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CROP WATER REQUIREMENT AND IRRIGATION SCHEDULING USING FAO CROPWAT 8.0: A GIS-BASED ANALYSIS OF MADIKERI REGION, INDIA

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***Abstract*-** **Efficient irrigation planning is essential for sustainable agricultural production under increasing water stress conditions. This study evaluates crop water requirement (CWR) and irrigation scheduling for rice cultivation in Madikeri, Karnataka, using the FAO CROPWAT 8.0 model integrated with GIS-based spatial analysis. Climatic, soil, and crop parameters were used to estimate reference evapotranspiration (ETo), crop evapotranspiration (ETc), and effective rainfall. The average ETo was found to be 3.65 mm/day, and the total crop water requirement was estimated as 389.7 mm. Effective rainfall contributed 217 mm, significantly reducing irrigation demand. The net irrigation requirement was calculated as 41.1 mm. Analytical calculations were performed to validate model outputs, demonstrating consistency with simulated results. The findings highlight that optimized irrigation scheduling can enhance water use efficiency and reduce dependency on external water sources**

Keywords: Crop water requirement; Irrigation scheduling; CROPWAT 8.0; Evapotranspiration; GIS; Effective rainfall; Water resource management

1. INTRODUCTION

Water scarcity has become a critical global concern due to population growth, climate variability, and increasing agricultural demand. Agriculture accounts for a major portion of freshwater consumption, making efficient irrigation practices essential for sustainability.

Crop water requirement (CWR) varies with climatic conditions, soil characteristics, and crop growth stages. Improper irrigation scheduling leads to water wastage, reduced crop yield, and soil degradation. So, scientific tools such as the FAO CROPWAT 8.0 model are widely used to estimate evapotranspiration and optimize irrigation scheduling.

This study focuses on estimating crop water requirement and irrigation scheduling for rice in Madikeri using CROPWAT, supported by GIS-based spatial analysis.

2. LITERATURE REVIEW

2.1 APPLICATION OF CROPWAT MODEL IN IRRIGATION PLANNING

The FAO CROPWAT 8.0 model has been widely used for estimating crop water requirement and developing irrigation schedules under varying agro-climatic conditions. The model integrates climatic, soil, and crop parameters to simulate water balance and irrigation demand.

Devakumar et al. [1] applied the CROPWAT model to estimate irrigation scheduling for rice in the Shivamogga district over a 20-year period. The study reported an irrigation requirement of 268.67 mm and observed a gradual increase in water demand over time, highlighting the influence of climatic variability on irrigation needs.

Similarly, Gabr [2] utilized the CROPWAT 8.0 model to assess irrigation requirements across different agroecological zones in Egypt using long-term climatic data.

The study found that evapotranspiration varied significantly between regions, with values ranging from 3.5 to 8 mm/day. It also indicated that traditional irrigation methods resulted in low efficiency (approximately 50%), emphasizing the need for improved water management practices.

Memon and Jamsa [5] evaluated crop water requirement and irrigation scheduling for soybean and tomato crops using CROPWAT. The study demonstrated that optimized irrigation scheduling can minimize yield reduction while improving water use efficiency, making the model a useful decision-support tool for farmers and planners.

These studies confirm that CROPWAT is a reliable and widely accepted tool for irrigation planning across diverse climatic conditions.

2.2 ESTIMATION OF EVAPOTRANSPIRATION AND CROP WATER REQUIREMENT

Accurate estimation of evapotranspiration is fundamental for determining crop water requirement. The Penman-Monteith equation, use d within the CROPWAT model, is considered the standard method due to its ability to incorporate multiple climatic parameters.

Reddy et al. [3] estimated reference evapotranspiration in the Raichur region and found that temperature, solar radiation, and sunshine hours significantly influence evapotranspiration rates. The study highlighted the superiority of the Penman-Monteith method over empirical methods due to its comprehensive parameter consideration.

Ewaid et al. [4] analyzed crop water requirements for major crops in southern Iraq and reported evapotranspiration values ranging from 2.18 to 10.5 mm/day. The study emphasized seasonal variation, with higher water demand during dry periods and lower demand during wet seasons.

Gangar et al. [6] estimated crop water requirement for rabi crops in Madhya Pradesh and reported an average evapotranspiration of 4.62 mm/day. The study reinforced the importance of accurate evapotranspiration estimation for effective irrigation planning at the regional scale.

