Original Research Article

Analysing the temporal variation of ET0 and water requirement of Mustard (*Brassica juncea* L.) over different Agroclimatic Zones of Uttar Pradesh by using CROPWAT

ABSTRACT

The agriculture sector is a major consumer of the water resource to fulfill the requirement of irrigation and its dependency on ground water is 70-90%. It is important to understand the crop water requirement to prepare a sustainable management of water resources. The Experiment was conducted for estimation of water requirement of Mustard crop and temporal variability of crop evapotranspiration for different Agroclimatic zones of Uttar Pradesh during time period (1992-2022). In this India Meteorological Department (IMD) Daily Gridded data (Maximum temperature, Minimum temperature and rainfall) is used and converted into Weekly, Monthly, Seasonally and Annually from Weather cock for run in the CROPWAT model which estimate the Reference evapotranspiration (ET_0), Effective Rainfall, Crop water requirement and Irrigation water requirement. After that we analyze the trend by using Mann-Kendall test. The result of the experiment revealed that the Average maximum temperature was 32.13±0.37□ and average minimum temperature was 18.96±0.35□ average rainfall estimated 638.45±170.92mm.The monthly analysis of maximum temperature for 30 years data revealed that the month of January has lowest maximum temperature while May month observes highest maximum temperature for all the nine Agroclimatic zones of Uttar Pradesh and the lowest minimum temperature was in month of January in all the agroclimatic zones. The monthly analysis of rainfall for time period (1992-2022) showed that for overall Uttar Pradesh region July, August month receives the highest amount of rainfall, while November, December month receives lowest rainfall.

Keywords: evapotranspiration, sustainable management, *Brassica juncea*, agricultural productivity

Introduction:

Indian mustard (*Brassica juncea*. L.) belonging to the Brassicaceae family is one of the oldest and most important oilseed crops. The Brassicaceae contains about 3500 species and 350

genera and is one of the 10 most economically important plant families. Rapeseed/Toria and mustard are the third most important edible oilseed crops of the world after soybean and palm oil. Two mostly cultivated species of Rapeseed and mustard are Brassica juncea and Brassica campestris. The oil content varies from 37 to 49%.

Globally, Indian mustard is one of the important oilseed crops and is currently ranked as the world's third important oil seed crop in terms of production and area. Total area, production and yield of rapeseed-mustard in world during 2023-24 was 42.53 million hectares (mha), 88.07 million metric tonnes and 2.07 metric tonnes per hectare. Globally, India account for 19.8 % and 9.8% of the total acreage and production **(USDA, 2024).** Rapeseed-mustard (12.64 million tonnes) is the second most important annual oilseed crop in India, next to soybean (14.98 million tonnes). In India, Mustard is grown over an area of about 6.26 million hectares with a production of 8.68 million tonnes and productivity of 1.3 t/ha. Total area coverage under rapeseed-mustard in Uttar Pradesh is 1.27 million hectares with a total production of 1.9 million tonnes and productivity of 1.5 t/ha **(GOI, 2023)**.

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 **(Surendran *et al.,* 2017).** 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 **[Rahaman *et al., 2004*].** 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.

The productivity is quite lower than developed countries mainly due to sub-optimal application of fertilizers and cultivation on marginal lands in rainfed conditions. Although mustard is a long day plant requiring 16 h of light period in 24 h cycle, it can made to flowering if it is provided with a cycle of 8 h of light period with 4 h of dark period (short night). Mustard can be made to flower in about 50 days under 16/8 h light/dark period **(Lal *et al.,* 2020)**

The growth and development of mustard crop is highly sensitive to weather variables. Weather

is an important uncontrollable factor influencing crop growth and development. Crop simulation models are extensively used to understand the influence of meteorological parameters, soil properties, crop genotype and crop management practices on various agricultural applications However, evaluation of crop simulation models at farmers' fields is rare. In comparison to experimental fields, the situation of farmer's fields is more challenging owing to large scale variability in sowing conditions, management practices and unavailability of precise measurements **(Goyal *et al.*, 2021).**

Objectives:

To analyze the trends and variations in key weather variables (such as temperature, precipitation, and humidity) and reference evapotranspiration over time, and assess their implications for agricultural practices and water resource management in Uttar Pradesh.

MATERIALS AND METHODS

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

3.1 Experimental Site: Uttar Pradesh is located between 23°52' to 30°24' northern latitude and 77°05' to 84°38' east longitude. It measures 650 km from east to west and 240 km from south to north. Uttar Pradesh has a total area of 243,286 km² sq km, which is 7.33% of the total area of India. Uttar Pradesh is India's fourth largest state by land area, and most populous state, located in the north-central part of the country. It spreads over a large area, and the plains of the state are quite distinctly different from the high mountains in the north. The climate of this state can also vary widely - primarily due to it being far from the moderating effect of the sea and the occasional cold air arising due to western disturbances.Uttar Pradesh experiences a range of climates and weather conditions due to its diverse geographical features. Generally, it has a subtropical climate with hot summers and cool winters. Monsoon season brings heavy rainfall from June to September, while winters can be quite cold, especially in the northern regions. Coastal areas tend to be more humid, while the western part experiences drier conditions.

3.1.2 Agroclimatic zones of Uttar Pradesh

Based on Thornthwaite’s classification Uttar Pradesh state can be broadly divided into nine climatic zones namely Southern-Western Semi-Arid region, Central Western Plains, Bhabar and

Terai Region, Northern-Eastern Plain, Bundelkhand Region, Central Plain, Western Plains, Vindhya Region, Eastern Plain.

Table 1 Selected Sites for the Experiment

S. No.	Agroclimatic Zones	Selected site
1	Southern-Western Semi-Arid region	Agra
2	Central Western Plains	Badaun
3	Bhabar and Terai Region	Bahraich
4	Northern-Eastern Plain	Gorakhpur
5	Bundelkhand Region	Jhansi
6	Central Plain	Kanpur
7	Western Plains	Meerut
8	Vindhya Region	Mirzapur
9	Eastern Plain	Varanasi

3.2 Data Collection

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

3.3 Methodology

Table 2 Crop coefficients of Mustard crop.

