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Research Paper

Spatio-temporal analysis of water requirement of maize *(Zea mays L.)* in Haryana state of India

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ABSTRACT

Climate change have a considerable impact on crop water demand (ETc). The present study analyzed the spatio-temporal variation of the crop water requirement (ET_c), crop water surplus deficit index (CWSDI), and the coupling degree of ETc and effective precipitation (P_e) for maize *(Zea mays L.)* crop grown in Haryana State of India using ArcMap 10.8 software. ET_c was calculated using the Penman-Monteith method and crop coefficient (K_c) approach for 34 years (1985-2018) climatic data. Two statistical models, namely Mann–Kendall test and Sen's slope estimator, were applied to understand the trend, while Pettitt's test was used to identify abrupt change points by using XLSTAT 2021 software. The result showed that for maize ET_c ranged from 571 to 766 mm, CWSDI ranged from -29 to -74% and the degree of coupling of ETc and Pe ranged from 0.26 to 0.71 during 1985-2018. The decadal temporal variation of these indices indicated that ET_c during 2007-2018 was relatively higher than it was from 1985-1995 and 1996-2006. The spatio-temporal values of CWSDI indicated that almost all the districts were under water deficit conditions for growing maize crop.Trend analysis showed significantly increasing trend of CWR for most of the districts except Jind, Mewat, Palwal, Panchkula, Rewari, Rohtak and Yamunanagar.The abrupt change point detection analysis of CWR indicates toward different change points, with maximum change points between the years 2004–2008.Such information will help to the farmers in the effective management of water for sustainable production under climate change in the near future.

Keywords: Maize, crop water requirement, reference evapotranspiration, effective precipitation (Pe), crop water surplus deficit Index (CWSDI) and GIS

Water is precious natural resource for the sustainability of life on the earth. Agriculture requires more water to meet the crop evapotranspiration due to increasing temperature under global warming (Mukherjee *et al.* 2012). Effective use of water in agriculture must be given more importance because the agricultural sector uses over 81% of India's water resources (Tiwari *et al.* 2017). As Haryana grapples with challenges associated with low and falling water tables there must be a serious concerned about agricultural water management for sustainable productivity. Therefore, understanding agricultural water needs is essential for better managing and planning of water resources to increase water production. In semi-arid region, growing the crops are challenging due to limited and unequal distribution of rainfall. To meet the higher crop water demand the supplement irrigations along with rainfall are imperative in a semi-arid environment to enhance crop production and productivity. The quality and yield of maize crop often suffer due to deficient water supply and improper irrigation scheduling. Several studies were carried out to estimate the water requirementof maize (Poddar *et al.* 2021; Bal *et al.* 2022) for different agro-climates.

Many studies used Penman-Monteith (P-M) to compute the crop water requirements like Kumar *et al.* (2015) adopted the P-M method to estimate the maize IWR (irrigation water requirement) in the temperate region of Kashmir valley, India and assessed the climate change effect on IWR. Mehta and Pandey (2016) calculated the crop water requirements of wheat, green gram, groundnut, cotton, mustard, rice, chickpea, pearlmillet and maize crops for Gujrat state of India, while Shaloo *et al.* (2021) estimated the water requirement of rice and wheat for Haryana state using the P-M method. In order to provide a theoretical and practical foundation for enhancing the effectiveness of water resources

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management and preparing a balanced irrigation system, the present study was carried out to determine the spatio-temporal distribution of crop water requirement (ETc), crop water surplus deficit index (CWSDI), and the coupling degree of ETc and effective precipitation (Pe) for maize.

MATERIAL AND METHODS

The study area is comprising 22 districts of Haryana, India which comes under two main agro-climatic zones, i.e., South western and North eastern agro climatic zones and a large portion of the state is located inside the Indo-Gangetic fertile belt. Temperature fluctuates between 15^{0}C to 5^{0}C during winter season and 15 ^{0}C to 45 ^{0}C in summer.The major crops grown during rabi season are wheat, mustard, tobacco and gram while rice, maize, jawar, bajra, cotton crops are grown during *kharif* crop growing season. The 34 years (1985 to 2018) data of maximum temperature, minimum temperature, wind speed, relative humidity and solar radiation at 1◦ × 1◦ spatial resolution acquired from NASA Climatology Resources for Agro-climatology and rainfall data from India Meteorological Department (IMD) were used in the analysis.

