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CROPWAT MODEL BASED ESTIMATION OF CROP WATER REQUIREMENT OF MUSTARD CROP FOR NALANDA DISTRICT OF BIHAR INDIA

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ABSTRACT

Agriculture remains the largest consumer of freshwater resources, with irrigation practices heavily dependent on groundwater accounting for approximately 70–90% of usage. Understanding crop water requirements is essential for sustainable water resource management, particularly in regions vulnerable to climatic variability. This study focuses on the estimation of crop water requirements of Mustard crop for Nalanda district Bihar, over a 30-year period (1992–2022). FAO CROPWAT model has been used to estimate Reference Evapotranspiration (ET_0), Effective Rainfall, Crop Water Requirement (CWR), and Irrigation Water Requirement (IWR). Temporal trends in climatic variables and water demands were assessed using the non-parametric Mann-Kendall test. Results indicated that the average maximum temperature in Nalanda during the study period was 31.43 ± 0.46°C, while the minimum temperature is 19.49 ± 0.43°C. While annual rainfall was 609.02 ± 129.81 mm. Monthly analysis revealed that January consistently exhibited the lowest maximum and minimum temperatures, while May recorded the highest maximum temperatures. Rainfall peaked in July, with November receiving the least precipitation. The trend analysis showed a significant increasing trend in minimum temperature (Tmin), a non-significant to slight increasing trend in maximum temperature (Tmax), and a decreasing trend in monsoon rainfall, particularly in August and September. These findings underscore the necessity of adaptive irrigation planning and targeted water conservation strategies for sustainable mustard cultivation in Nalanda agroecological context.
Keywords **:** CWR, IWR, ET0, CROPWAT, Weather Cock, XLSTAT, Nalanda.

Introduction

India with a geographical area of nearly 3.3 million square kilometers is home to 16% of the population of the world whereas it has only 4% of the total freshwater resources of the world. Moreover, there is huge inequality in the distribution of water resources within the country. The scarce natural resource is fundamental to life, livelihood, food security and development. Sustainable management of this scarce resource has become a challenge nowadays owing to increased demands of increasing population, growing urbanization and rapid industrialization. (Singh *et al.*,2019).

India is the third largest rapeseed-mustard producer in the world after China and Canada with 13.5 per cent of world's total production (DES, Government of India 2019-20). The area under rapeseed-mustard in the country was 6.23 million hectares, produced about 9.34 million tones with 1499 kg/ha productivity during the year 2018-19. Bihar ranked ninth among the states, in rapeseed-mustard production, with a growth rate of 7.34% during the eighties whereas Rajasthan state with top ranked. It is the most important crops among oilseeds in terms of both area (0.08 million ha) and production (0.11 million tones.) in Bihar (DES, Government of Bihar Patna, (2018-19) (Sachin *et al.,* 2022).

India's production (72.41 mt) and 24.7% in term of area and 29.4% in production, respectively, of oilseeds in India during 2018-19. Of the projected demand of 82-101 m t of oilseeds by 2030, contribution of rapeseed-mustard is projected at 16.4-20.5 m t, considering its share of 20%-25% in production. Near doubling the production of rapeseed-mustard from its current production of 9.26 m t within 10 years is a daunting challenge necessitating multi-pronged strategy. First and foremost, approach would be to bridge the exploitable yield reservoir (EP II) of 57.2% in rapeseed-mustard (Chauhan *et al.,* 2020).

Agriculture is the largest (81%) consumer of water in India and hence more efficient use of water in agriculture needs to be top most priority**.** Water is an essential input for crop production. Water supply matters in the world that will soon have to grow food for billions more people as the world's population is estimated to increase from 6 billion to 10 billion by mid-century, which will cause the high demand of world's population for food especially in developing countries The concept of agricultural productivity has been the volume of the yield per unit of land but the new concept has to be based on the scarcity of water. The productivity per unit of water requires being the basic point for measuring of agricultural productivity in developing countries. (Surendran *et al.,* 2013). Water is becoming valuable to its growing demand in agricultural activities Water demand is rising gradually as the crop yield is a serious problem throughout the world, particularly in developing countries, owing to population growth, rapid urbanization, and irrigation activities. The causes for this are the lack of adequate water management and water resources conservation. It is compulsory to apply significant approaches that help rise water efficiency. Water is an important input for agriculture so that this valuable resource is designed properly and deliverable. Reasonable information on evapotranspiration, crop water requirements, and net irrigation requirements is required for effective planning of this resource. The water demand for crops differs significantly between crops to crops, even during the entire growing season of a single crop. Thus, understanding CWR and IWR of mustard is crucial for efficient water management and maximizing yield especially in regions like Nalanda, India where water resources can be scare.