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

Gupta *et al*., (2017)

3.3.3 Soil data: Soil data taken from FAO Irrigation and drainage, paper no. 56, FAO

Table 3Different types of Soil data

S. No	Soil description	Loamy soil
1	Total available soil moisture (FC-WP), mm/m	200
2	Maximum rain infiltration rate, mm/day	30
3	Maximum rooting depth, cm	80
4	Initial soil moisture depletion (as % TAM), %	0

5	Initial available soil moisture, mm/m	200

RESULT AND DISCUSSION

Result obtained from the study entitled as Weather variables and Reference evapotranspiration of Mustard *(Brassica juncea L.)*crop for Uttar Pradesh, India: A trend analysishas been presented in this chapter with the help of tables and graphs, wherever it is necessary. The result obtained from the present study has been finalized in the following subheads:

4.1.1 Maximum Temperature:

The analysis that mean maximum temperature of Uttar Pradesh state for the given time period (1992-2022) was around 32.13 ± 0.37□ Out of all 9 agroclimatic zones the average annual maximum temperature was highest in Bundelkhand Region i.e. (32.82 ± 0.52□) and lowest in Central Western Plains& Western Plains (31.25 ± 0.52□). It may be observed that highest variation of maximum temperature in seasonal analysis was found in winter season. And the highest CV was found in winter season. in all the 9 agroclimatic zones the MK test and Sen's slope estimator calculations were performed on average monthly and seasonal maximum temperature and results are presented in table 4 From the table 4 it may be observed that there no significant trend in seasonal & annual analysis of maximum temperature time period (1992-2022), in Southern-Western Semi-Arid region, Central Western Plains, Bundelkhand Region, Western Plains, Eastern Plain will there is significant decreasing trend in Bhabar and Terai Region, Northern-Eastern Plain, Central Plain, Vindhya Region while in case of Bhabar and Terai Region and Northern-Eastern Plain, there is significant decreasing trend In case of Bhabar & Terai region it may be concluded that there is significant decrease in winter & post monsoon season. The similar pattern has been observed in Northern-Eastern plain agroclimatic zones shown significantly decreasing trend in maximum temperature during post monsoon season. **(Anurag *et al.*,2018)**

4.1.2 Minimum Temperature:

The lowest minimum temperature was in month of January in all the agroclimatic zones. The lowest minimum temperature was in western plains (7.13 ± 0.76□), followed by(7.29 ± 0.73□) in Central Western Plains. The highest minimum temperature was observed in month of June July over all the agroclimatic zones of Uttar Pradesh. The annual minimum temperature was observed highest in Northern-Eastern Plain, Central Plain, Eastern Plain with (19.24 ± 0.41□) and lowest in central western plains (18.42 ± 0.35□) from all the 9 agroclimatic zones. The MK test also identified significantly increasing trend in annual minimum temperature for Southern-Western Semi-Arid region, Northern-Eastern Plain, Bundelkhand Region, Western Plains, Eastern Plain with the magnitude of 0.018□/year, 0.015□/year, 0.019 □/year, 0.006 □/year, 0.020□/year respectively. **(Anurag *et al.*,2018)**

4.1.3 Rainfall variability analysis:

The mean annual rainfall was found to be 851.27 ± 201.90mm with variation around 24% for the overall Uttar Pradesh.The monthly analysis of rainfall showed that for overall Uttar Pradesh region July & August month receives the highest amount of rainfall(373.91±173.25mm), while November, December month receives lowest rainfall(5.02±13.54mm).

The MK test represents increasing and decreasing trend in all the different agroclimatic zones There is increasing significantly trend in annual rainfall Bhabar and Terai Region rainfall with magnitude of around 7.844 mm/year, while significantly decreasing trend for annual rainfall of Northern-Eastern Plain region with magnitude of about 9.933 mm/year. The similar pattern in central plain i.e. significantly increasing trend with 16.304 mm/year rainfall.

The seasonal analysis of the rainfall data shows that out of nine agroclimatic zones of Uttar Pradesh there is significantly increasing trend of rainfall in four Agroclimatic regions iv Pre monsoon seasons. The four are Southern-Western Semi-Arid region (1.13 mm/year), Central plain (0.713mm/year), Western plain (1.547mm/year) and Vindhya region with 0.883 mm/year. **(Anurag *et al.*,2017)**

4.3.1Trend analysis of Reference Evapotranspiration $ET_0$for duration 1992-2022 for different ACZs of Uttar Pradesh: From Table 8Trend analysis of ET_0 using Mann Kendal trend test in**:**Average annual $ET_0$54.41mm and seasonal ET_0 ranges from 5.53mm (Winter) to 20.28mm (Monsoon) it shows in decreasing annual ET_0 trend with slope (-0.02), but monsoon