Estimation of maize water requirement

The Penman-Monteith method (P-M method) was applied to calculate ET_o; identified as an efficient and effective method recommended by FAO. The equation can be expressed as

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where, ET_o stands for reference evapotranspiration [mm day^{-1}], R_n for net radiation at the crop surface [MJ m^{-2} day^{-1}], γ for the psychrometric constant [kP_a °C^{-1}], T for the mean daily air temperature at 2 m height [°C], G forthe soil heat flux density [MJ m^{-2} day^{-1}], [$e_s - e_a$] for the saturation vapour pressure deficit [kP_a], e_s for the saturation vapour pressure [kP_a], e_a for the actual vapour pressure [kP_a], u_2 for the wind speed at 2 m height [m s^{-1}], and Δ for the slope vapour pressure curve [kP_a °C^{-1}].

Further, the actual/ crop evapotranspiration was computed by multiplying the ET_o with the respective crop coefficient (Kc) value of maize.

$$ETc = Kc * ETo$$

where ET_c, K_c and ET_o are the crop water requirement (mm), crop coefficient and reference evapotranspiration (mm). The K_c value is influenced by crop type and its growth phases,climate and soil evaporation. The K_c values of maize for different growing stages were obtained from FAO-56 reports under standard conditions.

Effective precipitation (P_e)

In this study, P_e was computed in the CROPWAT software using the technique suggested by Soil Conservation Agency of the United States Department of Agriculture (USDA) (Moriondo *et al.* 2013), as per the equation given below:

$$P_e = \begin{cases} \frac{P(4.17 - 0.2P)}{4.17} & for\ P \leq 8.3\ mm \\ 4.17 + 0.1P & for\ P > 8.3\ mm \end{cases}$$

Where, Pe is the effective precipitation (mm) and P is precipitation (mm).

Crop water surplus deficit index (CWSDI)

We calculated the crop water demand index during the maize growth stage ETc and the water supply index Pe to accurately reflect the water supply and demand. CWSDI was constructed to describe water surplus and deficit in maize during the growth stages based on the water deficit index of maize (Gao *et al.* 2012).

$$CWSDI = \frac{Pe - ETc}{ETc}$$

CWSDI represents the crop water surplus deficit index, ETc is crop water requirement (mm), and Pe is effective precipitation (mm).

Coupling degree of ETc and Pe

The coupling degree of ETc and Pe was computed using following equation.

$$\lambda_i = \begin{cases} 1 & (P_e \geq ET_C) \\ P_e/ET_C & (P_e < ET_C) \end{cases}$$

λ_i, indicates the extent to which Pe meets ETc.

Data processing

In order to assess the parameter changing trend of ETc, Mann-Kendall (M-K) test (Mann 1945, Kendall 1975) was applied in XLSTAT 2021 software. Sen (1968) method was applied to assess the slope of an existing trend. The Pettitt test (non-parametric method) was used to determine the change point in the time series dataset of annual crop water requirement. The MATLAB software was used for the extraction of climatic parameters for the study region and computation of the reference evapotranspiration (ET_0). Spatial analyses and interpolation were carried out using the IDW interpolation technique in ArcMap 10.8 software.

RESULTS AND DISCUSSION

Spatio-temporal variability of ETc, CWSDI and coupling degree of ETc and Pe

The spatial distribution of ETc for the study area for 34 years (1985-2018) is presented in Fig. 1; ETc of maize was found to be ranged from 571mm to 766mm with an average ETc of 669mm during kharif season. Average ETc values during 1985–1995, 1996–2006, and 2007–2018 were 646, 630 and 695 mm, respectively. It is observed from the maps that highest CWR was found in Sirsa, Hisar and Bhiwani districts, whereas the lowest was observed in Ambala, Yamunanagar and Panchkula districts. Djaman *et al.* (2018) estimated the irrigation requirements for maize ranged from 758 to 848 mm with an average of 800 mm which is nearly close to the findings of the present study. The value of CWSDI ranged between -29% to -74%, with an average of -51.6% during the year 1985-2018 Fig. 1(d). CWSDI showed a trend of slowdown

