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Trend Analysis of Weather Variables and Reference Evapotranspiration of Mustard *(Brassica juncea* L.) Crop for Haryana, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The agriculture sector is a major consumer of the water resource to fulfil the requirement of irrigation. It is important to understand the crop water requirement to prepare a sustainable management of water resources. The present study was conducted for estimation of water requirement of Mustard crop and temporal variability of crop evapotranspiration for different Agroclimatic zones of Haryana during time period (1992-2022). In this 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

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estimates the reference evapotranspiration (ET_0), Effective rainfall, crop water requirement and irrigation water requirement. After that we analysed the trend by using Mann-Kendall test. The result of the experiment revealed that the analysis that maximum temperature of Haryana state for the time period 1992-2022 was around 30.43 ± 1.71℃ and minimum temperature was around 17.27±1.12℃ and rainfall was around 726.46±295.72mm. 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 and the lowest minimum temperature was in month of January in all the Agroclimatic zones of Haryana. The monthly analysis of rainfall for time period (1992-2022) showed that for overall Haryana region July month receives the highest amount of rainfall, while November month receives lowest rainfall.

Keywords: Weather variables; mustard; oilseed crop.

1. INTRODUCTION

Mustard (*Brassica juncea* L.) is a significant oilseed crop worldwide. It is one of the most significant and popular food items in the greater Indian subcontinent, including Bangladesh, particularly as an edible oil. This crop is deeply intertwined with the culture, traditions, society, and culinary practices of the region for various reasons. Mustard oil is essential in preparing numerous dishes, such as mustard-hilsha fish curry, various vegetable mashes (like potato, tomato, brinjal, okra, and pumpkin), and snacks like jhal muri. Beyond its culinary uses, mustard oil is also valued for its role in enhancing soil fertility through mustard oil cake and is commonly used for body massage and skincare [1]. Plant-origin oils are essential in human diets, ranking third after cereals and animal products, and are nutritionally superior to animal oils (Lal et al., 2020). Globally, Indian mustard is ranked as the third most important oilseed crop in terms of production and area. In 2023-24, the world saw a total of 42.53 million hectares cultivated, yielding 88.07 million metric tons, with an average yield of 2.07 metric tons per hectare. India contributes 19.8% of the global acreage and 9.8% of the production [2].

Among the major oilseed-producing states in India, Haryana boasts the highest yield (1533 kg/ha), followed by Rajasthan (1170 kg/ha) and Uttar Pradesh (1121 kg/ha), while West Bengal has the lowest yield (911 kg/ha). Although mustard is cultivated in 13 states, Rajasthan, Uttar Pradesh, Haryana, and West Bengal collectively account for 77% of the total production in the country (Kaur, 2017).

Haryana, a hot arid ecological region, experiences hot summers and cool winters with a mean annual precipitation of about 470 mm, typical of arid regions. This rainfall is only sufficient to meet 15-20% of the annual potential evapotranspiration (PET), resulting in a significant water deficit throughout the year [3]. The variability in rainfall is a major cause of crop failure and poor productivity during the kharif season under dryland conditions [4]. Moreover, soil moisture is a vital factor determining the optimum growth, development [5] and seed yield of mustard (Chowhan et al., 2023b).

Climate change and variability significantly impact rainfall patterns, which are crucial for managing water resources and preparing for extreme events like floods and droughts. Contrary, appropriate climate change adoption measures are necessary for sustaining crop yield [6]. Studies have shown that rainfall in Haryana's eastern districts is higher than in the western districts, with deviations being positive during the pre-monsoon season and negative during other seasons [1].

Climatic parameters such as temperature, wind speed, solar radiation, sunshine hours, and relative humidity play a crucial role in agriculture. Analyzing long-term climatic data using parametric and non-parametric methods, like the Mann-Kendall test, can help understand trends in climatic parameters, evaporation, reference evapotranspiration, stream flows, and groundwater fluctuations [7].

1.1 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 Haryana.

2. MATERIALS AND METHODS

This study was conducted to evaluate the temporal variation of ET_0 and crop

evapotranspiration for Mustard crop for three agroclimatic zone of Haryana during 1992-2022. Detail of materials used and experimental methodology followed during present study were described in this chapter.