shows decreasing trend with slope (-0.01) in Southern-Western Semi-Arid region. In Central Western Plains zone average annual Et0 51.88mm and seasonal ET_0 ranges from 5.16mm (Winter) to 19.72mm (Monsoon) it shows increasing annual ET_0 trend with slope (0.0wor1), but monsoon shows decreasing trend with slope (-0.00). In Bhabar and Terai Region average annual Et0 51.38mm and seasonal ET_0 ranges from 5.39mm (Winter) to 18.79mm (Monsoon) it shows decreasing annual ET_0 trend with slope (-0.02), but monsoon shows increasing trend with slope (0.01). In Northern-Eastern Plain average annual $ET_0$51.35mm and seasonal ET_0 ranges from 5.62mm (Winter) to 18.70mm (Monsoon) it shows decreasing annual ET_0 trend with slope (-0.02), but monsoon shows increasing trend with slope (0.01). In Bundelkhand average annual ET_0 56.58mm and seasonal ET_0 ranges from 6.26mm (Winter) to 20.28mm (Monsoon) it shows decreasing annual ET_0 trend with slope (-0.03), but monsoon shows decreasing trend with slope (-0.01). In Central Plain annual $ET_0$52.73mm and seasonal ET_0 ranges from 5.60mm (Winter) to 19.22 (Monsoon) it shows decreasing annual ET_0 trend with slope(-0.03) ,but monsoon shows decreasing trend with slope (-0.01).In Western Plains average annual ET_0 52.62mm and seasonal ET_0 ranges from 5.04mm (Winter) to 20.45mm(Monsoon) it shows increasing annual ET_0 trend with slope(0.01) ,but monsoon shows decreasing trend with slope(-0.01). In Vindhya Region average annual ET_0 53.46mm and seasonal ET_0 ranges from 5.97mm (Winter) to 19.09(Monsoon) it shows decreasing annual ET_0 trend with slope (-0.01), but monsoon shows increasing trend with slope (0.01). In Eastern Plain average annual ET_0 52.98mm and seasonal ET_0 ranges from 5.90mm (Winter) to 19.18mm (Monsoon) it shows decreasing annual ET_0 trend with slope (-0.02), but monsoon shows increasing trend with slope (0.01).**Narjary *et al.,(*2013)**

The analysis of MK test revels that reference evapotranspiration of mustard crop has shown decreasing trend in Uttar Pradesh. There is significantly decreasing trend of ET_0 during winter & post monsoon season in Northern-Eastern Plains. Similarly significantly decreasing trend of ET_0 in winter for Bhabar and Terai Region&Central Plain.

4.4.2 Trend analysis of effective rainfall: From Table 7 Theseasonal rainfall ranges from 16.81mm (Winter) to 333.20mm (Monsoon) it also shows nonsignificant increasing annual rainfall trend but monsoon season shows significantly increasing trend with slope (0.475mm/season) in Southern-Western Semi-Arid region. In Central Western Plains zone average annual rainfall of523.90mm and seasonal rainfall ranges from 32.07mm (Post Monsoon)

to 414.80mm (Monsoon) it also showsnonsignificant increasing annual rainfall trend. In Bhabar and Terai Region average annual rainfall 664.89mm and seasonal rainfall ranges from 36.47mm (Winter) to 518.46mm (Monsoon) it also shows nonsignificant increasing annual rainfall trend. In Northern-Eastern Plain average annual rainfall 664.37mm and seasonal rainfall ranges from 28.23mm (Winter) to 518.96mm (Monsoon) it also shows nonsignificant decreasing annual rainfall trend. In Bundelkhand average annual rainfall 516.30mm and seasonal rainfall ranges from 20.68mm (Winter) to 438.68mm (Monsoon) it also showsnonsignificant increasing annual rainfall trend.In Central Plain annual rainfall 452.03mm and seasonal rainfall ranges from 27.23mm (Winter) to 365.66mm (Monsoon) it also shows nonsignificant increasing annual rainfall trend.In Western Plains average annual rainfall 496.56mm and seasonal rainfall ranges from 20.26mm (Post-Monsoon) to 389.08mm (Monsoon) it also showsnonsignificant increasing annual rainfall trend. In Vindhya Region average annual rainfall 516.57mm and seasonal rainfall ranges from 25.68mm (Winter) to 436.70mm (Monsoon) it also showsnonsignificant increasing annual rainfall trend. In Eastern Plain Plains average annual rainfall 499.08mm and seasonal rainfall ranges from 19.92mm (Winter) to 424.13mm (Monsoon) it also shows nonsignificant decreasing annual rainfall trend.

From table 7 it may be concluded overall that from 9 agroclimatic zones five agroclimatic zones shows decreasing rainfall trend in monsoon season. It may be reveled from the Observation that regions receiving high rainfall i.e. Northern-Eastern Plain&Bhabar and Terai Region has show significantly decreasing trend of effective rainfall while for central plains significantly increasing trend of effective rainfall**(Chauhan *et al* .,2022).**

4.4.3Trend analysis of Crop water requirement: Trend analysis of Crop water requirement of mustard by MK test reveled that out of 9 zones only Central plain has shown significantly decreasing trend with magnitude of 2.08mm/season. Though all other zone also support negative trend but they are not significant**(Babu *et al.*,2015).**

Table:4Average Maximum temperature (□) in various Agroclimatic zones of Uttar Pradeshfor duration 1992-2022

1. Southern-Western Semi-Arid region						
Time series	**Mean**	**SD**	**CV**	**Mk**	**Trend**	**Slope**
Annual	32.35	0.52	1.60	-0.018	↓	-0.002
Winter	23.33	1.29	5.51	-0.153	↓	-0.035

