Spatio-temporal Variability and Climate Change Impact on the Crop Water Requirement of Pigeonpea (*Cajanus cajan*) - A Case Study, North-Eastern Karnataka, India

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ABSTRACT

Background: Global climate change and its impact on crop water requirement have widely discussed in recent years. In the present century, climate change had become a significant concern and atmospheric temperature is the dominant climatic factor that indicates the changes in both regional and global scales. This study was undertaken to evaluate the trend and predict the changes in crop water requirement under various climate change scenarios.

Methods: The statistical nonparametric Mann-Kendall test and Sen's slope used to identify trend in the data series. In this study ArcGIS V. xx software used for investigating spatial patterns in data. CROPWAT-8.0 model used for calculation of crop water requirement under various climate change scenarios. Total six climate change scenarios were considered for assessment.

Result: The crop water requirement (ET_c) of pigeonpea estimated and exhibited an increasing trend and a decreasing trend in study area in the past 35 years. The spatial distribution maps reveal that the distribution of ET_c is found an increasing trend in all the scenarios to reference ET_c. An increasing trend of ET_c of pigeon pea was observed in all the places under various climate change scenarios. It was suggested to promote rainwater harvesting, soil and water conservation and increase ground water recharge in the study area to minimize the risk of yield reduction due to the availability of minimum water under changing climatic condition.

Key words: CROPWAT-8.0, Land use, Spatial analysis, Trend analysis.

INTRODUCTION

Climate change is an alteration in annual, seasonal variation of weather conditions, or in the time variation of weather within the context of longer-term average conditions (IPCC, 2007). It was also observed that the global mean surface temperature increased by (0.74°C±0.18°C) from 1906 to 2005 (Trenberth *et al*., 2007). Intergovernmental Panel on Climate Change (IPCC) predictions indicates that the average global surface temperature expected to rise by (1.4 to 5.8°C) by 2100 under different greenhouse gas emission scenarios (IPCC, 2007). According to Indian Network for Climate Change Assessment (INCCA), the annual mean surface air temperature of Indian subcontinent projected to rise by (1.7°C) and (2.0°C) in the 2030s (INCCA, 2010). As temperature rises, it may bring an adverse effect on the availability of water (Kambale *et al*., 2017). As we all know, agriculture is the largest sector in water use in many countries, including India. The impact of climate change on crop evapotranspiration (ET_c) becomes essential for water management and agricultural sustainability. Climatic factors other than temperature, like solar radiation, relative humidity, wind speed and rainfall also influence the ET_c. Consequently, any variation in these factors will also affect the ET_c. These changes are, however, difficult to project, especially on regional or local scales (Chattopadhyay and Hulme, 1997). It also reveals an increase in ET_c rate over different regions in the world due to the rising temperature (Ficklin *et al*., 2012). In the Indian subcontinent, the precipitation trend has been random *i.e.* both regions reported decreasing and increasing trend. However, total precipitation occurred over the country has increased (Darshana and Pandey, 2013).

India ranks first in yearly pigeon pea production with (2.65 MT) followed by Myanmar (0.9 MT), Malawi (0.23 MT), Tanzania (0.20 MT) and Kenya (0.09 MT) (www.faostat.org.). India is the largest producer, with about (2.65 MT), accounting of about (72 per cent) of total world production which concentrated in central and southern parts of India. Mishra *et al*. (2017) examined the impact of the difference in climatic variables, *viz*. temperature and rainfall on a yield

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of pigeon pea by using district-level panel data from 1980-2011 in Gujarat. Abdrabbo *et al*. (2016) investigated the projected changes in evapotranspiration (ETo) in Egypt, revealed that ETo significantly increased in different tested time series compared to current ETo values.

Numerous authors, researchers and scientists have studied the climate change impact on agriculture, crop yield, irrigation water requirement, crop water requirement and also changes in weather parameters all over the world (Ahalavat and Kaur, 2015; Chakraborty and Hazari, 2017; Wang *et al*., 2016; Rotich, 2017; Rao *et al* 2015; Parekh and Prajapati, 2013; Mohan and Ramsundram, 2014). The impact of climate change on crop water requirement was studied by statistical methods as well as different climatic models. With the help of these techniques, one can investigate the impact under different climatic scenarios, which would otherwise be costly and time-consuming if done experimentally. Considering the above facts, the research carried out to investigate the long term spatio-temporal variability, analysis of its trend of crop water requirement of pigeon pea.