2.1 Experimental Site

Haryana is located in India with the coordinates of 29° 3' 31.59' N and 76° 5' 8.16 E. Haryana, located in northern India, experiences a diverse range of climates and weather conditions throughout the year. Haryana experiences a semi-arid climate, characterized by hot summers, a brief monsoon season, and cool winters.

2.1.1 Agroclimatic zones of Haryana

Based on Thornthwaite's classification Haryana state can be broadly divided into three climatic zones namely arid, semi-arid and dry sub-humid.

2.2 Data Collection

2.2.1 Weather data

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

Table 1. Selected sites for the Experiment

S.No.	Agroclimatic zones	Districts Selected for study
1	Arid Zone	Hisar, Bhiwani, Rohtak
2	Semi-arid Zone	Kurukshetra, Panipat, Sonipat,
3	Dry sub humid Zone	Panchkula, Yamuna nagar

Source: A text book on Agricultural meteorology by Ram Niwas et al. 2006

2.3 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

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2.3.1 Soil data

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

Table 3. Different 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

3. RESULTS AND DISCUSSION

Result obtained from the study entitled as "Analyzing the temporal variation of ET_0 and water requirement of Mustard (*Brassica juncea L.*) over different Agroclimatic Zones of Haryana by using CROPWAT" has 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:

3.1 Maximum Temperature

The result obtained in Table 4. the present study has been finalized in the following:

The 30-year analysis (1992-2022) of maximum temperatures in Haryana revealed that January had the lowest and May the highest temperatures, with the state's average maximum temperature being around 30.43 ± 1.71°C. The highest average annual maximum temperature was recorded in the arid zone (31.9°C), followed by the semi-arid zone (31.4°C), and the lowest in the dry sub-humid zone (28.2°C). Seasonal analysis showed the greatest variation in maximum temperature during winter, particularly in the dry sub-humid zone (CV of 5.76%). Trend analysis using the Mann-Kendall test and Sen's slope estimator indicated a decreasing trend in maximum temperatures for December and January. The arid zone showed no significant temperature changes, while the semi-arid zone exhibited a significant increase in annual, pre-monsoon, and post-monsoon maximum temperatures. In the dry sub-humid zone, significant temperature increases were observed in July, August, and September, as well as in annual, pre-monsoon, and monsoon periods.

Overall, the study found a significant increasing trend in annual maximum temperatures across all three agroclimatic zones of Haryana, particularly during the pre-monsoon and monsoon seasons. This contrasts with the findings of Anurag et al.

[3], who reported a decreasing trend in maximum temperatures for a shorter period (1995-2014) in Hisar. The longer study period in the current research suggests an overall increasing trend in maximum temperatures in Haryana.

3.1.1 Minimum temperature

The result obtained in Table 5. the present study has been finalized in the following:

The analysis of mean minimum temperatures across different agroclimatic zones of Haryana from 1992 to 2022 revealed key patterns. January recorded the lowest minimum temperatures in all zones, with the dry sub-humid zone being the coldest (5.60 ± 0.78°C), followed by the arid (6.44 ± 0.80°C) and semi-arid zones (6.73 ± 0.80°C). The highest minimum temperatures were observed in June and July, with the arid region showing a temperature range from 6.44°C (January) to 26.9°C (June). The average annual minimum temperatures were similar in the arid (18.04 ± 0.39°C) and semi-arid zones (18.08 ± 0.41°C), while the dry sub-humid zone was cooler (15.7 ± 0.42°C). The overall trend indicated an increase in minimum temperatures across all agroclimatic zones. The Mann-Kendall test confirmed a significant upward trend in annual minimum temperatures with rates of 0.017°C/year in the arid zone, and 0.020°C/year in both the semi-arid and dry sub-humid zones. During the monsoon season, minimum temperatures also showed significant increases, ranging from 0.018°C/year in the arid zone to 0.023°C/year in the semi-arid zone. Over a century, these trends suggest an increase in minimum temperatures by 1.8°C to 2.6°C across the different zones.