Pre-Monsoon	37.44	0.99	2.64	0.078	↑	0.014
Monsoon	35.68	0.68	1.91	0.115	↑	0.010
Post Monsoon	28.84	0.97	3.37	-0.164	↓	-0.022
2.Central Western Plains						
Annual	31.25	0.52	1.66	0.048	↑	0.004
Winter	22.23	1.23	5.54	-0.145	↓	-0.030
Pre-Monsoon	35.71	1.07	3.00	0.118	↑	0.027
Monsoon	34.97	0.63	1.81	0.168	↑	0.016
Post Monsoon	27.84	0.94	3.38	-0.164	↓	-0.020
3.Bhabar and Terai Region						
Annual	31.50	0.50	1.60	-0.126	↓	-0.011
Winter	23.40	1.34	5.72	-0.234	↓*	-0.058
Pre-Monsoon	36.23	0.94	2.61	0.009	↑	0.000
Monsoon	34.31	0.71	2.06	0.078	↑	0.010
Post Monsoon	28.41	0.82	2.90	-0.304	↓**	-0.037
4.Northern-Eastern Plain						
Annual	31.52	0.47	1.48	-0.023	↓	-0.001
Winter	23.93	1.19	4.98	-0.249	↓*	-0.043
Pre-Monsoon	36.02	0.94	2.61	0.063	↑	0.007
Monsoon	34.18	0.67	1.97	0.219	↑*	0.029
Post Monsoon	28.55	0.69	2.40	-0.261	↓**	-0.024
5.Bundelkhand Region						
Annual	32.82	0.52	1.60	0.018	↑	0.001
Winter	25.06	1.31	5.23	-0.097	↓	-0.020
Pre-Monsoon	38.34	1.00	2.61	0.141	↑	0.027
Monsoon	34.96	0.75	2.14	0.104	↑	0.015
Post Monsoon	29.59	1.00	3.37	-0.083	↓	-0.012
6.Central Plain						
Annual	31.85	0.50	1.58	-0.149	↓	-0.014
Winter	23.67	1.35	5.71	-0.215	↓	-0.054
Pre-Monsoon	36.83	0.93	2.53	0.021	↑	0.006
Monsoon	34.64	0.75	2.18	0.035	↑	0.004
Post Monsoon	28.62	0.85	2.96	-0.260	↓**	-0.031
7.Western Plains						
Annual	31.25	0.52	1.66	0.048	↑	0.004
Winter	22.23	1.23	5.54	-0.145	↓	-0.030
Pre-Monsoon	35.71	1.07	3.00	0.118	↑	0.027
Monsoon	34.97	0.63	1.81	0.168	↑	0.016
Post Monsoon	27.84	0.94	3.38	-0.164	↓	-0.020
8.Vindhya Region						
Annual	31.97	0.46	1.44	-0.037	↓	-0.003
Winter	24.36	1.22	5.02	-0.185	↓	-0.038
Pre-Monsoon	37.00	0.92	2.49	0.058	↑	0.012
Monsoon	34.36	0.71	2.06	0.104	↑	0.014
Post Monsoon	28.81	0.73	2.52	-0.237	↓*	-0.024

9.Eastern Plain						
Annual	31.83	0.47	1.49	0.080	↑	0.005
Winter	24.32	1.15	4.72	-0.132	↓	-0.021
Pre-Monsoon	36.67	0.95	2.58	0.072	↑	0.012
Monsoon	34.37	0.68	1.98	0.212	↑	0.026
Post Monsoon	28.62	0.67	2.33	-0.216	↓	-0.017
Where, (↑) indicates increasing trends, (↓) indicates decreasing trend, *** 0.1 level of significance, **0.05 level of significance, * 0.01 level of significance						

Table:5Average Minimum temperature (□) in various Agroclimatic zones of Uttar Pradeshfor duration 1992-2022

1.Southern-Western Semi-Arid region						
Time series	**Mean**	**SD**	**CV**	**Mk**	**Trend**	**Slope**
Annual	19.05	0.39	2.04	0.276	↑**	0.018
Winter	9.09	0.67	7.38	0.135	↑	0.015
Pre-Monsoon	21.20	0.74	3.49	0.199	↑	0.024
Monsoon	26.33	0.38	1.44	0.418	↑**	0.023
Post Monsoon	13.85	0.64	4.59	0.102	↑	0.008
2.Central Western Plains						
Annual	18.42	0.35	1.89	0.161	↑	0.010
Winter	8.72	0.66	7.58	0.090	↑	0.010
Pre-Monsoon	19.92	0.72	3.63	0.058	↑	0.005
Monsoon	25.79	0.39	1.51	0.307	↑**	0.019
Post Monsoon	13.54	0.63	4.62	-0.012	↓	0.000
3.Bhabar and Terai Region						
Annual	19.10	0.38	1.97	-0.064	↓	-0.004
Winter	9.96	0.68	6.80	-0.032	↓	-0.005
Pre-Monsoon	20.66	0.67	3.26	0.028	↑	0.004
Monsoon	25.77	0.33	1.26	0.044	↑	0.002
Post Monsoon	14.73	0.63	4.27	-0.173	↓	-0.017
4.Northern-Eastern Plain						
Annual	19.24	0.46	2.39	0.283	↑**	0.015
Winter	10.15	0.72	7.09	0.143	↑	0.021
Pre-Monsoon	20.58	0.67	3.27	0.204	↑	0.015
Monsoon	25.63	0.47	1.84	0.221	↑*	0.017
Post Monsoon	15.44	0.67	4.33	0.162	↑	0.014
5.Bundelkhand Region						
Annual	18.63	0.49	2.64	0.295	↑**	0.019
Winter	9.13	0.79	8.63	0.174	↑	0.025
Pre-Monsoon	21.27	0.79	3.73	0.185	↑	0.025
Monsoon	25.24	0.54	2.12	0.307	↑**	0.024

Post Monsoon	13.50	0.72	5.33	0.099	↑	0.014
6.Central Plain						
Annual	19.24	0.38	1.98	0.131	↑	0.007
Winter	10.01	0.71	7.05	0.112	↑	0.013
Pre-Monsoon	21.05	0.70	3.35	0.120	↑	0.017
Monsoon	25.83	0.39	1.50	0.113	↑	0.007
Post Monsoon	14.80	0.66	4.46	-0.065	↓	-0.006
7.Western Plains						
Annual	18.48	0.35	1.90	0.121	↑	0.006
Winter	8.59	0.64	7.39	0.047	↑	0.003
Pre-Monsoon	20.16	0.73	3.63	0.000	↑	0.000
Monsoon	25.96	0.40	1.53	0.291	↑**	0.019
Post Monsoon	13.42	0.62	4.60	0.035	↑	0.002
8.Vindhya Region						
Annual	19.22	0.41	2.14	0.058	↑	0.003
Winter	10.06	0.68	6.76	0.028	↑	0.003
Pre-Monsoon	20.95	0.67	3.20	0.072	↑	0.004
Monsoon	25.66	0.41	1.59	0.092	↑	0.009
Post Monsoon	15.00	0.64	4.24	-0.134	↓	-0.014
9.Eastern Plain						
Annual	19.24	0.40	2.10	0.265	↑**	0.020
Winter	10.20	0.69	6.80	0.192	↑	0.018
Pre-Monsoon	20.92	0.67	3.18	0.268	↑**	0.022
Monsoon	25.46	0.43	1.70	0.301	↑**	0.024
Post Monsoon	15.29	0.63	4.14	0.078	↑	0.008
Where, (↑) indicates increasing trends, (↓) indicates decreasing trend, *** 0.1 level of significance, **0.05 level of significance, * 0.01 level of significance						