MATERIALS AND METHODS

Description of study area

The area selected for the present study comes under the north eastern dry zone of the agro-climatic condition of Karnataka state, India (Fig 1). The study presented here, carried out during 2018-19 at the College of Agricultural Engineering, University of Agricultural Sciences, Raichur. Work process flow chart presented in Fig 2. The entire district located on Deccan plateau and altitude range from (300 to 750 m) above mean sea level (MSL). Most of the area is covered with black soil and to some extent, red soil as well. The study area lies between (17°12′ and 17°46′ N) latitude and (76°04′ and 77°54′ E) longitude.

Climate

The climate of the district is generally dry with, temperature ranging from a minimum of (8°C) to a maximum of (45°C) and annual rainfall is about (750 mm). May is the hottest month with an average maximum temperature of (40°C) and December is the coldest month, with an average minimum temperature of (15.9°C). During peak summer, the temperature shoots up to (45°C) and average wind speed is (5.5 ms^{-1}), average day length varies from (10-12 hours) and relative humidity ranges from (26 per cent) during summer to (62 per cent) during rainy and winter season.

Weather data

The long-term weather data of average temperature (°C), maximum and minimum temperature (°C), rainfall (mm), wind speed (ms^{-1}), relative humidity (%) and solar radiation ($MJm^{-2}day^{-1}$) obtained from the National Aeronautics and Space Administration prediction of worldwide energy resource (NASA POWER) project (Hassan *et al*., 2019, Siddharam *et al*., 2020). Historical data for all weather parameters collected for seven weather stations *viz.* Aland, Afzalpur, Chincholi, Chittapur, Kalaburgi, Sedam and Jewargi, for the periods of 1981-2018.

Soil properties

The data related to soil properties include soil type, field capacity, wilting point maximum infiltration rate, initial soil moisture depletion and initially available soil moisture collected from CROPWAT 8 standard datasets and presented in Table 1.

Crop data

The crop data were pertinent to growth such as crop coefficient (k_c), crop growth stages, crop growth yield

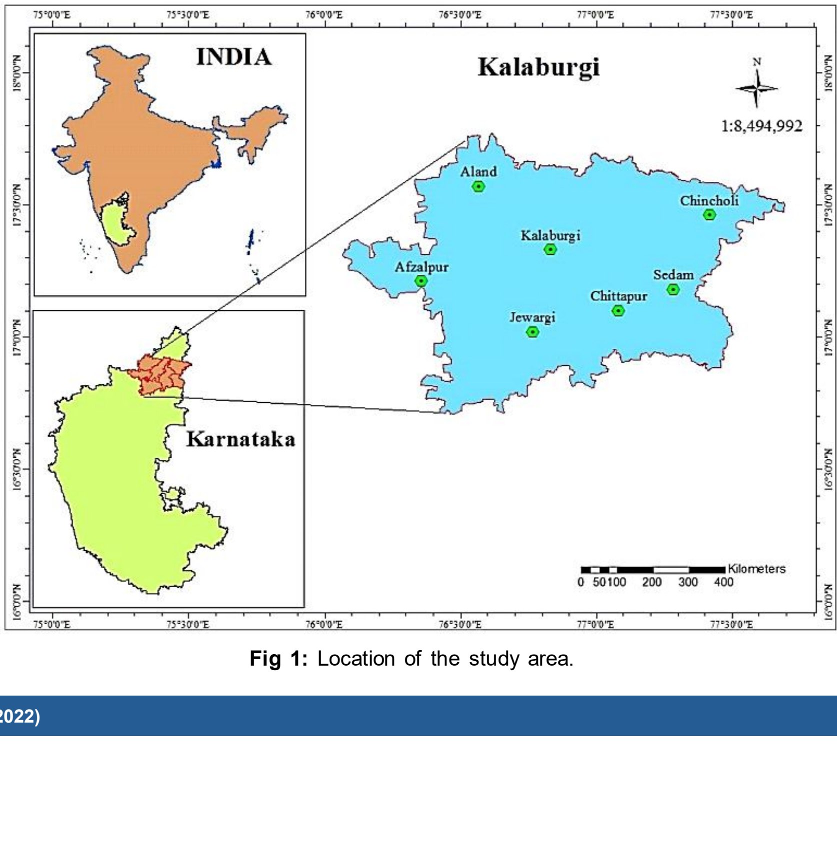

Fig 1: Location of the study area.