3.1.2 Rainfall variability analysis

The result obtained in Table 6. the present study has been finalized in the following:

The 30-year rainfall data analysis for Haryana (1992-2022) revealed high variability, with an average annual rainfall of 726.46 ± 295.72 mm and a variation of around 40%. July received the highest rainfall, particularly in the dry sub-humid zone (306.46 ± 105.00 mm), while November had the lowest rainfall across all zones. The semi-arid region recorded the lowest rainfall in November (1.68 ± 3.6 mm) with the highest variability (217.68%). The study found that the majority of rainfall in Haryana is due to the southwest monsoon, with less than 40% variability across all agroclimatic zones during this period. The Mann-Kendall test and Sen's slope analysis indicated a non-significant increasing trend in rainfall for most months, except for a significant increase in May (1.22 mm/year). The semi-arid zone showed a significant decrease in monsoon rainfall (6.5 mm/year), while the arid zone showed a non-significant increase in monsoon rainfall but a significant increase in pre-monsoon rainfall (1.2 mm/year). The dry sub-humid zone also showed a significant increase in post-monsoon rainfall (1.246 mm/year). These findings align with previous studies, such as Bemal et al. [8] and Anurag et al. [9], which observed similar trends in rainfall patterns across Haryana, particularly the decreasing trend of southwest monsoon rainfall in the semi-arid zone and increasing pre-monsoon rainfall in the arid zone.

3.2 Trend Analysis of Reference Evapotranspiration ET_0 for Duration 1992-2022 for Different ACZs of Haryana

The result obtained in Fig 1. the present study has been finalized in the following:

The Crop water requirement, Effective rainfall was estimated for duration 1992-2022 using CROPWAT. Then trend analysis was done using MK test. The MK test results of monthly, seasonally and annually ET_0 of different study regions presented in tale 4.8. It revealed that there is significantly increasing trend in ET_0 during Pre-monsoon having magnitude 0.026 to 0.031mm/year. There is non-significant decreasing trend of ET_0 in Arid region during Winter, Monsoon and Post-monsoon season. While in Semi-arid and Dry sub humid Agroclimatic zone there is non-significant increasing trend during winter and post monsoon season.

There is non-significant increasing trend annually in all three different Agroclimatic zones. The trend analysis of ET_0 revealed that there is increasingly trend overall annually which is not a very good sign from Agricultural point. If we talk about specially Rabi season there is non-significant decreasing trend in ET_0 during this period which is associated with increasing productivity of Mustard crop and all Rabi season crops Patel et al. [9].

3.3 Trend Analysis of Effective Rainfall

The result obtained in Fig 2. the present study has been finalized in the following:

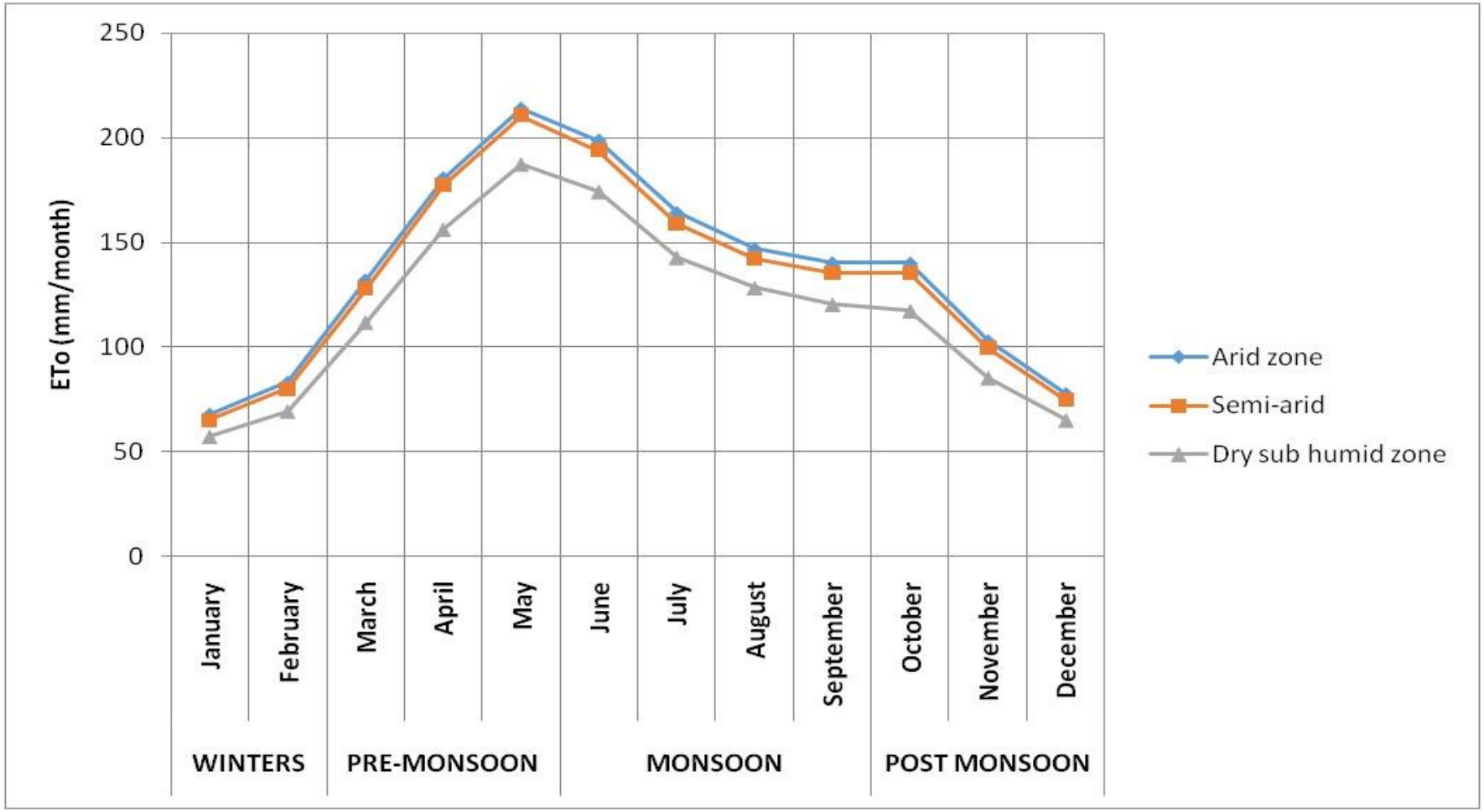

Fig. 1. Reference Evapotranspiration

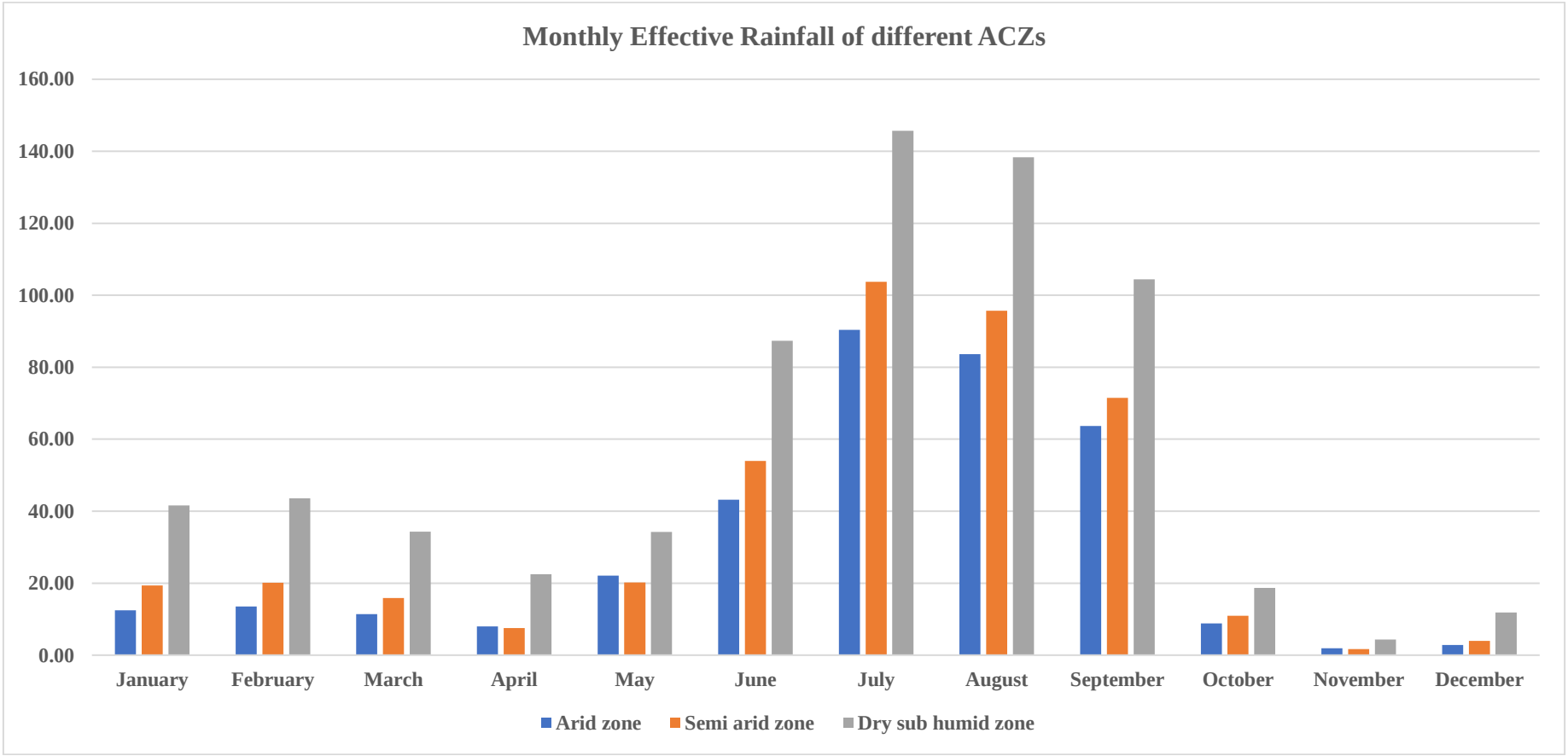

Fig. 2. Effective Rainfall

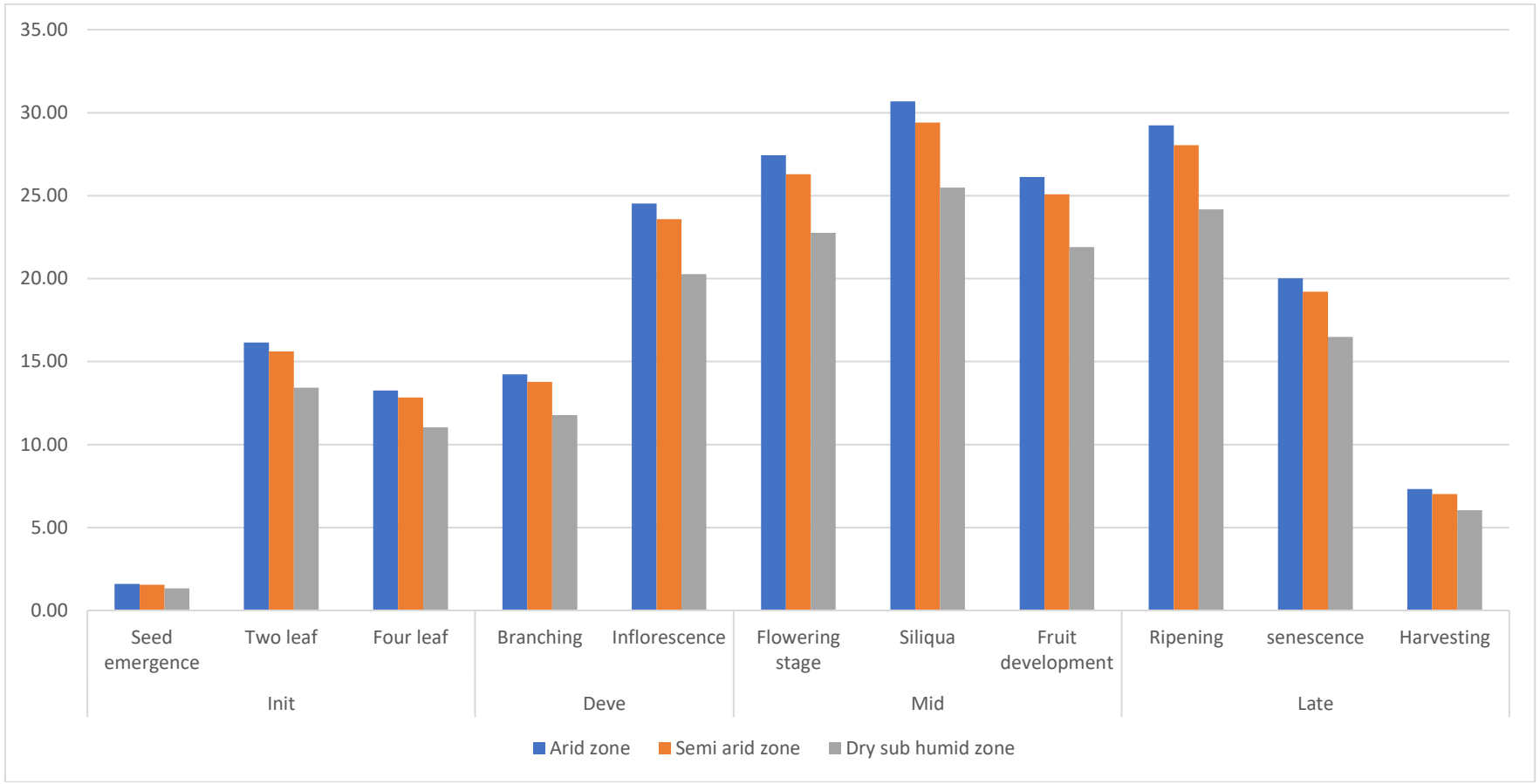

Fig. 3. Crop water requirement

Table 4. Average Maximum temperature (℃) in various Agroclimatic zones of Haryana for duration 1992-2022

Time series	Mean	SD	CV	MK	Significance	Slope
Arid zone						
Annual	31.85	0.57	1.79	0.101	↑	0.008
Winter	22.19	1.17	5.27	-0.015	↓	-0.004
Pre-monsoon	35.98	1.17	3.26	0.198	↑	0.046
Monsoon	36.19	0.58	1.61	0.168	↑	0.009
Post-monsoon	28.36	1.11	3.92	-0.123	↓	-0.018
Semi-arid zone						
Annual	31.41	0.57	1.82	0.226	↑*	0.019
Winter	21.85	1.17	5.36	0.039	↑	0.005
Pre-monsoon	35.54	1.18	3.31	0.239	↑*	0.049
Monsoon	35.70	0.57	1.61	0.237	↑*	0.017
Post-monsoon	27.93	1.08	3.85	-0.073	↓	-0.007
Dry sub humid zone						
Annual	28.02	0.56	2.01	0.226	↑*	0.020
Winter	19.14	1.10	5.76	0.009	↑	0.003