Table:6Average Rainfall (mm) in various Agroclimatic zones of Uttar Pradeshfor duration 1992-2022

1.Southern-Western Semi-Arid region						
Time series	**Mean**	**SD**	**CV**	**Mk**	**Trend**	**Slope**
Annual	591.26	275.82	46.65	0.032	↑	3.047
Winter	17.55	17.63	100.45	0.104	↑	0.261
Pre-Monsoon	25.92	29.80	114.97	0.389	↑**	1.133
Monsoon	515.02	258.32	50.16	-0.032	↓	-0.882
Post Monsoon	32.77	48.90	149.23	0.145	↑	0.242
2.Central Western Plains						

Annual	827.76	193.47	23.37	-0.002	↓	-0.020
Winter	35.84	31.76	88.60	0.032	↑	0.186
Pre-Monsoon	47.10	34.23	72.68	0.191	↑	1.130
Monsoon	707.59	215.99	30.52	-0.056	↓	-2.192
Post Monsoon	37.23	48.05	129.06	0.136	↑	0.257
3.Bhabar and Terai Region						
Annual	1134.09	227.46	20.06	0.222	↑**	7.844
Winter	38.98	33.92	87.02	0.067	↑	0.226
Pre-Monsoon	75.22	56.48	75.08	0.178	↑	1.300
Monsoon	959.43	218.60	22.78	0.114	↑	4.938
Post Monsoon	60.46	86.26	142.67	0.026	↑	0.033
4.Northern-Eastern Plain						
Annual	1207.48	336.58	27.87	-0.230	↓*	-9.933
Winter	30.95	44.00	142.19	-0.026	↓	-0.023
Pre-Monsoon	79.21	73.74	93.10	0.092	↑	0.805
Monsoon	1029.30	312.86	30.40	-0.187	↓	-9.895
Post Monsoon	68.02	77.91	114.53	0.011	↑	0.000
5.Bundelkhand Region						
Annual	850.02	250.81	29.51	0.123	↑	4.443
Winter	22.30	28.42	127.46	0.231	↑*	0.373
Pre-Monsoon	25.04	24.07	96.15	0.157	↑	0.400
Monsoon	765.15	239.52	31.30	0.062	↑	2.670
Post Monsoon	37.54	46.61	124.16	0.015	↑	0.000
6.Central Plain						
Annual	651.34	264.64	40.63	0.389	↑**	16.304
Winter	28.70	33.89	118.08	0.179	↑	0.482
Pre-Monsoon	29.25	37.09	126.81	0.220	↑*	0.713
Monsoon	556.84	235.77	42.34	0.325	↑**	12.450
Post Monsoon	36.55	49.34	134.98	0.187	↑	0.735
7.Western Plains						
Annual	774.13	238.77	30.84	-0.105	↓	-3.589
Winter	49.06	48.38	98.61	0.123	↑	0.645

Pre-Monsoon	46.64	36.91	79.13	0.299	↑**	1.547
Monsoon	653.91	235.73	36.05	-0.200	↓	-8.130
Post Monsoon	24.52	46.66	190.31	0.376	↑**	0.443
8.Vindhya Region						
Annual	845.75	307.80	36.39	0.114	↑	4.600
Winter	27.29	26.56	97.33	-0.013	↓	-0.016
Pre-Monsoon	29.33	33.78	115.17	0.250	↑**	0.883
Monsoon	759.26	303.97	40.03	0.045	↑	2.838
Post Monsoon	29.87	37.36	125.09	0.075	↑	0.100
9.Eastern Plain						
Annual	779.61	252.67	32.41	-0.196	↓	-7.029
Winter	21.11	25.79	122.16	-0.122	↓	-0.191
Pre-Monsoon	26.42	30.84	116.75	0.030	↑	0.038
Monsoon	696.81	245.14	35.18	-0.286	↓**	-8.458
Post Monsoon	35.27	45.88	130.05	-0.026	↓	-0.030
Where, (↑) indicates increasing trends, (↓) indicates decreasing trend, *** 0.1 level of significance, **0.05 level of significance, * 0.01 level of significance						