Materials and Methods

Study area and Weather Data Collection

This study was conducted to evaluate the temporal variation of ET_0 and crop evapotranspiration for Mustard crop for Nalanda Region during 1992-2022. Detail of materials used and experimental methodology followed during present study were described in this chapter.

Nalanda is located in the eastern Indian state of Bihar has the coordinates approximately 25° 7' 0" N and 85° 26' 0" E. Nalanda, situated in eastern India, experiences a subtropical climate, influenced by the northern plains' weather patterns. The region sees hot and humid summers, a distinct monsoon season, and cool winters. Summers, lasting from March to June, can be intense, with temperatures often soaring above 40°C. The monsoon season, from late June to September, brings the majority of the annual rainfall, which is vital for the region's agriculture. Winters, from November to February, are typically mild to cool, with temperatures occasionally dropping below 10°C, especially in the early mornings and late nights.

Data Collection

Weather Data*:* IMD Gridded data is used from year 1992 to 2022. Rainfall data and temperature weather variable data is used for ET calculation

CROPWAT 8.0 Model:

CROPWAT is a decision support system developed by the land and water development division of FAO. It is used to estimate

(a) Reference evapotranspiration

(b) Crop water requirements

(c) Crop Irrigation requirements in order to develop irrigation schedules under various management conditions (FAO, 1992).

It is also used to develop

(a) Irrigation schedules with various management options

(b) Scheme water supply

(c) Rainfed production and drought affects

(d) Efficiency of irrigation practices and the assessment of production under rainfed conditions or deficit irrigation (Marica *et al.,*1999)

Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage

Crop coefficients data

Table 1 : Crop coefficients of Mustard crop

Crop	Crop Coefficients		
	Initial (Kc1)	Development (Kc2)	Late Season (Kc3)
Mustard	0.35	1.15	0.6

Source: FAO Irrigation and drainage, paper no.56, FAO

Soil data

Table 2 : Different types of Soil data

S. No	Soil description	Clay Loam soil
1	Total available soil moisture (FC-WP), mm/m	130
2	Maximum rain infiltration rate, mm/day	100
3	Maximum rooting depth, cm	30
4	Initial soil moisture depletion (as % TAM), %	30
5	Initial available soil moisture, mm/m	91

Source: FAO Irrigation and drainage, paper no. 56, FAO

Weather Cock: 2022

It is the software used for data management and converting the daily data into annual, monthly seasonal. This software was developed and managed by AICRPAM, CRIDA, Hyderabad.

XLSTAT: 2022.3.1

It is the leading data analysis and statistical solution for Microsoft Excel. The statistical analysis software is compatible with all Excel versions from version 2003 to version 2016 and is compatible with Windows Vista to Windows 10 systems, as well as with PowerPC and Intel based Mac systems, because it is powerful, reliable, affordable, easy to install and to use, XLSTAT has grown to be one of the most commonly used statistical software packages on the market. The one-month trial version of software has been used for temperature, rainfall, water requirements and ET_0 Trend analysis with the help of Mann- Kendell Test &Sen's slope estimator.

Calculation of Reference evapotranspiration (ET_0)

The evapotranspiration rate from a reference surface, not short of water, is called the reference evapotranspiration and is denoted as ET_0. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions. The reference evapotranspiration (ET_0) was computed by Penman Monteith Model (Allen *et al.,* 1998). In this model, most of the equation parameters are directly measured or can be readily calculated from weather data. The equation can be utilized for the direct calculation of any crop evapotranspiration (ET_c). The FAO Penman-Monteith equation is a close, simple representation of the physical and physiological factors governing the evapotranspiration process. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiration surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ET_0 values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface (FAO 56, 1998).

Effective rainfall (ER)

Total rainfall is not utilized by the plants, effective rainfall is defined as a part of rainfall which is effectively used by the crop after rainfall losses due to surface run off and deep percolation have been accounted (Babu *et al.,* 2015). According to Dastane (1974) effective rainfall is defined as that portion of rainfall which is useful directly and/or indirectly for crop production at the site where it falls. Consideration of effective rainfall can help in predicting more precisely the water requirement of crops. Effective rainfall is influenced by factors such as quantity and intensity of rainfall, evapotranspiration and percolation losses; crop and irrigation management practices. Estimates of effective rainfall are extremely useful for operation planning and management issues including determine optimal cropping pattern; determining optimal operational policies for irrigation systems; design of drainage systems and real-time control. The model has available four Effective Rainfall methods but the USDA Soil Conservation Service method is the default. To calculate the effective rainfall from 1990-2019, the USDA Soil Conservation Service method was used. For the present study USDA Soil

Conservation Service method (Smith *et al.*, 1991) employed to estimate effective rainfall. This method, commonly Integrated into the CROPWAT model, provides a reliable approach for determining rainfall contributions to crop water supply under varying agroclimatic conditions.