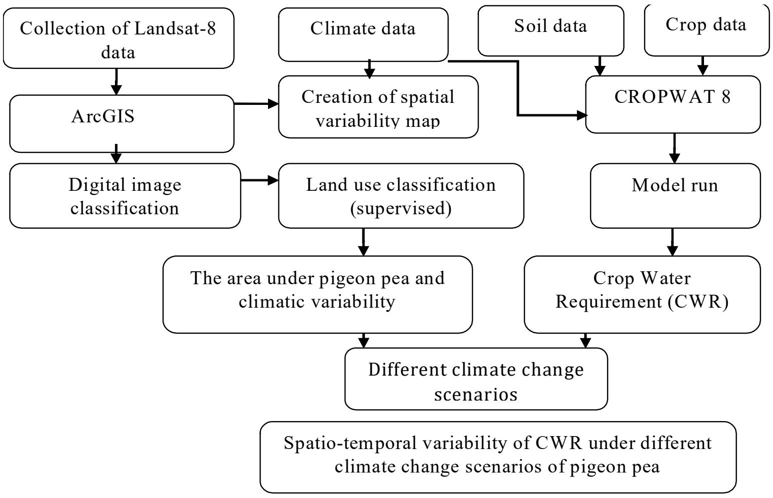

Fig 2: Study process flow chart.

response factor and crop height collected and used as an input parameter to CROPWAT 8 model for calculation of crop water requirement in pigeonpea. The crop growth stage, yield response factor and crop height data obtained by *in situ* samplings from the study area. The parameters like k_c, canopy factor were collected according to Nagraj (2019). The k_c values of pigeonpea with growth stages presented in Table 2.

Land use

The Landsat-8 satellite imagery/images acquired from the United States Geological Survey (USGS) through earth explorer (Alam, 2019) on 21/11/2018 used in this study. Landsat-8 images contain eleven spectral bands. Landsat-8 having a spatial resolution of (30 m) except band 8 and that is (15 m). Approximate scene size is (170 km) north-south by (183 km) east-west. The band combination of 7, 5, 2 - (False colour image) conveniently used for the monitoring of crops displayed in bright green colour, bare earth in purple colour and not cultivated vegetation appears in subtle green. The Kalaburgi district has mixed land use. The general land use map of pigeonpea Kalaburgi district is presented in Fig 3.

Spatial analysis

A spatial analysis tool available in the ArcGIS V. xx software used for investigating spatial patterns in data. Spatial interpolation, or the estimation of a variable at an unsampled location using data from surrounding sampled areas, has great importance in all-natural and atmospheric sciences. The spatial analysis tool in the Arc GIS V. xx software used for interpolation creating and analysing the map of long term annual meteorological data. The inverse distance weighting (IDW) interpolation technique used to create the map of weather parameters of the study area. We used this technique because IDW technique takes the less neighbouring unknown location points and it will give more accurate results than the kriging and spline or any other interpolation technique (Po *et al*., 2017).

Crop water requirement

Prediction methods for crop water requirements invariably used owing to the complexity of obtaining accurate field measurements. The methods often need to be applied under climatic and agronomic conditions very different from those under which they were initially developed. Testing the accuracy of the methods under a new set of circumstances is difficult, time-consuming and costly. Yet, crop water requirement data frequently needed at short notice for project planning. The CROPWAT 8.0 model developed by the Food and Agriculture Organization (FAO) is an irrigation management model used to evaluate crop water requirements and irrigation needs (Clarke *et al*., 1998).

CROPWAT 8

It is a decision support system developed by the Land and Water Development Division of Food and Agriculture Organization (FAO). CROPWAT can estimate reference

Table 1: Properties of Soil.

Properties	Values	
Soil type	Red soil	Black soil
Total available soil moisture, $mm^{-1}m$	25-100	200
Initial available soil moisture, $mm^{-1}m$	25 -100	175 - 250
Field capacity, %	45-55	25-35
Wilting point, %	15-20	10-15
Maximum infiltration rate, mm h^{-1}	20 - 30	5 - 10

Source: (FAO, 56, 1998).

Table 2: Crop coefficient for crop growth parameters.

Parameters	Crop growth stages				
	Initial	Development	Mid	Late	Harvest
Crop coefficient	0.40	0.7	1.12	0.67	
Number of days	40	35	40	33	145
Critical depletion	0.45	-	0.45	0.5	(Total)
Yield response factor	0.20	0.80	0.60	0.20	0.70

Source: Nagraj (2019).

evapotranspiration, crop water requirements and irrigation requirements. It can also be used to evaluate the effect of variations in climatic parameters on crop water requirement and assess the impact of climate change. The major inputs requirements of CROPWAT model include crop parameters, meteorological data and soil type. The required meteorological data are maximum and minimum temperatures, wind speed, solar radiation, relative humidity and rainfall. CROPWAT was used to estimate the ETo using Penman-Monteith method. Crop water requirement of pigeonpea estimated for each year starting from 1981-2018 using ETo, crop coefficients and number of growing days. The crop coefficients and stages of crop development are presented in Table 2 previously. Climate change scenarios considered with reference scenarios (baseline) consist of average values of various weather parameters from 1981-2018 (Table 3). Water requirement for different scenarios was compared to evaluate the impact of climate on it.