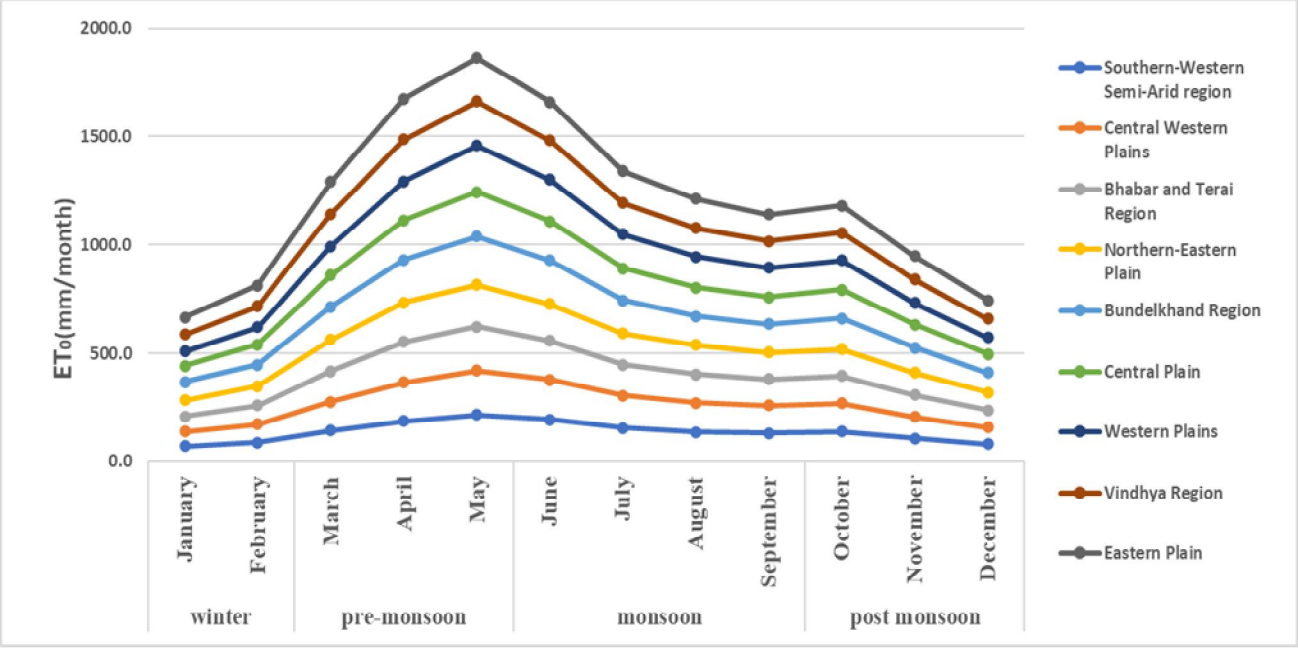

Figure 1 Reference Evapotranspiration

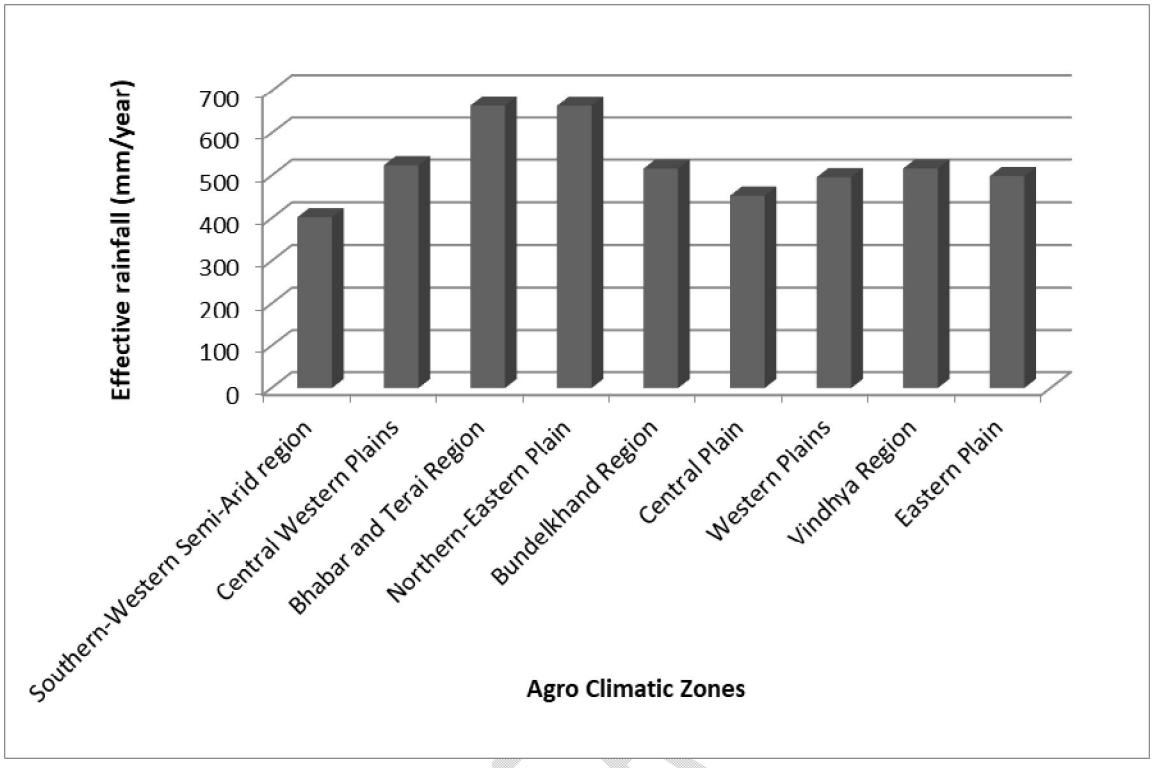

Figure 2 Yearly effective rainfall of different ACZs

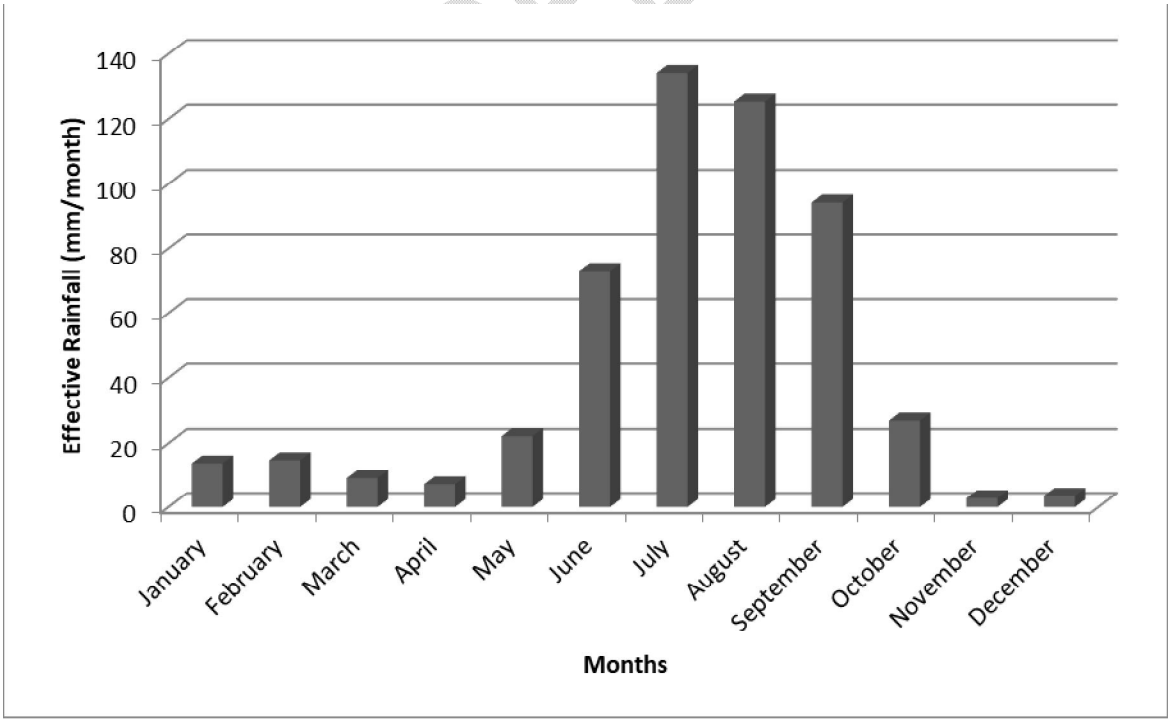

Figure 3 Monthly effective rainfall of different ACZs

The effective rainfall estimated using CROPWAT has been shown in Table 5. The temporal variation of effective rainfall for all the agroclimatic zones shows a similar pattern. The highest amount of effective rainfall is estimated during July month with an average value of around 134.12 mm/month, while lowest effective rainfall is estimated for December month average value of (3.47mm/month) as shown in Figure no. 2. This is a similar pattern which we have observed in rainfall variability. Table 7 The spatial variability of different agroclimatic zones shows that Northern-EasternPlain and Bhabar and Terai Region has highest effective rainfall amount received i.e. 664.37 & 664.89mm/year while Southern-Western Semi-Arid region receives lowest effective rainfall (402.71mm/year).

Table:7Trend analysis of ET_0(mm/month)using Mann Kendal trend testfor duration 1992-2022

1.Southern-Western Semi-Arid region						
Time series	**Mean**	**SD**	**CV**	**Mk**	**Trend**	**Slope**
Annual	54.41	1.27	2.33	-0.07	↓	-0.02
Winter	5.53	0.35	6.38	-0.17	↓	-0.01
Pre-Monsoon	17.90	0.59	3.28	0.04	↑	0.01
Monsoon	20.28	0.83	4.10	-0.07	↓	-0.01
Post Monsoon	10.70	0.51	4.77	-0.12	↓	-0.01
2.Central Western Plains						
Annual	51.88	1.23	2.36	0.05	↑	0.01
Winter	5.16	0.33	6.32	-0.10	↓	-0.01
Pre-Monsoon	16.95	0.64	3.77	0.12	↑	0.02
Monsoon	19.72	0.73	3.72	-0.02	↓	0.00
Post Monsoon	10.05	0.47	4.72	-0.09	↓	-0.01
3.Bhabar and Terai Region						