Estimation of Crop Water Requirement (ETc)

Crop Water Requirement is the amount of water needed to meet the water loss through Evapotranspiration. Estimation of the crop water requirement is derived from crop evapotranspiration (crop water use) which is the product of the reference evapotranspiration (ET_0) and the crop coefficient (Kc). The reference evapotranspiration (ET_0) is estimated based on the FAO Penman-Monteith method, using climatic data (FAO, 1998). This method ensures standardized and accurate estimation of water demand across varying agroecological conditions.

Mann Kendell Test

The Mann-Kendall test is a non-parametric method used for trend analysis of time series data (Kendall 1975). Major advantage of Mann-Kendall test is that it is free from statistical distributions which are required for parametric method. Due to its simplicity and broader application, World Meteorological Organization (WMO) has recommended this method to assess the monotonic trend in hydro-meteorological time-series (Tian *et al.*, 2012). The null hypothesis (H0) for the Mann-Kendall test is that there is no trend or serial correlation among the analysed population against the alternative hypothesis (H1), which assumes increasing or decreasing monotonic trend. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1 and if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S (Shahid *et al.*, 2011).

Results and Discussion

Temperature and Rainfall analysis for Nalanda

Minimum Temperature: The monthly, Seasonal and annual variation in mean minimum temperature of Nalanda Region with mean, Standard deviation and CV. in Nalanda, the lowest minimum temperature was recorded in the month of January (9.19 ± 1.19 °C). On the other hand, the highest minimum temperature was observed during the months of June followed by July and August reaching around 25.67 ±0.41°C. During the time period from 1992 to 2022, the average annual minimum temperature in Nalanda was approximately 19.49 ±0.43°C.

Table 3 : Average Minimum temperature (℃) duration 1992-2022 for Nalanda Bihar.

Time Series	Mean	SD	CV	MK	Significance	Slope
January	9.19	1.19	12.98	0.100	↑	0.022
February	12.11	0.93	7.74	0.186	↑	0.026
March	16.63	1.02	6.16	0.358	↑*	0.053
April	21.57	0.94	4.39	0.374	↑*	0.005
May	24.29	0.67	2.79	0.165	↑	0.023
June	25.83	0.75	2.91	0.254	↑**	0.033
July	25.67	0.41	1.61	0.402	↑*	0.026
August	25.48	0.41	1.62	0.391	↑*	0.023
September	24.9	0.58	2.35	0.503	↑*	0.037
October	21.84	0.85	3.89	0.253	↑***	0.034
November	15.61	1.09	7.02	0.037	↑	0.005
December	10.76	0.91	8.49	0.307	↑**	0.004
Annual	19.49	0.43	2.21	0.495	↑*	0.032
Winter	10.65	0.73	6.94	0.235	↑***	0.031
Pre - monsoon	20.83	0.68	3.27	0.423	↑*	0.036
Monsoon	25.47	0.45	1.76	0.466	↑*	0.032
Post - monsoon	16.07	0.71	4.45	0.261	↑**	0.033

Maximum Temperature: The monthly analysis of maximum temperature based on 30 years of data for the Nalanda region revealed that January records the lowest maximum temperature i.e. 22.16±1.51 °C, whereas the month of May experiences the highest maximum temperature. From this analysis, it can be concluded that the maximum temperature in the Nalanda region during the period 1992–2022 was 37.40±1.43°C. The average annual maximum temperature was highest in Nalanda i.e. 37.40 ℃.

Table 4 : Average Maximum temperature (℃) duration 1992-2022 for Nalanda Bihar.