Pre-monsoon	31.49	1.24	3.93	0.233	↑*	0.054
Monsoon	32.19	0.58	1.79	0.304	↑**	0.022
Post-monsoon	24.91	0.95	3.82	-0.069	↓	-0.005

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

Table 5. Average Minimum temperature (℃) in various Agroclimatic zones of Haryana for duration 1992-2022

Time series	Mean	SD	CV	MK	Significance	Slope
Arid zone						
Annual	18.04	0.39	2.14	0.252	↑**	0.017
Winter	7.98	0.71	8.89	0.174	↑	0.017
Pre-monsoon	19.78	0.80	4.05	0.142	↑	0.020
Monsoon	25.88	0.38	1.46	0.303	↑**	0.018
Post monsoon	12.55	0.66	5.24	0.138	↑	0.013
Semi-arid zone						
Annual	18.08	0.41	2.25	0.265	↑**	0.020
Winter	8.22	0.73	8.88	0.172	↑	0.018
Pre-monsoon	19.73	0.81	4.13	0.161	↑	0.020
Monsoon	25.82	0.39	1.53	0.394	↑**	0.023
Post monsoon	12.67	0.68	5.34	0.140	↑	0.013
Dry sub humid zone						
Annual	15.69	0.42	2.69	0.286	↑**	0.020
Winter	6.73	0.80	11.81	0.162	↑	0.018
Pre-monsoon	16.73	0.86	5.13	0.095	↑	0.014
Monsoon	22.86	0.41	1.81	0.462	↑**	0.026
Post monsoon	11.08	0.65	5.90	0.161	↑	0.018

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

The MK test of effective rainfall has not revealed any significant result in seasonally and Annually analysis. In arid and dry sub humid zone there is non-significant increasing trend for annual test while decreasing trend in semi-arid zone.

3.4 Trend Analysis of Crop Water Requirement

The result obtained in Fig 3. the present study has been finalized in the following:

The trend analysis of water requirement of Mustard crop (CWR) in different Agroclimatic zones of Haryana has been shown in Table 4 The trend analysis has shown no significant trend in any Agroclimatic zone but a non-significant decreasing trend has been observed in all study area of Haryana. Thus it indicates the decrease in crop water requirement of Mustard of Haryana.