These studies collectively highlight that precise estimation of evapotranspiration is critical for reliable computation of crop water requirements and irrigation scheduling.

2.3 RESEARCH GAP AND NEED FOR STUDY

Despite the extensive use of the CROPWAT model, most studies focus primarily on regional-scale analysis without integrating spatial tools such as GIS for terrain and land use evaluation. Additionally, limited research validates model outputs using analytical calculations, which is important for ensuring accuracy.

Furthermore, there is a lack of detailed studies in high rainfall regions like Madikeri, where effective rainfall significantly influences irrigation requirements.

2.4 SIGNIFICANCE OF PRESENT STUDY

The present study addresses these gaps by integrating GIS-based spatial analysis with CROPWAT modeling and validating the results using analytical calculations. This approach enhances the reliability of irrigation scheduling and provides a more comprehensive understanding of water resource management in high rainfall regions.

3. MATERIAL AND METHODOLOGY

3.1 STUDY AREA

Madikeri (12.42°N, 75.73°E) lies in the Western Ghats at an elevation of 1170 m. The region experiences high rainfall and moderate climatic conditions, making it suitable for rice cultivation. The terrain and hydrological characteristics significantly influence water availability and irrigation requirements.

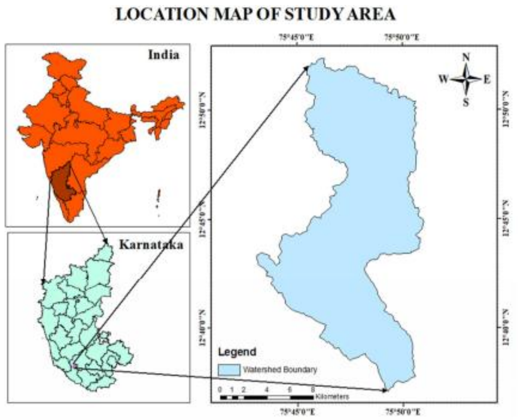


Fig 1: Location Map of Study Area

3.2 OVERVIEW OF METHODOLOGY

The present study integrates climatic, soil, crop, and spatial datasets to estimate crop water requirement (CWR) and irrigation scheduling using the FAO CROPWAT 8.0 model.

A GIS-based approach is incorporated to analyze terrain characteristics and land use patterns influencing water availability.

The methodology consists of the following steps:

1. Collection of climatic, soil, and crop data.
2. Preparation of spatial datasets using GIS.
3. Estimation of reference evapotranspiration (ETo).
4. Calculation of crop evapotranspiration (ETc) and crop water requirement (CWR).
5. Determination of effective rainfall.
6. Estimation of irrigation requirement and scheduling.

3.3 DATA COLLECTION AND INPUT PARAMETERS

Meteorological data required for the estimation of reference evapotranspiration were obtained from the CLIMWAT database corresponding to the Madikeri station.

The following parameters were used:

1. Mean daily temperature (°C)
2. Relative humidity (%)
3. Wind speed at 2 m height (m/s)
4. Sunshine duration (hours/day)

These parameters are essential inputs for the Penman-Monteith equation used in CROPWAT.

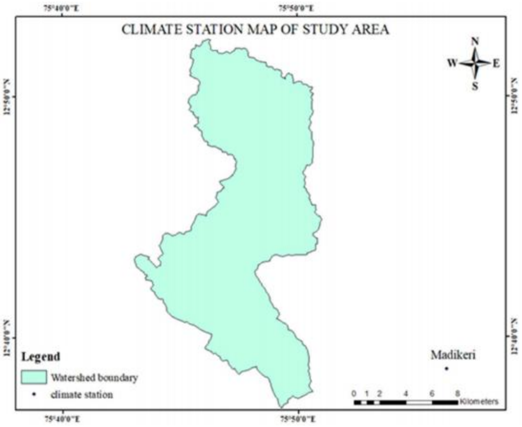


Fig 2: Climate Station Map of Study Area

3.4 SOIL DATA

The study area is characterized by red loamy soil, which has moderate water holding capacity and infiltration characteristics.

The following soil parameters were used:

1. Total available soil moisture (mm/m).
2. Maximum rooting depth (m).
3. Initial soil moisture depletion (%).
4. Infiltration rate (mm/day).