Time series	Mean	SD	CV	MK	Significance	Slope
January	22.16	1.51	6.84	-0.158	↑	-0.042
February	26.56	1.44	5.43	0.112	↑	0.029
March	32.17	1.42	4.43	0.071	↑	0.010
April	37.00	1.48	4.01	-0.008	↓	0.001
May	37.40	1.43	3.82	-0.134	↓	-0.036
June	36.34	1.69	4.67	0.006	↑	0.004
July	33.64	0.68	2.04	0.154	↑	0.018
August	33.29	0.53	1.61	0.441	↑*	0.035
September	32.9	0.72	2.21	0.380	↑*	0.044
October	32.05	0.82	2.56	0.078	↑	0.001
November	29.21	0.51	1.76	0.046	↑	0.003
December	24.43	1.07	4.40	-0.199	↓	-0.023
Annual	31.43	0.46	1.47	0.070	↑	0.003
Winter	24.36	1.18	4.84	-0.075	↓	-0.011
Pre-monsoon	35.52	0.99	2.79	-0.025	↓	-0.006
Monsoon	34.04	0.59	1.76	0.241	↑***	0.027
Post- monsoon	28.56	0.58	2.03	-0.114	↓	-0.008

Where, (↑) indicates increasing trends, (↓) indicates decreasing trend, *** 0.1 level of significance, **0.05 level of significance, * 0.01 level of significance

Rainfall variability analysis: The rainfall data over the past 30 years in Nalanda, Bihar, shows high variability. A statistical analysis was carried out to study annual, monthly, and seasonal rainfall patterns and identify any trends. The mean annual rainfall was found to be 609.02 with SD of 129.81mm with a coefficient of variation (CV) of about 40%, indicating considerable year-to-year changes, resulting in inter annual Variability. Monthly analysis (from 1992 to 2022) showed that July receives the highest rainfall, while December(3.4mm) receives the least. Specifically, in July month the average rainfall was 142.44 ±25.84 mm, This indicates that rainfall in Nalanda is not only seasonal but also highly inconsistent, especially in the post-monsoon months like December with 3.48 ± 12.03.

Table 5 : Average Rainfall(mm) trend for duration 1992-2022 for Nalanda Region.

Time Series	Mean	SD	CV	MK	Significance	Slope
January	13.74	28.29	205.80	0.060	↑	0.001
February	11.5	19.42	168.90	0.025	↑	0.001
March	8.37	23.03	275.04	0.185	↑	0.002
April	11.32	21.26	187.73	0.063	↑	0.003
May	46.79	47.56	101.65	0.137	↑	0.691
June	120.75	82.72	68.50	0.015	↑	0.115
July	270.73	137.55	50.80	-0.126	↓	-1.988
August	204.73	88.31	43.13	-0.243	↓	-2.703
September	189.65	95.14	50.16	-0.139	↓	-2.557
October	52.88	62.14	117.51	0.086	↑	0.055
November	6.11	16.58	271.30	-0.293	↓**	0.003
December	3.78	13.37	353.77	0.140	↑	0.002
Annual	940.39	286.14	30.42	-0.066	↓	-3.777
Winter	25.24	39.58	156.79	0.058	↑	0.002
Pre-Monsoon	66.49	65.94	99.17	0.174	↑	1.075
Monsoon	785.87	252.15	32.08	-0.208	↓	-6.475
Post-Monsoon	62.77	63.45	101.07	-0.066	↓	-0.521

Where, (↑) indicates increasing trends, (↓) indicates decreasing trend, *** 0.1 level of significance, **0.05 level of significance, * 0.01 level of significance.

Temporal variation of reference ET_0: Over the past 30 years, the monthly reference evapotranspiration (ET_0) in Nalanda has shown moderate seasonal variation. The long-term monthly ET_0 ranged from 78.06 mm/month in January to 187.41mm/month in May, indicating that May experiences the highest water loss through evapotranspiration. Overall, the annual average reference ET_0 for the region was 1555.075 mm/year, reflecting the local climate conditions. The relatively lower ET_0, compared to Other Region of Bihar is due to moderate temperatures and lower solar radiation levels in Nalanda. Despite these differences, May consistently recorded the highest ET_0 across years, which aligns with findings from previous studies, such as Patel *et al.,* (2017) who observed similar patterns during the 1970–2012 period in case of Nalanda.

Table 6 : Monthly reference ET_0 (mm/month) estimated by CROPWAT for duration 1992-2022

Seasons	**Months**	**ET_0**
WINTERS	January	78.06
	February	94.36
		86.21
PRE-MONSOON	March	143.89
	April	177.73
	May	187.41
		169.67
MONSOON	June	167.33
	July	144.16
	August	135.89
	September	121.40
		142.19
POST MONSOON	October	120.52
	November	104.43
	December	85.28
		103.41
	Total	**1555.075**

