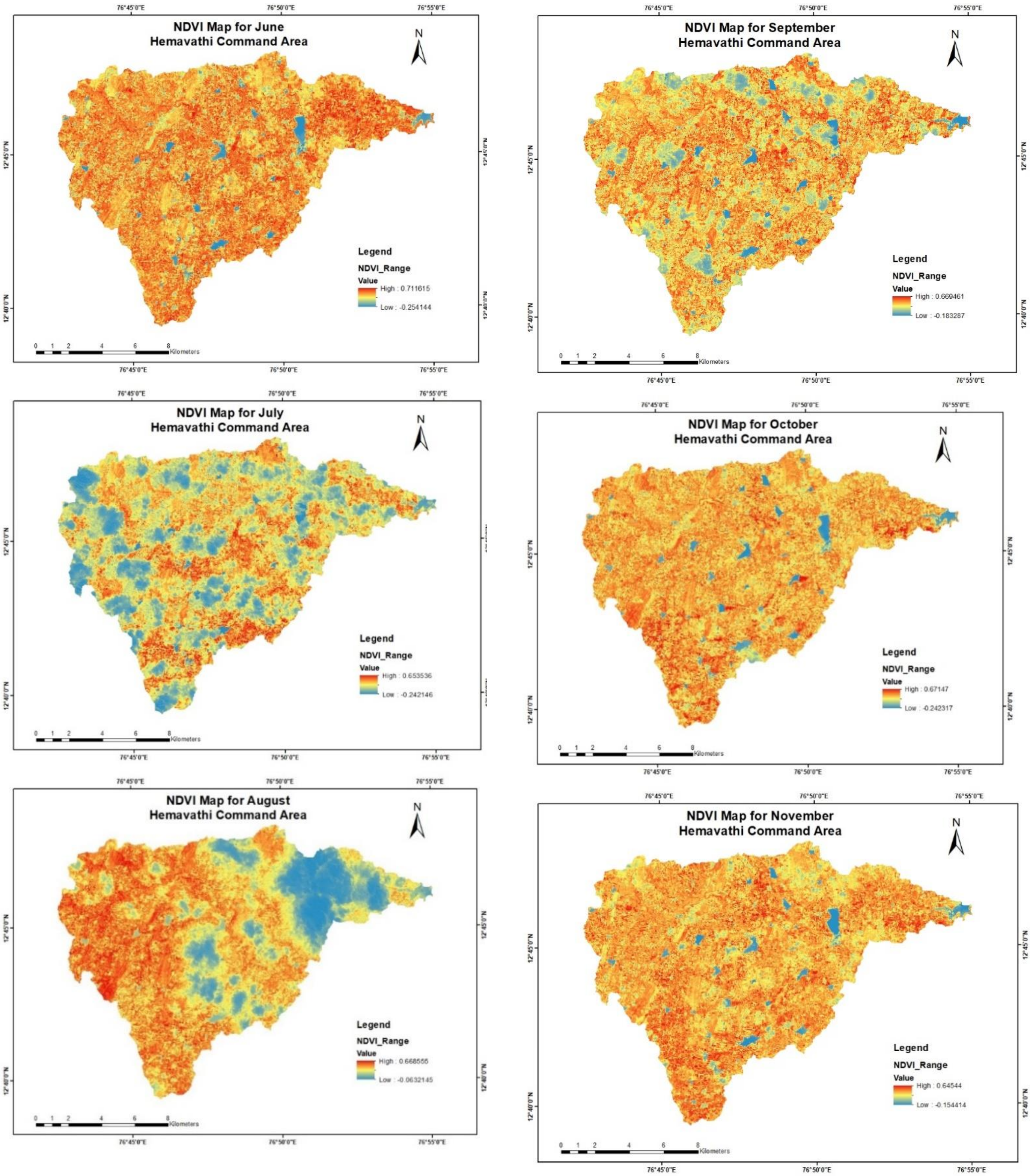

Fig. 8 NDVI maps generated for the study area for June to November, 2022

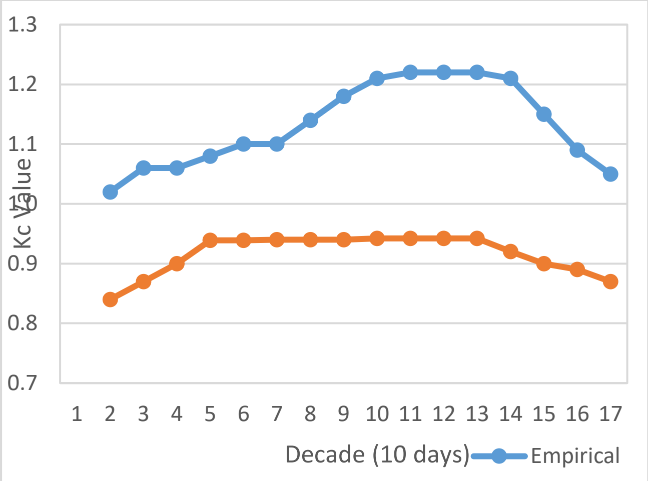

Fig. 9 Crop Coefficient curve for Paddy through empirical method and NDVI

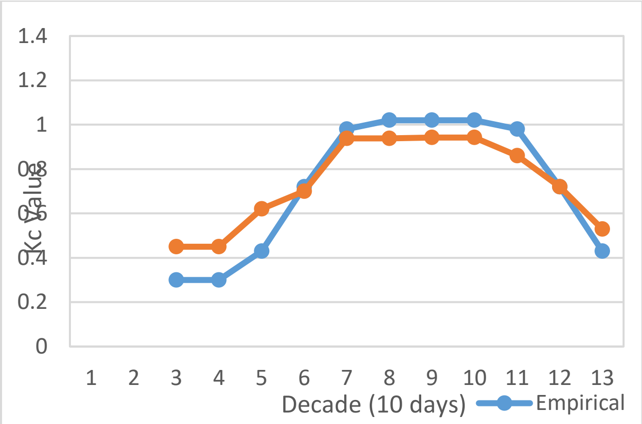

Fig. 10 Crop Coefficient curve for Finger Millet through empirical method and NDVI

The highest ETo values were recorded in April 2022, with 5.05 mm/day at Basaralu, 4.86 mm/day at Devalapura, 4.96 mm/day at Honakere, and 4.98 mm/ day at Nagamangala. Conversely, the lowest ETo values were observed in December 2022, measuring 3.0 mm/day at Basaralu, 2.9 mm/day at Devalapura, 2.92 mm/day at Honakere, and 2.91 mm/ day at Nagamangala. During the pre-monsoon period (April to May), land preparation and sowing activities take place for crops such as jowar, green gram, black gram, cowpea, sesame, sunflower, and cotton. In contrast, December marks the final harvesting stage for Kharif crops like paddy and finger millet, with harvesting completed in some areas. To compute the monthly ETo for the study area, meteorological data—including daily minimum and maximum temperature, wind speed, sunshine duration, and relative humidity—were collected for the Basaralu, Devalapura, Honakere, and Nagamangala weather stations and input into the CROPWAT model. The model generated ETo values for each station for the year 2022, as displayed in Table 5. The highest ETo values were recorded in April, with 4.76 mm/day at Basaralu, 4.57 mm/day at Devalapura, 4.71 mm/day at Honakere, and 4.66 mm/day at Nagamangala. Similarly, the lowest ETo values were observed in December, with 2.66 mm/day at Basaralu, 2.55 mm/day at Devalapura, 2.68 mm/day at Honakere, and 2.69 mm/day at Nagamangala.