These parameters influence water retention and availability for crop uptake.

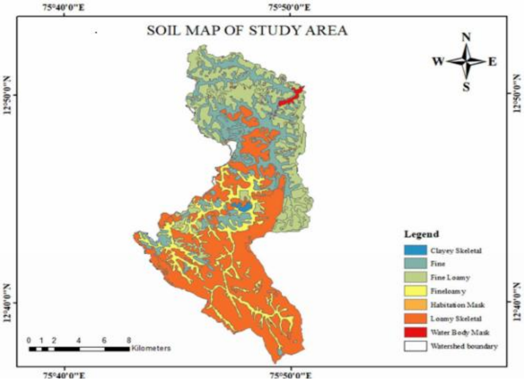


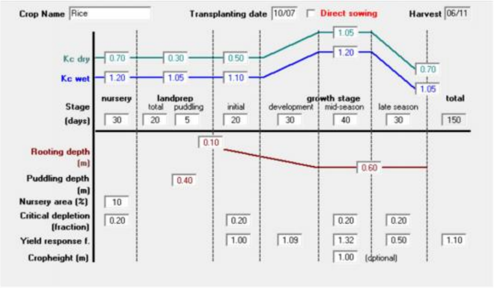
Fig 3: Soil Map of Study Area

3.5 CROP DATA

Rice was selected as the representative crop for the study. Crop parameters were obtained from FAO databases within the CROPWAT model.

The parameters include:

1. Crop coefficient (Kc) for different growth stages.
2. Rooting depth variation Crop growth stages (initial, development, mid, late).
3. Yield response factor.



Crop Name Rice

Transplanting date 10/07 ☐ Direct sowing Harvest 06/11

Stage	nursery	landprep total	landprep puddling	initial	development	mid-season	late season	total
Kc dry	0.70	0.30		0.50		1.05	0.70	
Kc wet	1.20	1.05		1.10		1.20	1.05	
(days)	30	20	5	20	30	40	30	150
Rooting depth (m)				0.10		0.60		
Puddling depth (m)			0.40					
Nursery area (%)	10							
Critical depletion (fraction)	0.20			0.20		0.20	0.20	
Yield response f.				1.00	1.09	1.32	0.50	1.10
Cropheight (m)						1.00 (optional)		

Fig 4: Crop Data

3.6 GIS-BASED SPATIAL ANALYSIS

Spatial datasets were prepared using GIS software to analyze terrain and land use characteristics. The DEM was used to assess elevation and slope variations, which influence runoff and infiltration patterns.

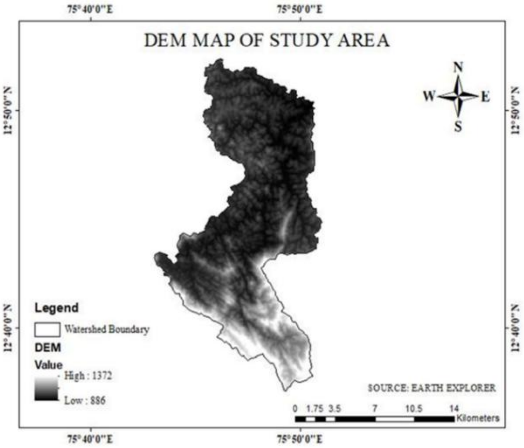


Fig 5:DEM Map

Land use data were used to identify agricultural areas and vegetation cover affecting evapotranspiration.

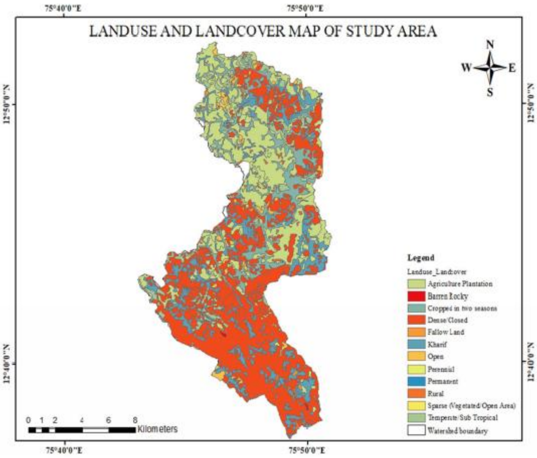


Fig 6: Land-use Map

Reference evapotranspiration (ETo) was calculated using the FAO Penman-Monteith equation:

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

Where:
R_n= net radiation
G= soil heat flux
T= mean temperature
u_2= wind speed
$e_s - e_a$= vapor pressure deficit
Δ= slope of vapor pressure curve
γ= psychrometric constant
Using representative values from the study area:
$T=22 \circ C$
$U_2 = 2m/s$
$(R_n - G) \approx 10MJ/m\ 2\ /day$
$(e_s - e_a) \approx 1.5kPa$
Substituting into the equation:
$Eto \approx 3.5-3.8mm/day$
The computed value closely matches the model output of 3.65 mm/day, validating the reliability of the model.

3. 7 ESTIMATION OF CROP EVAPOTRANSPIRATION **(ET_c)**

Crop evapotranspiration was calculated using:
$ET\ c = K\ c \times ETo$
Sample Calculation
For mid-growth stage of rice:
$Kc=1.1$
$ETo=3.65$
$ET\ c = 1.1\times3.65 = 4.015mm/day$
This represents the actual water requirement of the crop under given climatic conditions.

3.8 ESTIMATION OF CROP WATER REQUIREMENT (CWR)

Crop water requirement is obtained by summing ETc over the crop growth period.
Calculation:
Crop duration = 120 days
$CWR= 4.015\times120 \quad =481.8mm$
However, considering stage-wise variation in crop coefficient:
Final CWR obtained from CROPWAT = 389.7 mm

3.9 ESTIMATION OF CROP WATER REQUIREMENT (CWR)

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Calculation:
Crop duration = 120 days
$CWR=4.015\times120 \quad =481.8mm$
However, considering stage-wise variation in crop coefficient:
Final CWR obtained from CROPWAT = 389.7 mm

3.10 ESTIMATION OF EFFECTIVE RAINFALL

Effective rainfall was estimated using methods available in CROPWAT, accounting for losses due to runoff, deep percolation, and evaporation.
The total effective rainfall for the study area was:
$P_{eff} = 217mm$

3.11 IRRIGATION REQUIREMENT AND SCHEDULING

Net Irrigation Requirement
$NIR= CWR-P_{eff}$
$NIR=389.7-217 \qquad =172.7mm$

3.12 GROSS IRRIGATION REQUIREMENT

Considering irrigation efficiency of 70%:
$GIR= NIR\ /Efficiency$
$GIR= 47.4/\ .7 \quad =67.7mm$

3.13 IRRIGATION SCHEDULING

Irrigation scheduling was carried out by maintaining soil moisture at field capacity and considering critical depletion levels.

Irrigation was applied during **deficit** periods when rainfall was insufficient to meet crop water demand.

4. RESULTS AND DISCUSSION

4.1 SPATIAL RAINFALL DISTRIBUTION

The spatial variability of rainfall was assessed using the Thiessen polygon method, which assigns area-weighted influence to individual rain gauge stations.

The analysis indicates a relatively uniform distribution across the study area, suggesting that a single representative climatic dataset is adequate for modeling purposes.

This spatial consistency reduces uncertainty in evapotranspiration estimation and supports the reliability of model inputs.

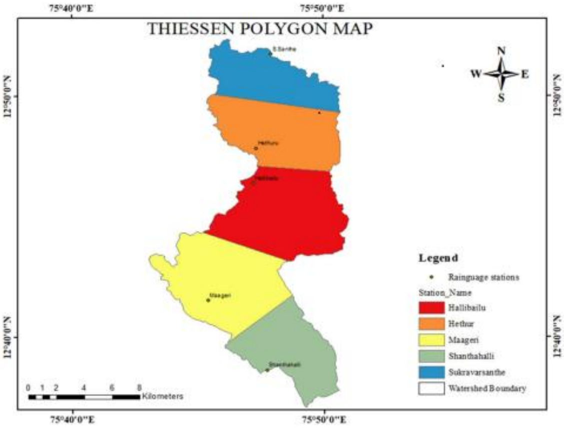


Fig 7: Thiessen Polygon Map

4.2 DRAINAGE CHARACTERISTICS AND HYDROLOGICAL INFLUENCE

The drainage analysis reveals a well-developed network consisting of five stream orders. Such a drainage pattern indicates moderate runoff potential, which directly affects the fraction of rainfall available for infiltration.