Temporal variation of Effective Rainfall for Nalanda Region: During the monsoon months (July to September), heavy and high-intensity rains occur in Nalanda. However, only a portion of this water can be absorbed and stored in the root zone of crops, making the effectiveness of such rainfall relatively low. In contrast, frequent light rains during the post-monsoon period (October to May) have close to 100% effectiveness, as they are better utilized by crops. Doorenbos *et al.* (1977) Based on data from 1992 to 2022, the average annual effective rainfall in Nalanda was estimated to be around 609.03 mm. The monsoon season contributes the highest amount of effective rainfall, while the winter season shows the lowest. As per the monthly data: July recorded the highest effective rainfall at 142.44 mm, followed by August at 127.33 mm, September at 120.21 mm, and June at 86.98 mm. These values indicate that most of the effective rainfall occurs during the monsoon, which is crucial for crop planning and water resource management in the region.

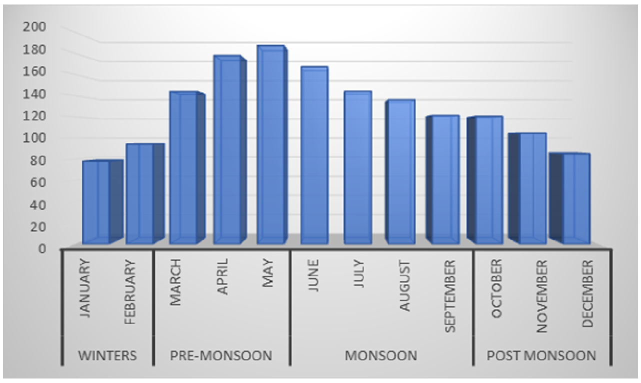

Fig. 1 : Reference Evapotranspiration

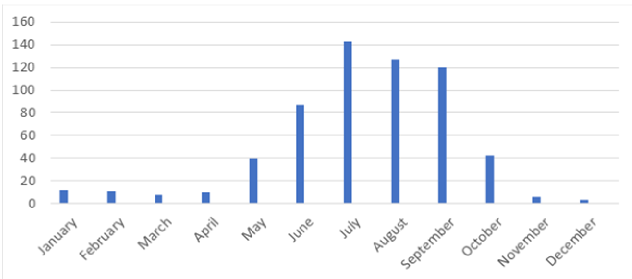

Fig. 2 : Monthly Effective Rainfall of Nalanda Region

Table 7 : Effective rainfall(mm/month) estimated by CROPWAT for duration 1992-2022

Months	Effective Rainfall
January	12.20323
February	10.70645
March	7.43871
April	10.42581
May	39.78387
June	86.98065
July	142.4452
August	127.3355
September	120.2129
October	42.39355
November	5.625806
December	3.480645
Total	**609.0323**

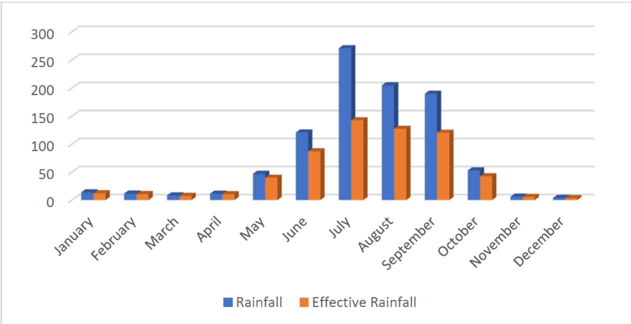

Fig. 3 : Rainfall vs Effective Rainfall

Estimation of Crop water requirement for mustard crop:

The crop water requirement (CWR) for mustard (*Brassica juncea* L.) in the Nalanda region of Bihar was estimated using the CROPWAT model over the period 1992–2022. Nalanda falls within the Middle Gangetic Plain agro-climatic zone, characterized by a subtropical climate with moderate rainfall and temperature variations. The average CWR for mustard in this region was found to be approximately 336.36 mm per season. The sowing period for mustard in Nalanda typically ranges from October 15th to October 25th, aligning with regional agricultural practices. Analysis indicates that the highest water demand occurs during the mid-growth stage, particularly during flowering and pod development phases in January and February.

As plants establishes its root system and develop its canopy, its needs sufficient water to support this rapid vegetative growth. Water stress during flowering can significantly reduce the number of flower and consequently the number of pods that form. Adequate water ensures proper flower development and successful pollination. After flowering the plant shift its energy to developing the pod and filling the seeds with them. This process also required substantial amount of water for nutrient uptake and efficient translocation of photosynthates to developing seeds. Water stress at this stage can lead to poorly filled pods and reduce seed size and oil content.