Table 6. Average Rainfall(mm) trend in various Agroclimatic zones of Haryana for duration 1992-2022

Time series	Mean	SD	CV	MK	Significance	Slope
Arid zone						
Annual	468.33	148.52	31.71	-0.002	↓	-0.482
Winter	27.27	23.65	86.74	-0.011	↓	-0.051
Pre-monsoon	44.94	33.06	73.57	0.273	↑**	1.222
Monsoon	381.67	144.72	37.92	0.028	↑	0.890
Post monsoon	14.46	21.46	148.39	0.141	↑	0.170
Semi-arid zone						
Annual	570.56	154.81	27.13	-0.234	↓	-6.157
Winter	42.92	33.83	78.84	-0.049	↓	-0.213
Pre-monsoon	46.93	35.23	75.07	0.209	↑	0.875
Monsoon	462.83	152.56	32.96	-0.265	↓**	-6.449
Post monsoon	17.88	23.27	130.13	0.185	↑	0.300
Dry sub humid zone						
Annual	1140.49	214.94	18.85	0.153	↑	4.479
Winter	104.04	74.24	71.35	-0.006	↓	-0.027
Pre-monsoon	106.31	59.63	56.09	0.127	↑	0.931
Monsoon	890.12	200.39	22.51	0.028	↑	1.050
Post monsoon	40.01	48.40	120.99	0.342	↑**	1.246

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

Table 7. Trend analysis of ET_0 (mm/month) using Mann Kendal trend test

Months	Arid Zone		Semi-arid zone		Dry sub humid zone	
	Kendall's tau	Sen's slope	Kendall's tau	Sen's slope	Kendall's tau	Sen's slope
Annual	0.05	0.013	0.14	0.029	0.16	0.033
Winter	-0.03	-0.002	0.01	0.000	-0.02	-0.001
Pre-monsoon	0.25*	0.026	0.25**	0.030	0.25**	0.031
Monsoon	-0.06	-0.007	0.03	0.003	0.07	0.006
Post monsoon	-0.09	-0.006	-0.04	-0.003	-0.04	-0.003

Table 8. Trend analysis of effective rainfall(mm) using Mann Kendal trend test

Time series	Mean	SD	CV	MK	Significance	Slope
Arid zone						
Annual	361.93	88.07	24.33	0.092	↑	1.374
Winter	25.68	21.21	82.57	-0.006	↓	-0.053
Pre-monsoon	41.90	29.13	69.52	0.277	↑**	1.127
Monsoon	280.77	79.04	28.15	0.002	↑	0.073
Post monsoon	13.58	19.41	142.87	0.145	↑	0.169
Semi-arid zone						
Annual	424.44	84.92	20.01	-0.135	↓	-1.694
Winter	39.42	29.60	75.10	-0.049	↓	-0.152
Pre-monsoon	43.65	31.07	71.19	0.204	↑	0.833
Monsoon	324.86	77.40	23.82	-0.200	↓	-3.217
Post monsoon	16.52	20.67	125.13	0.180	↑	0.270
Dry sub humid zone						
Annual	686.73	111.16	16.19	0.204	↑	3.875
Winter	85.18	49.90	58.59	0.006	↑	0.061
Pre-monsoon	90.98	43.29	47.58	0.131	↑	0.818
Monsoon	475.72	77.78	16.35	0.080	↑	1.143
Post monsoon	34.85	37.32	107.10	0.342	↑**	1.171

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

During the crop's development stage (November and December), the highest water requirement was in the arid zone (58.80 mm), while the lowest was in the dry sub-humid zone (48.57 mm). In the middle stage (December and January), the arid zone again had the highest water requirement (139.50 mm), with the lowest in the dry sub-humid zone (116.57 mm). In the

late stage (January to March), the arid zone's water requirement remained the highest (83.18 mm), and the dry sub-humid zone the lowest (68.58 mm).

4. CONCLUSION

The 30-year analysis (1992-2022) of maximum temperatures in Haryana revealed that January had the lowest and May the highest temperatures, with the state's average maximum temperature being around 30.43 ± 1.71°C. The average annual minimum temperatures was in the arid (18.04 ± 0.39°C) and semi-arid zones (18.08 ± 0.41°C), while the dry sub-humid zone was cooler (15.7 ± 0.42°C). It may be concluded from the study that the Crop water requirement of Mustard crop ranges from 259.51mm (Dry sub humid zone) to 312.49mm (Arid zone) for the Haryana 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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