Table 4 Monthly mean ET_o (mm/day) values for year 2022 of different stations using empirical method

Station Name	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Basaralu	3.31	4.01	4.81	5.05	4.28	3.99	3.37	3.6	3.87	3.45	3.01	3.0
Devalapura	3.35	4.01	4.65	4.86	4.3	4.12	3.4	3.59	3.85	3.41	3.0	2.9
Honakere	3.26	4.09	4.91	4.96	4.25	3.99	3.37	3.59	3.73	3.41	2.94	2.92
Nagamangala	3.25	3.95	4.82	4.98	4.22	4.0	3.33	3.58	3.73	3.40	2.93	2.91

Table 5 Monthly mean ET_o (mm/day) values for year 2022 of different stations using CROPWAT Model

Station Name	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Basaralu	3.28	3.78	4.56	4.76	4.34	3.72	3.36	3.55	3.74	3.67	3.47	2.66
Devalapura	3.46	3.85	4.44	4.57	4.27	3.75	3.43	3.55	3.71	3.65	3.45	2.55
Honakere	3.26	3.91	4.64	4.71	4.30	3.71	3.38	3.52	3.69	3.68	3.47	2.68
Nagamangala	3.15	3.53	4.53	4.66	4.26	3.70	3.36	3.52	3.68	3.66	3.45	2.69

A comparison between the ETo values obtained from the empirical (FAO) method and the CROPWAT model is illustrated in Fig. 11 and 12. The close alignment between the estimated and calculated values suggests that the CROPWAT model can be effectively used for ETo estimation. Additionally, it serves as a reliable tool for predicting crop water requirements (CWR) and net irrigation requirements (NIR) for various crops.

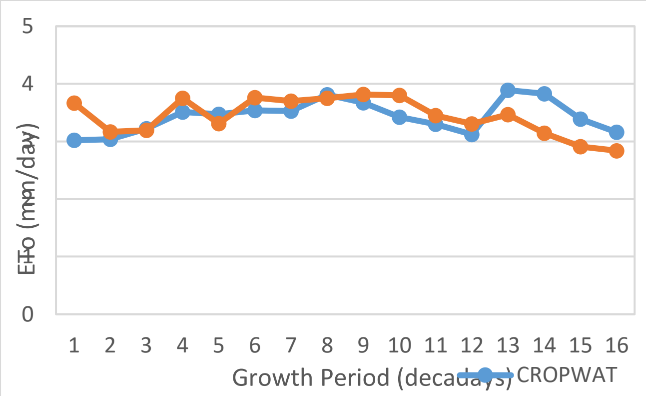

Fig. 11 Comparison of ETo for paddy/rice between CROPWAT model and Empirical(FAO) method

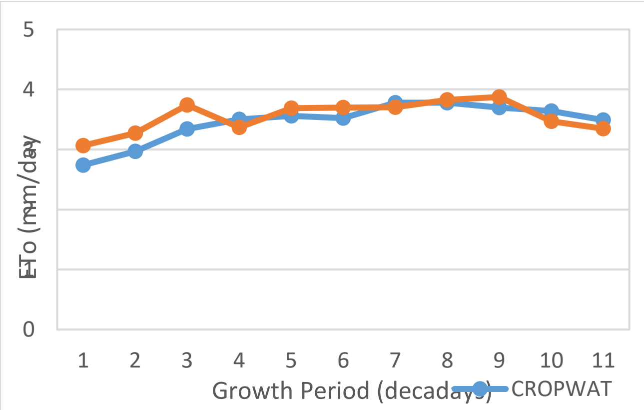

Fig. 12 Comparison of ETo for finger millet using CROPWAT model and Empirical(FAO) method

C. Crop Water Requirement

CWR is the amount of water which is needed by each crops as depth of water needed to overcome the water loss through evapotranspiration. CWR are assessed for each ten days as decadays of the growth period of crops. The results of the CWR for both paddy / rice and finger millet have been presented below:

1) Paddy / Rice

The total CWR for paddy was found to be 624.06 mm from empirical method and 503.80 mm from NDVI method for 2022 year. CWR for paddy/rice using empirical method and NDVI method are given in Table 6 and Table 7.