Table 8 : Crop water requirement(mm/dec) of mustard for Nalanda Region from 1992-2022.

Month	Stage	Phenological Stages	Nalanda
Oct	Init	Seed emergence	8.148387
		Two Leaf	14.43871
			22.5871
Nov	Deve	Four Leaf	12.91935
		Branching	18.20968
			24.39677
Dec		Inflorescence	29.36129
			84.8871
	Mid	Flowering Stage	31.46129
		Siliqua	33.8871
Jan		Fruit development	29.39677
			28.1871
			122.9323
	Late	Ripening	34.31935
Feb			30.07742
		Senescence	26.7
		Harvesting	14.86129
			105.9581
Total			**336.3645**

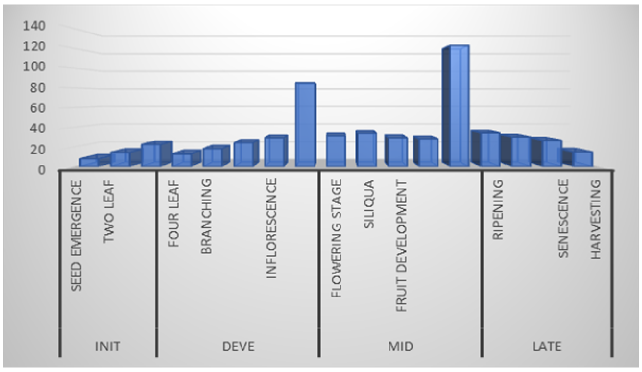

Fig. 4 : Crop water requirement

Irrigation water requirement analysis*:* The Irrigation water requirement of Mustard crop was highest in Nalanda (278.62mm/season) It can be observed from table 4.7 that during middle stage of Mustard when crop is at flowering stage to pod formation time, the requirement of irrigation is essential. The irrigation water requirement is important in development and middle stage of Mustard. Solanki *et al.* (2015) carried out an experiment on phenology and productivity of Indian Mustard (*Brassica juncea* L.) under varying sowing environment and irrigation levels consisting of four irrigation levels (no irrigation, at vegetative stage, at vegetative and flowering stages and at vegetative, flowering and siliqua development stages) and they reported that application of three irrigations gave significantly higher seed yield by 92.0, 28.0 and 4.0 per cent over no irrigation, one and two irrigations, respectively.

Table 9 : Irrigation water Requirement(mm/dec) of mustard for Nalanda Region from 1992-2022.

Month	Stage	Phenological Stages	Nalanda
Oct	Init	Seed emergence	5.26
		Two Leaf	9.04
			14.31
Nov	Deve	Four Leaf	15.98
		Branching	22
Dec			27.5
		Inflorescence	29.33
			94.81
Jan	Mid	Flowering Stage	31.94
		Siliqua	25.19
		Fruit development	22.99
Feb			29.15
			109.27
	Late	Ripening	25.59
		Senescence	21.94
		Harvesting	12.7
			60.23
Total			**278.6229**

Trend analysis of Reference Evapotranspiration ET_0 for duration 1992-2022 for Nalanda: The Mann-Kendall test results for monthly, seasonal, and annual reference evapotranspiration (ET_0) of Nalanda, Bihar. The analysis shows at which level a significant decreasing trend in ET_0 during the Pre-monsoon season, with a rate ranging from 0.25 mm/year. In Nalanda, non-significant decreasing trends were observed during Winter, Monsoon, and Post-monsoon seasons. This reduction in water loss is negatively associated with increased productivity of Rabi crops, especially mustard, in the Nalanda region.

Table 10 : Trend analysis of ET_0 (mm/month) using Mann Kendal trend test

Year	Kendall's Tau	Sen's Slope
Annual	-0.13	-0.03
Winter	-0.12	-0.00
Pre-Monsoon	**-0.25*** **	-0.02
Monsoon	0.07	0.00
Post Monsoon	-0.17	-0.01

Trend analysis of effective rainfall : Overall, no significant trend in effective rainfall was found in Nalanda region for most seasons and the year as a whole. This means the amount of rainfall useful for crops has mostly remained stable over the last 30 years. However, small changes should still be monitored regularly to plan farming and water use better.