Table 3: Climate change scenarios considered for prediction of crop water requirement under pigeonpea.

Climate Scenarios	Descriptions
Reference (baseline)	Average values of 1981 to 2018 weather parameters
1	IPCC Scenario for 2050s
	Increase in temperature 1.5°C
2	INCCA scenario for 2030s
	Increase in temperature 1.7°C
3	IPCC Scenario for 2080 to 2100s
4	Increase in temperature 2°C
5	Increase in temperature 2.3°C
6	Increase in temperature 4°C
	Increase in temperature 5.4°C

Statistical analysis

Statistical analysis of long-term crop water requirement data executed in MS office Excel spreadsheet package. The analysis carried out by using statistical methods of the nonparametric Mann-Kendall test for testing the presence of the monotonic increasing or decreasing trend and the nonparametric Sen's method for estimating the slope of a linear trend in the study area. The detailed estimation procedure and formulae used for its calculations given in (Siddaram *et al.*, 2020).

RESULTS AND DISCUSSION

Crop water requirement (ET_c)

Crop water requirements of pigeonpea were estimated by taking the past 35 years long term data (Mohan and Ramsundram, 2014) of Aland, Afzalpur, Chincholi, Chittapur, Jewargi, Kalaburgi and Sedam and the results are presented in Fig 4 (a to g). Table 4 presents Mann- Kendall trend (Z), Sen's slope value (Q) long term average, yearly highest and lowest values of ET_c in mm from 1981 to 2018 over the Afzalpur, Aland, Chincholi, Chittapur, Kalaburgi, Sedam and Jewargi. These were estimated using all-important climatic parameters which control crop water requirement. In the Aland, the highest ET_c (690.8 mm) for pigeon pea was observed in 2013 and the lowest (280.4 mm) in 1984 and recorded the average ET_c of (550 mm) (Fig 4a). The statistical analysis carried out for ET_c over Aland observed positive trend in the series for Mann- Kendall test (Z) with 0.795 and Sen's slope (Q) with 0.850. The highest ET_c of (785.7 mm) was recorded at Afzalpur in 1988 and the lowest of (533 mm) in 2007 and the average ET_c of (533 mm) was recorded of pigeon pea (Fig 4b). The ET_c of pigeonpea calculated at

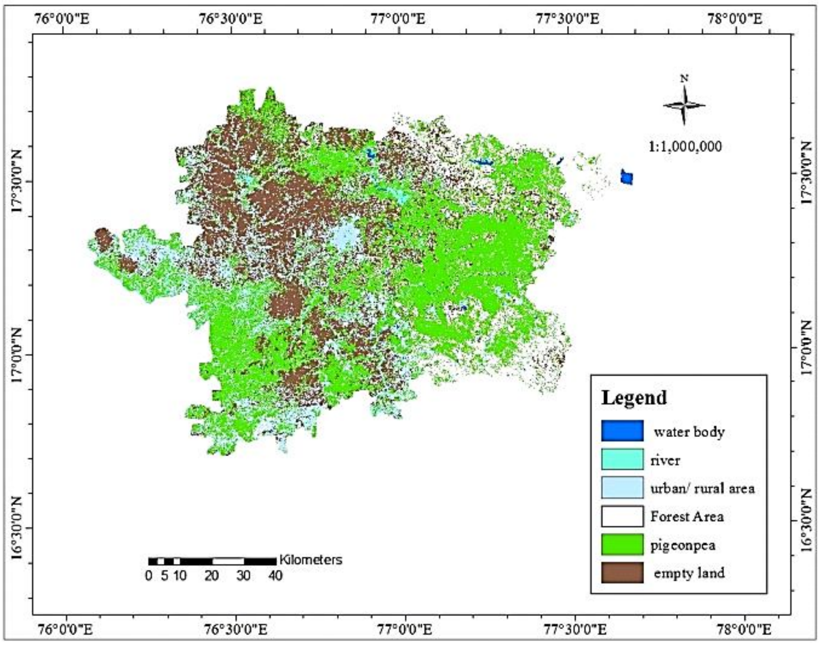

Fig 3: Land use classification of the study area.