Annual	51.38	1.32	2.56	-0.10	↓	-0.02
Winter	5.39	0.39	7.21	-0.24	↓*	-0.02
Pre-Monsoon	17.11	0.60	3.50	-0.03	↓	0.00
Monsoon	18.79	0.91	4.84	0.02	↑	0.01
Post Monsoon	10.08	0.43	4.25	-0.18	↓	-0.01
4.Northern-Eastern Plain						
Annual	51.35	1.43	2.79	-0.11	↓	-0.02
Winter	5.62	0.37	6.51	-0.24	↓*	-0.01
Pre-Monsoon	16.99	0.66	3.88	-0.11	↓	-0.01
Monsoon	18.70	0.84	4.49	0.04	↑	0.01
Post Monsoon	10.04	0.39	3.86	-0.24	↓*	-0.01
5.Bundelkhand Region						

Annual	56.58	1.38	2.45	-0.08	↓	-0.03
Winter	6.26	0.41	6.53	-0.05	↓	0.00
Pre-Monsoon	18.66	0.61	3.25	0.02	↑	0.00
Monsoon	20.28	0.93	4.60	-0.10	↓	-0.01
Post Monsoon	11.39	0.61	5.35	0.03	↑	0.00
6.Central Plain						
Annual	52.73	1.33	2.52	-0.14	↓	-0.03
Winter	5.60	0.39	7.05	-0.22	↓*	-0.02
Pre-Monsoon	17.50	0.59	3.39	-0.03	↓	0.00
Monsoon	19.22	0.94	4.91	-0.03	↓	-0.01
Post Monsoon	10.41	0.48	4.63	-0.08	↓	-0.01
7.Western Plains						
Annual	52.62	1.16	2.20	0.03	↑	0.01
Winter	5.04	0.31	6.15	-0.05	↓	0.00
Pre-Monsoon	17.07	0.62	3.64	0.17	↑	0.01
Monsoon	20.45	0.69	3.38	-0.07	↓	-0.01
Post Monsoon	10.06	0.49	4.84	-0.14	↓	-0.01
8.Vindhya Region						
Annual	53.457	1.266	2.367	-0.043	↓	-0.008
Winter	5.967	0.395	6.615	-0.173	↓	-0.014
Pre-Monsoon	17.765	0.569	3.203	-0.028	↓	-0.003
Monsoon	19.091	0.828	4.337	0.052	↑	0.009
Post Monsoon	10.634	0.421	3.959	-0.106	↓	-0.009
9.Eastern Plain						
Annual	52.98	1.32	2.50	-0.05	↓	-0.02
Winter	5.90	0.36	6.03	-0.19	↓	-0.01
Pre-Monsoon	17.51	0.60	3.40	-0.07	↓	-0.01
Monsoon	19.18	0.79	4.14	0.05	↑	0.01
Post Monsoon	10.39	0.42	4.02	-0.17	↓	-0.01
Where, (↑) indicates increasing trends, (↓) indicates decreasing trend, *** 0.1 level of significance, **0.05 level of significance, * 0.01 level of significance						