Table 11 : Trend analysis of effective rainfall(mm) using Mann Kendal trend test

Time Series	Mean	SD	CV	MK	Significance	Slope
January	12.20	23.73	194.45	0.06	↑	0.001
February	10.70	17.62	164.60	0.026	↑	0.001
March	7.43	19.05	256.11	0.185	↑	0.002
April	10.42	17.80	170.75	0.064	↑	0.003
May	39.78	32.98	82.91	0.138	↑	0.593
June	86.98	43.74	50.28	0.015	↑	0.065
July	142.44	25.84	18.14	-0.127	↓	-0.483
August	127.33	28.23	22.17	-0.243	↓***	-0.983
September	120.21	32.29	26.86	-0.14	↓	-0.835
October	42.39	38.50	90.83	0.086	↑	0.456
November	5.62	14.91	265.07	-0.293	↓**	0.003
December	3.48	12.03	345.62	0.141	↑	0.002
Annual	609.02	129.81	469.14	-0.037	↓	-0.931
Winter	22.90	33.92	67.54	0.057	↑	0.002
Pre - monsoon	57.64	50.32	114.54	0.17	↑	0.095
Monsoon	476.97	80.88	589.71	-0.174	↓	-2.405
Post - monsoon	51.50	40.97	125.68	-0.075	↓	-0.621

Where, (↑) indicates increasing trends, (↓) indicates decreasing trend, *** 0.1 level of significance, **0.05 level of significance, * 0.01 level of significance

Trend Analysis of Crop water requirement: The trend analysis of water requirement of Mustard crop (CWR) in Nalanda. The trend analysis has shown no significant trend but a non-significant decreasing trend has been observed in the study area of Nalanda. Thus, it indicates the decrease in crop water requirement of Mustard of Nalanda.

Table 12 : Trend analysis of Crop water requirement(mm/dec) using Mann Kendal trend test

Region	Kendall's tau (10%)	Kendall's tau (5%)	Kendall's tau (1%)
Nalanda	-0.314	-0.314	-0.314

Conclusion

By applying the CROPWAT model to the Nalanda region, the average maximum temperature was found to be 31.43±1.65°C, and the average minimum temperature was 19.49±0.43°C. The average annual rainfall was estimated to be 609.03 mm. The highest reference evapotranspiration (ET_0) occurred during the pre-monsoon season, while the lowest ET_0 was observed during the winter season. The annual ET_0 for Nalanda was found to be approximately 1555.08 mm. The crop water requirement (CWR) of mustard for Nalanda was estimated at 336.36 mm, and the irrigation water requirement (IWR) was 278.62 mm. Reference evapotranspiration (ET_0), effective rainfall, and crop evapotranspiration for mustard were estimated using CROPWAT from 1992–2022. ET_0 peaked in the pre-monsoon season, highlighting the increased evaporative demand in month of April–May.

It is concluded from the study that there is a non-significant declining trend in CWR of mustard for Nalanda region which indicate favorable environmental condition for the crop. The CWR of mustard was estimated to be around 336 mm.

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References

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements*. FAO Irrigation and Drainage Paper No. 56, Food and Agriculture Organization of the United Nations, Rome.

Banik, P., Tiwari, N.K. & Ranjan, S. (2014). Comparative crop water assessment using CROPWAT. *International Journal of Sustainable Materials, Processes & ECO-efficient-IJSMPE*, *1* (3).

Chhabra, V. (2015). Climate variability, extreme rainfall and temperature events over different agroecological zones of Bihar. *Journal of AgriSearch*, **2**(3), 189-194.

Chandra, R., & Kumari, S. (2021). Estimation of crop water requirement for rice-wheat and rice-maize cropping system using CROPWAT model for Pusa, Samastipur district, Bihar: Estimation of crop water requirement for cropping System at Pusa Bihar. *Journal of Agri. Search*, **8**(2), 143-148.

DD, P., & PATEL, H. Assessment of Mustard Yield Response, Soil Moisture Depletion and Yield Reduction Under Different Irrigation Levels Using Cropwat Model.

Doorenbos, J. & Pruitt, W. O. (1977). *Guidelines for Predicting Crop Water Requirements*. FAO Irrigation and Drainage Paper No. 24, FAO, Rome.

FAO. (2009). *CROPWAT 8.0 for Windows: Crop Water Requirements and Irrigation Scheduling*. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/land-water/databases-and-software/cropwat

Gill, S., Rawat, S., & Kulariya, S. S. (2024). Trend Analysis of Weather Variables and Reference Evapotranspiration of Mustard (*Brassica juncea* L.) Crop for Haryana, India. *International Journal of Environment and Climate Change*, **14**(9), 13-22.

Halimi, A.H. and Tefera A.H. (2019) Application of Cropwat Model for Estimation of Irrigation Scheduling of Tomato in Changing Climate of Eastern Europe: the Case Study of Godollo, Hungary *SSRG International Journal of Agriculture & Environmental Science,* **6**(1):01-11.