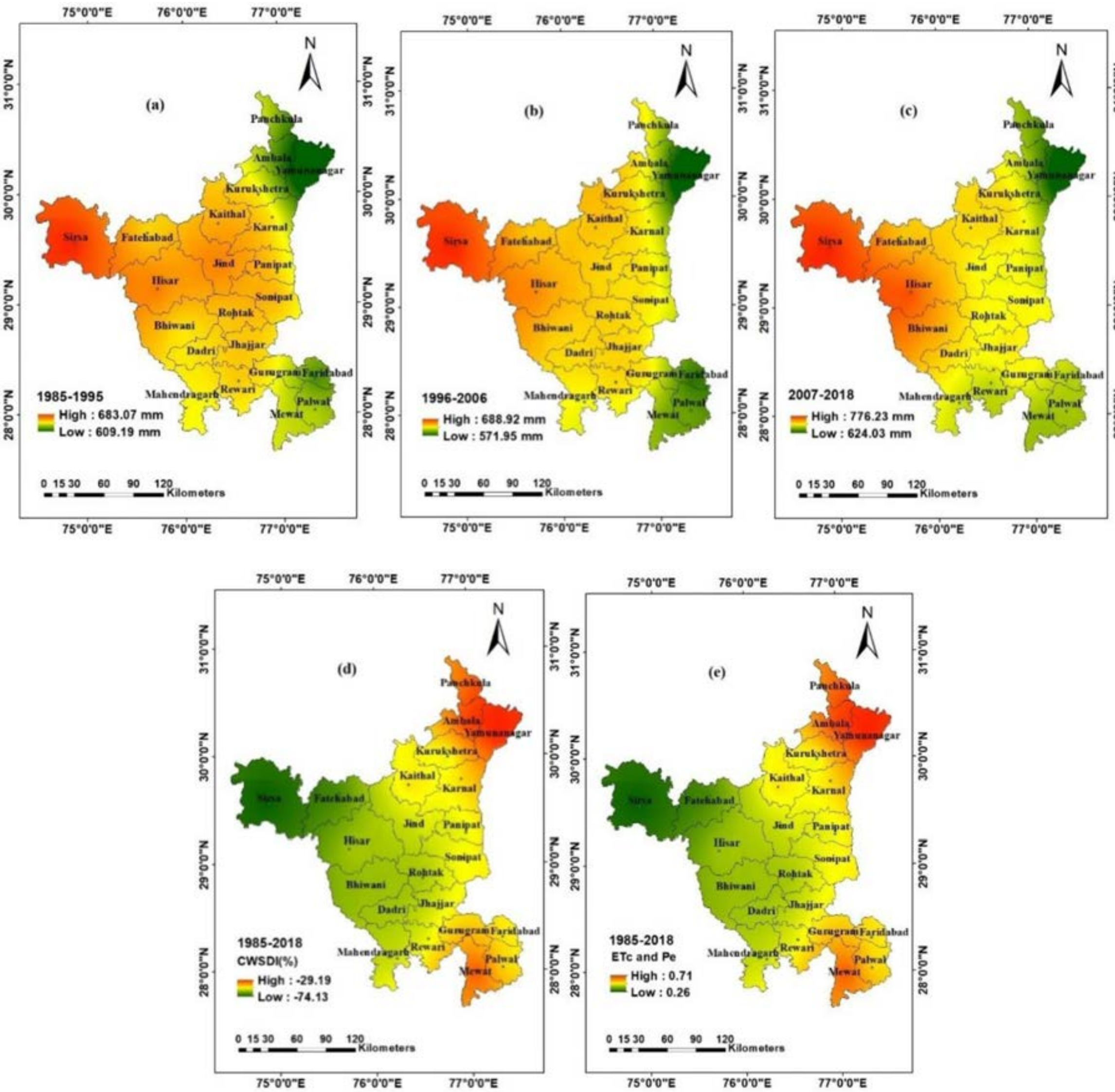

Fig. 1: Spatial distribution of variation paramenets .Average ETc during (a) 1985–1995, (b) 1996–2006, and (c) 2007–2018. (d) Average CWSDI and (e) coupling degree of ETc and Pe for maize during 1985–2018.

in water deficit from southwestern to northeastern. Additionally, the water deficit of maize was higher with CWSDI value of less than -50% in the south western areas. It is observed that, no area was found in a water surplus state in this study. The spatio-temporal variability of the coupling degree of ETc and Pe of maize crop is shown in Fig. 1 (e). The coupling degree of ETc and Pe varied from 0.26 to 0.71 with an average value of 0.48. The high-value areas are Panchkula, Yamunanagar, Ambala and Mewat districts with an average coupling degree of ETc and Pe greater than 0.70, where the effective Pe meets the higher CWR and the low-value areas less than 0.5 are Sirsa, Fatehabad, Hisar, Bhiwani and Dadri.