Table: 8 Trend analysis of effective rainfall(mm) using Mann Kendal trend testfor duration 1992-2022

1.Southern-Western Semi-Arid region						
Time series	**Mean**	**SD**	**CV**	**Mk**	**Trend**	**Slope**
Annual	402.71	140.69	34.94	0.088	↑	2.965
Winter	16.81	16.58	98.64	0.112	↑	0.254
Pre-Monsoon	24.40	26.82	109.92	0.390	↑**	1.104

Monsoon	333.20	119.66	35.91	0.032	↑	0.475
Post Monsoon	28.30	39.50	139.57	0.145	↑	0.242
2.Central Western Plains						
Annual	523.90	79.63	15.20	0.009	↑	0.030
Winter	33.33	27.76	83.29	0.030	↑	0.167
Pre-Monsoon	43.71	30.49	69.76	0.183	↑	0.972
Monsoon	414.80	81.64	19.68	-0.114	↓	-1.830
Post Monsoon	32.07	36.78	114.69	0.141	↑	0.272
3.Bhabar and Terai Region						
Annual	664.89	79.23	11.92	0.088	↑	1.667
Winter	36.47	31.08	85.21	0.062	↑	0.207
Pre-Monsoon	65.25	44.42	68.07	0.166	↑	1.137
Monsoon	518.46	59.85	11.54	-0.045	↓	-0.450
Post Monsoon	44.72	46.76	104.57	0.022	↑	0.032
4.Northern-Eastern Plain						
Annual	664.37	118.12	17.78	-0.170	↓	-2.582
Winter	28.23	36.72	130.07	-0.056	↓	-0.071
Pre-Monsoon	65.79	42.77	65.01	0.103	↑	0.750
Monsoon	518.96	79.74	15.36	-0.217	↓**	-2.783
Post Monsoon	51.38	50.91	99.08	0.009	↑	0.000
5.Bundelkhand Region						
Annual	516.30	87.57	16.96	0.226	↑*	3.384
Winter	20.68	25.38	122.68	0.235	↑*	0.340
Pre-Monsoon	23.83	22.04	92.48	0.161	↑	0.400
Monsoon	438.68	65.05	14.83	0.161	↑	2.157
Post Monsoon	33.11	38.96	117.66	0.015	↑	0.000
6.Central Plain						
Annual	452.03	149.34	33.04	0.419	↑**	7.680
Winter	27.23	28.52	104.74	0.147	↑	0.407
Pre-Monsoon	28.08	31.71	112.92	0.211	↑**	0.610

Monsoon	365.66	118.45	32.39	0.312	↑**	5.188
Post Monsoon	31.05	37.83	121.83	0.187	↑	0.675
7.Western Plains						
Annual	496.56	113.34	22.82	0.099	↑	1.124
Winter	44.06	41.22	93.55	0.121	↑	0.600
Pre-Monsoon	43.16	32.29	74.81	0.308	↑**	1.471
Monsoon	389.08	87.86	22.58	-0.127	↓	-1.819
Post Monsoon	20.26	33.30	164.35	0.379	↑**	0.435
8.Vindhya Region						
Annual	516.57	128.04	24.79	0.170	↑	3.238
Winter	25.68	24.48	95.33	-0.017	↓	-0.020
Pre-Monsoon	27.68	29.46	106.46	0.276	↑**	0.900
Monsoon	436.70	109.64	25.11	0.041	↑	0.894
Post Monsoon	26.52	29.38	110.78	0.071	↑	0.110
9.Eastern Plain						
Annual	499.08	116.37	23.32	-0.135	↓	-2.573
Winter	19.92	23.86	119.75	-0.122	↓	-0.200
Pre-Monsoon	24.37	25.79	105.79	0.030	↑	0.038
Monsoon	424.13	100.39	23.67	-0.166	↓	-3.075
Post Monsoon	30.66	37.99	123.92	-0.035	↓	-0.036
Where, (↑) indicates increasing trends, (↓) indicates decreasing trend, *** 0.1 level of significance, **0.05 level of significance, * 0.01 level of significance						

Table:9 Trend analysis of Crop water requirement (mm/dec) using Mann Kendal trend testfor duration 1992-2022

Agroclimatic zones	Kendall's tau	Sen's slope
Southern-Western Semi-Arid region	-0.18	-1.16

Central Western Plains	-0.07	-0.65
Bhabar and Terai Region	-0.16	-1.27
Northern-Eastern Plain	-0.08	-0.81
Bundelkhand Region	-0.14	-1.17
Central Plain	**-0.28****	-2.08
Western Plains	-0.17	-1.20
Vindhya Region	-0.10	-0.46
Eastern Plain	-0.05	-0.22

CONCLUSION

The 30-year analysis (1992-2022) of maximum temperatures in Uttar Pradesh revealed that January had the lowest and May the highest temperatures, with the state's average maximum temperature being around 32.13 ± 0.37°C.The average annual minimum temperatures washighest inthe Northern eastern plain, Central plain and eastern plain i.e 19.24°C and lowest in the Central western plain i.e. 18.42°C. Itmay be concluded from the study that the Crop water requirement of Mustard crop ranges from 302.8mm (Western Plain) to 372.5mm (Bundelkhand region) for the Uttar Pradesh region. It may be deduced further that different districts require different amount of water for Mustard due to varying ET_0 and variation in crop water requirement in different growth stages because of variation in crop coefficient. Thus in particular Agroclimatic zone selection of crop should be made on basis of crop water requirement and ET_0.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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