Table 6 CWR for Paddy using empirical method

Crop	Stages of crop	Kc Value	ET_o (mm/ day)	ET_c (mm/ day)	ET_c (mm/ dec)
PADDY	Nursery	1.02	3.67	3.74	37.38
		1.06	3.17	3.35	33.55
		1.06	3.20	3.39	33.87
	Initial	1.08	3.75	4.05	40.50
		1.10	3.31	3.64	36.41
	Development	1.10	3.76	4.14	41.36
		1.14	3.70	4.22	42.18
		1.18	3.75	4.43	44.25
	Mid-Season	1.21	3.82	4.62	46.16
		1.22	3.80	4.64	46.36
		1.22	3.45	4.21	42.09
		1.22	3.31	4.03	40.32
	Late Season	1.21	3.47	4.19	41.93
		1.15	3.15	3.62	36.17
		1.09	2.91	3.17	31.72
		1.05	2.84	2.98	29.82
		Total		62.41	624.06

Table 7 CWR for Paddy using NDVI vegetation index method

Crop	Stages of crop	Kc Value	ET_o (mm/ day)	ET_c (mm/ day)	ET_c (mm/ dec)
PADDY	Nursery	0.84	3.02	2.54	25.37
		0.87	3.04	2.64	26.45
		0.90	3.22	2.90	28.98
	Initial	0.94	3.51	3.30	32.95
		0.94	3.47	3.26	32.58
	Development	0.94	3.54	3.33	33.27
		0.94	3.53	3.32	33.18
		0.94	3.81	3.58	35.81
	Mid-Season	0.94	3.67	3.46	34.58
		0.94	3.42	3.22	32.22
		0.94	3.3	3.11	31.09
		0.94	3.12	2.94	29.40
	Late Season	0.92	3.89	3.58	35.79
		0.90	3.83	3.45	34.47
		0.89	3.39	3.02	30.17
		0.87	3.16	2.75	27.49
		Total		50.38	503.80

2) Finger Millet

The total CWR for finger millet is found to be 287.40 mm from empirical method and 285.13 mm from NDVI method for 2022 year, CWR for finger millet using empirical method and using NDVI method are given in Table 8 and Table 9.

Table 8 CWR for Finger Millet using empirical method

Crop	Stages of crop	Kc Value	ET_o (mm/ day)	ET_c (mm/ day)	ET_c (mm/ dec)
FINGER MILLET	Initial	0.3	3.07	0.92	9.20
		0.3	3.27	0.98	9.81
	Development	0.43	3.74	1.61	16.08
		0.72	3.37	2.43	24.26
	Mid-Season	0.98	3.69	3.62	36.16
		1.02	3.70	3.77	37.74
		1.02	3.71	3.78	37.79
		1.02	3.83	3.90	39.02
	Late Season	0.98	3.88	3.80	37.98
		0.72	3.47	2.50	24.98
		0.43	3.35	1.44	14.38
		Total		28.74	287.40

Table 9 CWR for Finger Millet using NDVI vegetation index method

Crop	Stages of crop	Kc Value	ET_o (mm/day)	ET_c (mm/ day)	ET_c (mm/dec)
FINGER MILLET	Initial	0.45	2.74	1.23	12.33
		0.45	2.97	1.34	13.37
	Development	0.62	3.34	2.07	20.71
		0.70	3.5	2.45	24.50
	Mid-Season	0.94	3.56	3.34	33.43
		0.94	3.52	3.31	33.05
		0.94	3.78	3.56	35.61
		0.94	3.78	3.56	35.61
	Late Season	0.86	3.7	3.18	31.82
		0.72	3.64	2.62	26.21
		0.53	3.49	1.85	18.50
		Total		28.51	285.13

V. CONCLUSIONS

In Nagamangala taluk, finger millet is the rainfed crop and its farming relies mainly on rainfall for water. Around 80% of its irrigation depends upon effective rainfall of that area and 20% of it is dependent upon net irrigation requirement which gets fulfilled by the release of water from the distributaries of Hemavathi left bank canal. For all the growing seasons, the mean values of ET_c, fluctuate throughout the crop development cycle and between seasons depending on weather and soil conditions. It has shown the significance of requirement of scientific planning for irrigation. Also, CROPWAT model can be used productively in estimating ET_o values and predicting CWR and calculating NIR for various crops. Results on ET_c and IR provided practical assessment for irrigation scheduling of paddy and finger millet grown in the semi-arid environment. These results can be utilized forwell-planned use of water and to optimize the production of crops in the Hemavathi command area.

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