Areas with higher drainage density are associated with increased surface runoff, whereas regions with lower density favor soil moisture retention. This spatial variability influences the effectiveness of rainfall in meeting crop water demand.

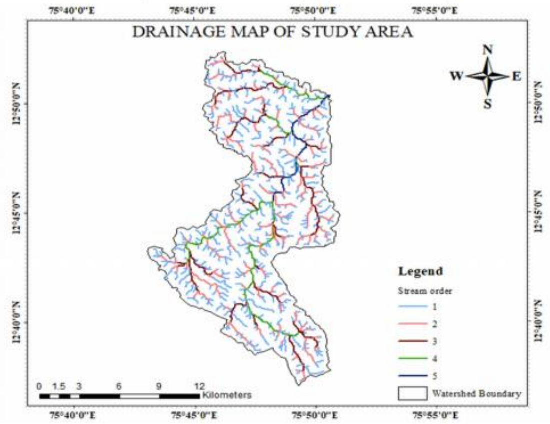
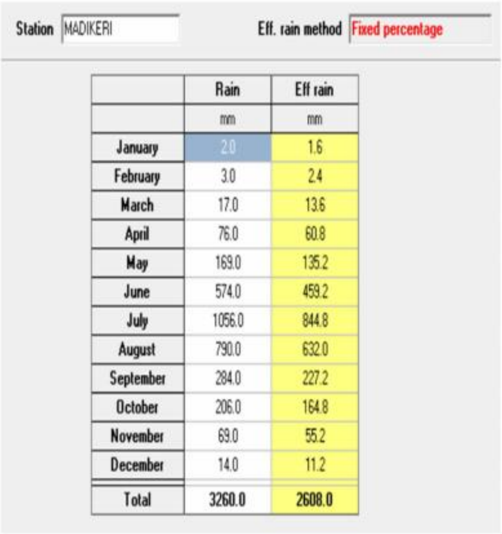


Fig 8: Drainage Map

4.3 EFFECTIVE RAINFALL BEHAVIOR

The analysis of effective rainfall shows strong seasonal dependency. During monsoon months, a significant portion of total rainfall contributes to soil moisture, whereas during non-monsoon periods, the contribution is minimal.

This uneven distribution highlights that rainfall availability alone does not determine water sufficiency; it's timing relative to crop growth stages is equally critical. Consequently, irrigation demand is concentrated in periods of low rainfall despite adequate annual precipitation.



Station MADIKERI

Eff. rain method Fixed percentage

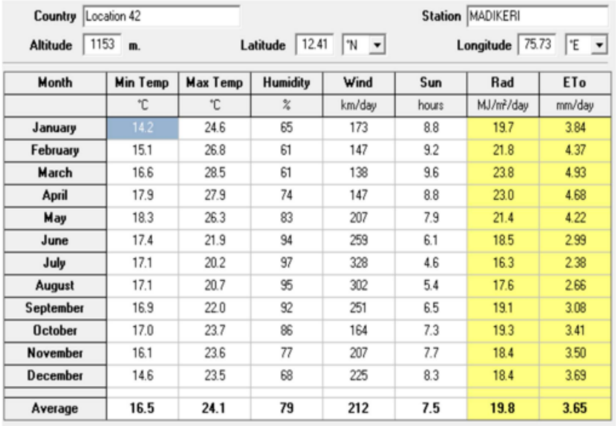
	Rain	Eff rain
	mm	mm
January	2.0	1.6
February	3.0	2.4
March	17.0	13.6
April	76.0	60.8
May	169.0	135.2
June	574.0	459.2
July	1056.0	844.8
August	790.0	632.0
September	284.0	227.2
October	206.0	164.8
November	69.0	55.2
December	14.0	11.2
Total	3260.0	2608.0

Fig 9: Monthly Rainfall and Effective Rainfall

4.4 REFERENCE EVAPOTRANSPIRATION DYNAMICS

Reference evapotranspiration exhibits clear seasonal variation governed by climatic parameters. Higher values are observed during pre-monsoon months due to increased temperature and solar radiation, while reduced values during the monsoon are attributed to elevated humidity and cloud cover.