Trend analysis of CWR

The result of Mann Kendall trend test of maize crop showed that the trend is increasing significantly in all the districts except Jind (Kendall's tau value of 0.20 and Sen's slope of 2.21), Mewat (Kendall's tau value of 0.21 and Sen's slope of 2.43), Palwal (Kendall's tau value of 0.24 and Sen's slope of 2.35), Panchkula (Kendall's tau value of Sen's 0.20 and slope of 1.94), Rewari (Kendall's tau value of 0.22 and Sen's slope of 1.70), Rohtak (Kendall's tau value of 0.22 and Sen's slope of 2.53) and Yamunanagar (Kendall's tau value of 0.17 and Sen's slope of 1.89) with p-value ≤ 0.05 (at 95% confidence level) (Table. 1). There crop water requirement of maize is increasing due to decrease in rainfall and increase in maximum and minimum temperature (Srivastava *et al.* 2021).

Fig. 2 shows the empirical significance level (p-value of Pettitt's test). The results of Pettitt's test showed that the change point for CWR based on the performances (p-value) was detected significantly at 95% confidence level for Ambala (in the year 2008), Bhiwani (in the year 2006), Gurugram and Mahendragarh (in the year 2005), Fatehabad (in the year 2004) and for Faridabad, Hisar, Karnal, Kurukshetra, Panipat, Sirsa and Sonipat (in the year 2003).

Table 1: Trend analysis statistics of maize CWR of Haryana (districtwise)using M-K test

Districts name	Kendall's tau	p-value	Sen's slope	Trend
Ambala	0.45	0.0004	3.38	Increasing*
Bhiwani	0.46	0.0002	4.24	Increasing*
Faridabad	0.38	0.003	4.19	Increasing*
Fatehabad	0.49	0.0001	3.59	Increasing*
Gurugram	0.36	0.005	3.21	Increasing*
Hisar	0.51	0.0001	4.77	Increasing*
Jhajjar	0.26	0.041	3.02	Increasing*
Jind	0.20	0.118	2.21	Increasing
Kaithal	0.27	0.038	2.76	Increasing*
Karnal	0.30	0.021	2.59	Increasing*
Kurukshetra	0.34	0.008	3.37	Increasing*
Mahendergarh	0.28	0.027	2.42	Increasing*
Mewat	0.21	0.096	2.43	Increasing
Palwal	0.24	0.062	2.35	Increasing
Panchkula	0.20	0.118	1.94	Increasing
Panipat	0.30	0.021	2.68	Increasing*
Rewari	0.22	0.083	1.70	Increasing
Rohtak	0.22	0.089	2.53	Increasing
Sirsa	0.57	0.0001	4.85	Increasing*
Sonipat	0.27	0.038	2.70	Increasing*
Yamunanagar	0.17	0.185	1.89	Increasing

* indicates significant

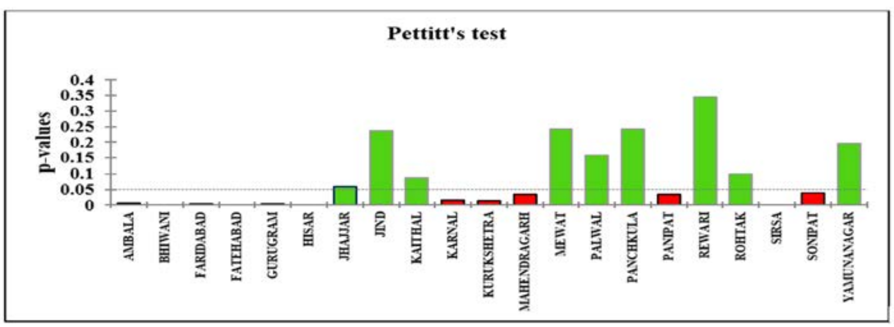

Fig. 2: Change points of CWR of maize from 1985-2018

CONCLUSIONS

ETc of maize was found to be ranged from 571 mm to 766 mm with increasing trend of 1.70 to 4.85 mm/year and the abrupt increase was observed from the years 2003 to 2008 . The value of CWSDI ranged between -29% to -74% which indicates the water deficit condition during the maize growing season in the state. The coupling degree of ETc and Pe indicates that Pe meets the crop water requirement of maize upto 26% to 71%. The study revealed the increasing trend of crop water requirement of maize which indicates the situation is crucial in Haryana for growing maize. Water-saving irrigation measures such as micro-irrigation methods (drip and sprinkler) with mulching should be given attention to increase water use efficiency as well as the crop yield. Further, the irrigation should be given as per the crop water requirements in Haryana and other semi-arid parts of the country.

Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

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