India Meteorological Department (IMD). (2022). *Daily Gridded Temperature and Rainfall Data*. Pune: Ministry of Earth Sciences, Government of India. Retrieved from https://www.imdpune.gov.in

Kendall, M. G. (1975). *Rank Correlation Methods* (4th ed.). London: Charles Griffin.

Kumar, J., Singh, A. K. P., & Hasan, W. (2018). Root Zone Water Uptake of Irrigated Mustard and Lentil. *Int. J. Pure App. Biosci. SPI*, **6**(1), 56-62.

Kulariya, S. S., Rawat, S., James, A., & Gill, S. (2024) Analysing the Temporal Variation of ET0 and Water Requirement of Mustard (*Brassica juncea* L.) Over Different Agroclimatic Zones of Uttar Pradesh by Using CROPWAT.

Kullu, N. P., Job, M., Rusia, D. K., Rai, P., & Dubey, A. (2019). Comparative study of irrigation scheduling for mustard crop using climatological method and CROPWAT model. *Int. J. of Current Microbio. and Appl. Sci,* **8***(12), 1575-1582.*

Mehanuddin, H., Nikhitha, G.R., Prapthishree, K.S., Praveen, L.B. & Manasa, H.G. (2018). Study on water requirement of selected crops and irrigation scheduling using CROPWAT 8.0. *International Journal of Innovative Research in Science, Engineering and Technology*, **7** (4), 3431-3436.

Ministry of Agriculture and Farmers Welfare. (2021). *District Agriculture Plan – Nalanda, Bihar*. Government of India.

Mukherjee, J. and Mondal, S. (2017). Comparison of crop evapotranspiration by FAO, BREB and pristley-taylor methodsin mustard crop in central Bihar region. *Journal of Agri. Search*, *4*(1), 55-59.

Praveen, K., Ray, R., Roy, L.B., & Tiwari, D.K. (2025). Assessment of irrigation water management using FAO-CROPWAT 8 in the Paliganj distributary of the Sone irrigation scheme in Bihar: a case study. *Journal of Water and Climate Change*, **16**(1), 34-50.

Rao, G. (2016). *Climate Resilient Agriculture for Ensuring Food Security in India*. National Institute of Agricultural Sciences, New Delhi.

Rathour, S., Kumari, M., Kumar, S., Panda, C.K., Nahakpam, S., & Behera, S.K. (2022). Economics of rapeseed-mustard production in Begusarai district of Bihar.

Shankar, V., Ojha, C.S.P. & Prasad, K. S. (2012). Irrigation scheduling for maize and Indian-mustard based on daily crop water requirement in a semi-arid region. *International Journal of Civil and Environmental Engineering,* **6**, 476-485.

Sinha, A., Ray, S., Majumder, S., Dash, B., Barik, B. R., & Reddy, (2024). M. D. Assessment of Wheat Crop Water Requirement for South Bihar by FAO CROPWAT 8.0. Agricultural Science Digest-A Research Journal, (Of).

Solanki, N.S. & Mundra, S.L. (2015). Phenology and productivity of mustard (*Brassica juncea* L.) under varying sowing environment and irrigation levels. *Annals of Agricultural Research*, *36*(3).

Surendran,U.,Sushanth, C.M., Mammen, G. and Joseph. (2017) FAO-CROPWAT Water Requirement of Selected Crops and Irrigation Scheduling Using CROPWAT 8.0.

Tesfaye, K., Aggarwal, P. K., Mequanint, F., Shirsath, P. B., Stirling, C. M., Khatri-Chhetri, A., & Rahut, D. B. (2017). Climate variability and change in Bihar, India: Challenges and opportunities for sustainable crop production. *Sustainability*, *9*(11), 1998.

Kuldeep Tiwari, K.T., Rohit Goyal, R. G., & Archana Sarkar, A. S. (2017). Impact of wheat and mustard crop water requirements on water resources management of development corridor.

Varshney, N. & Satpathy, S. (2017). Trend and change point analysis of rainfall of various districts of Bihar. *Int Res J Agricultural Econ Stat, 8(2),* 393-400.

Verma, R., & Singh, R.M. (2019). Water Requirement of Sugarcane Using Cropwat 8.0 Model: A Case Study of North India. *Int. J. Curr. Microbiol. App. Sci.,* **8**(10): 1452, 1459.

Zakwan, M., & Ara, Z. (2019). Statistical analysis of rainfall in Bihar. Sustainable (Water Resources Management), **5**(4), 1781-1789.