This variation directly influences crop water demand and determines the temporal pattern of irrigation requirement.



Country Location 42
Station MADIKERI
Altitude 1153 m.
Latitude 12.41 °N
Longitude 75.73 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	14.2	24.6	65	173	8.8	19.7	3.84
February	15.1	26.8	61	147	9.2	21.8	4.37
March	16.6	28.5	61	138	9.6	23.8	4.93
April	17.9	27.9	74	147	8.8	23.0	4.68
May	18.3	26.3	83	207	7.9	21.4	4.22
June	17.4	21.9	94	259	6.1	18.5	2.99
July	17.1	20.2	97	328	4.6	16.3	2.38
August	17.1	20.7	95	302	5.4	17.6	2.66
September	16.9	22.0	92	251	6.5	19.1	3.08
October	17.0	23.7	86	164	7.3	19.3	3.41
November	16.1	23.6	77	207	7.7	18.4	3.50
December	14.6	23.5	68	225	8.3	18.4	3.69
Average	**16.5**	**24.1**	**79**	**212**	**7.5**	**19.8**	**3.65**

Fig 10: Monthly Rainfall and Effective Rainfall

4.5 CROP WATER REQUIREMENT VARIATION

The crop water requirement varies across different growth stages, reflecting changes in canopy development and physiological activity. The demand increases from the initial stage, reaches a peak during the mid-growth stage, and gradually decreases during the late stage.

The total crop water requirement estimated for the study is 389.7 mm, representing the cumulative water demand over the entire crop period. This stage-wise variation highlights the importance of aligning water supply with crop growth phases.

The irrigation requirement is determined by the balance between crop water demand and effective rainfall. The analysis indicates that irrigation is required only during specific deficit periods when rainfall is insufficient to meet crop needs.

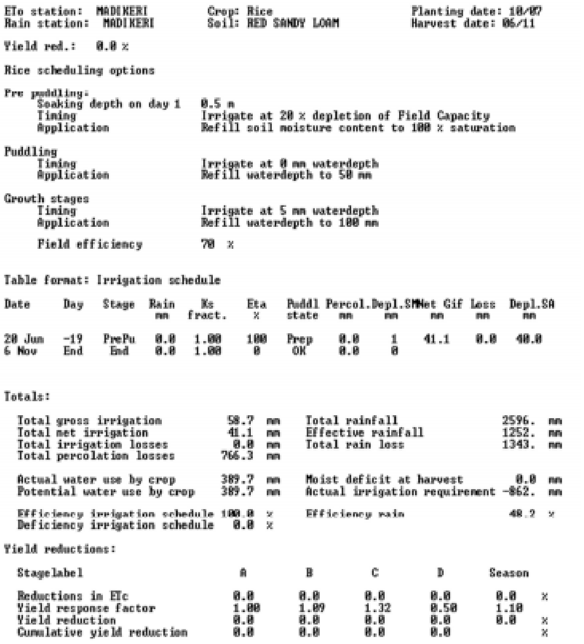
Although the theoretical irrigation demand is higher, the actual irrigation applied is approximately 47.4 mm, which is significantly reduced due to effective rainfall contribution and soil moisture retention.

This demonstrates that a targeted irrigation scheduling approach is sufficient, where water is applied only during critical growth stages experiencing moisture stress. Such an approach minimizes unnecessary water application and enhances overall water use efficiency.

Rain station MADIKERI
Planting date 10/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Nurs	1.20	0.41	0.4	11.5	0.4
Jun	2	Nurs/LPr	1.19	0.64	6.4	150.2	40.4
Jun	3	Nurs/LPr	1.06	2.97	29.7	194.0	0.0
Jul	1	Init	1.07	2.76	27.6	257.7	0.0
Jul	2	Init	1.10	2.62	26.2	310.1	0.0
Jul	3	Deve	1.10	2.72	29.9	276.9	0.0
Aug	1	Deve	1.11	2.85	28.5	240.4	0.0
Aug	2	Deve	1.13	2.99	29.9	219.8	0.0
Aug	3	Mid	1.14	3.19	35.1	171.8	0.0
Sep	1	Mid	1.14	3.36	33.6	109.9	0.0
Sep	2	Mid	1.14	3.52	35.2	59.5	0.0
Sep	3	Mid	1.14	3.65	36.5	58.0	0.0
Oct	1	Late	1.14	3.76	37.6	63.3	0.0
Oct	2	Late	1.10	3.75	37.5	57.1	0.0
Oct	3	Late	1.05	3.60	39.6	44.2	0.0
Nov	1	Late	1.00	3.48	20.9	17.1	6.6
					454.6	**2241.4**	**47.4**

Fig 11: Crop Requirement



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ETo station:  MADIKERI          Crop: Rice                    Planting date: 10/07
Rain station:  MADIKERI         Soil: RED SANDY LOAM          Harvest date: 06/11

Yield red.:   0.0 %

Rice scheduling options

Pre puddling:
     Soaking depth on day 1   0.5 m
     Timing                   Irrigate at 20 % depletion of Field Capacity
     Application              Refill soil moisture content to 100 % saturation

Puddling
     Timing                   Irrigate at 0 mm waterdepth
     Application              Refill waterdepth to 50 mm

Growth stages
     Timing                   Irrigate at 5 mm waterdepth
     Application              Refill waterdepth to 100 mm

     Field efficiency         70  %

Table format: Irrigation schedule

Date      Day    Stage   Rain    Ks     Eta    Puddl  Percol.Depl.SMNet Gif  Loss   Depl.SA
                         mm    fract.    %     state   mm     mm     mm     mm      mm

20 Jun    -19    PrePu   0.0   1.00    100    Prep    0.0     1    41.1    0.0    40.0
6 Nov     End    End     0.0   1.00     0      OK     0.0     0


Totals:

  Total gross irrigation         58.7  mm    Total rainfall                2596.  mm
  Total net irrigation           41.1  mm    Effective rainfall            1252.  mm
  Total irrigation losses         0.0  mm    Total rain loss               1343.  mm
  Total percolation losses      766.3  mm

  Actual water use by crop      389.7  mm    Moist deficit at harvest        0.0  mm
  Potential water use by crop   389.7  mm    Actual irrigation requirement -862.  mm

  Efficiency irrigation schedule 100.0 %     Efficiency rain                48.2  %
  Deficiency irrigation schedule   0.0 %

Yield reductions:

  Stagelabel                     A        B        C        D       Season

  Reductions in ETc             0.0      0.0      0.0      0.0      0.0    %
  Yield response factor         1.00     1.09     1.32     0.50     1.10
  Yield reduction               0.0      0.0      0.0      0.0      0.0    %
  Cumulative yield reduction    0.0      0.0      0.0      0.0             %
```

Fig 12: Irrigation Schedule

5. DISCUSSION

The results highlight the dominant role of rainfall in meeting crop water requirements in the study area. Despite sufficient annual rainfall, its uneven temporal distribution necessitates supplemental irrigation during specific growth stages.

The seasonal variation in evapotranspiration reflects the influence of climatic parameters such as temperature and humidity, which directly affect crop water demand. Higher evapotranspiration during pre-monsoon months increases water demand, while reduced values during monsoon decrease irrigation requirements.

The relatively low irrigation requirement observed in the study indicates efficient utilization of rainfall and soil moisture. This distinguishes the study area from semi-arid regions where irrigation demand is significantly higher.

The integration of GIS-based spatial analysis supports the understanding of hydrological processes such as runoff and infiltration, which influence effective rainfall and water availability. This enhances the reliability of irrigation planning.

6. CONCLUSION

This study evaluated crop water requirement and irrigation scheduling using the FAO CROPWAT 8.0 model integrated with GIS-based analysis. The findings indicate that climatic conditions and rainfall distribution are the primary factors influencing crop water demand.

The total crop water requirement was estimated as 389.7 mm, with a significant portion met through effective rainfall. Consequently, the actual irrigation requirement was relatively low, approximately 47.4 mm, demonstrating efficient utilization of natural precipitation.

The variation in evapotranspiration and crop water demand across growth stages highlights the importance of precise irrigation scheduling. The results confirm that irrigation should be applied selectively during deficit periods rather than uniformly throughout the crop cycle.

Overall, the study demonstrates that optimized irrigation practices can improve water use efficiency and support sustainable agricultural management. The methodology provides a practical framework for application in similar agro-climatic regions.

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