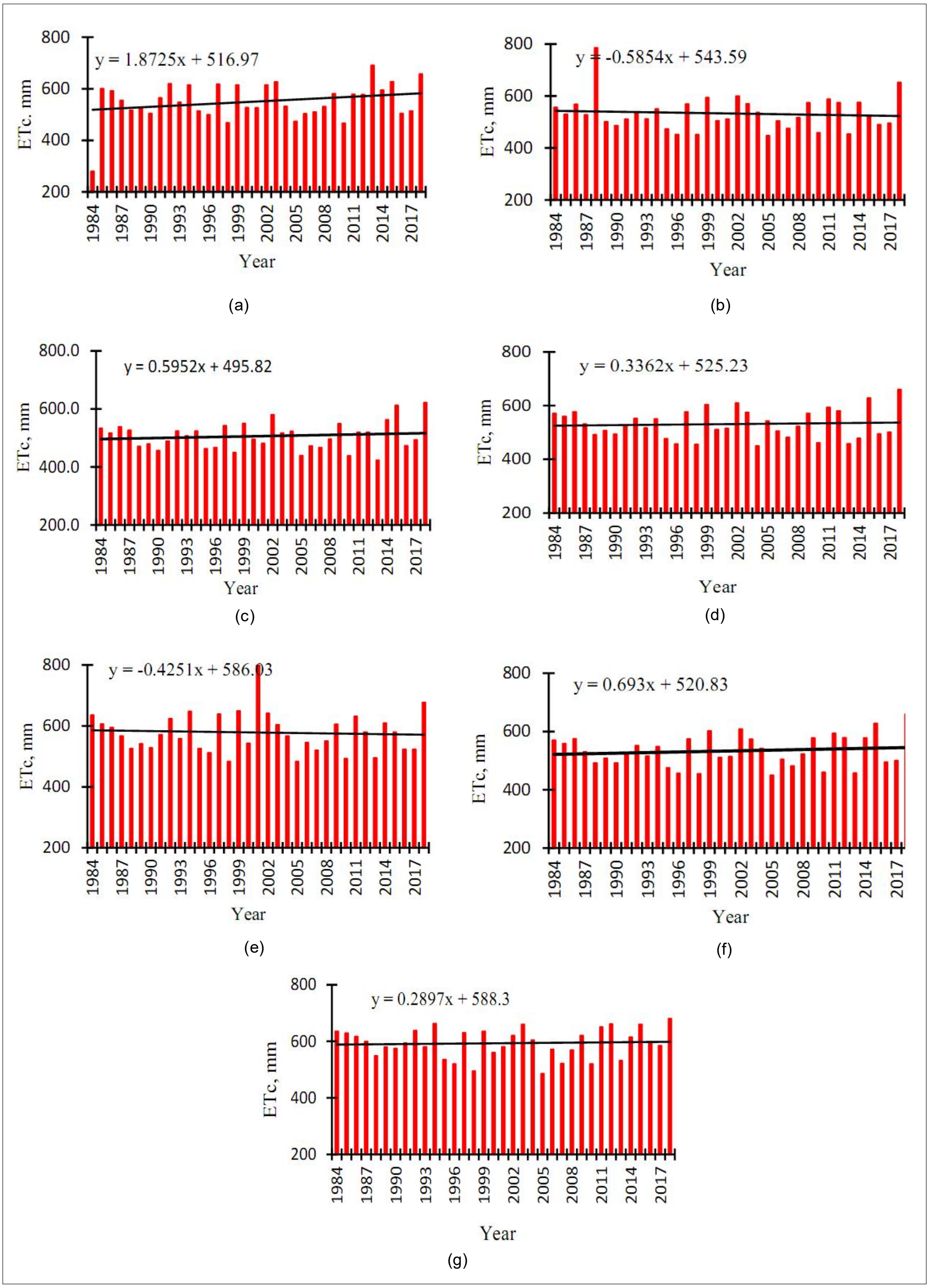

Fig 4: Crop water requirement of pigeonpea at (a) Aland, (b) Afzalpur, (c) Chincholi, (d) Chittapur, (e) Kalburgi, (f) Sedam and (g) Jewargi.

Chincholi recorded the highest of (881.1 mm) in 2000, the lowest of (509.8 mm) in 1998 and the average of (608.22 mm). The highest ET_c of (660.7 mm) in 2018, the lowest of (450.4 mm) in 2004 and the average of (531.2 mm) were recorded at Chittapur (Fig 4d). The highest ET_c (857.9 mm) was recorded in 2001, while the lowest (483.4 mm) was in 2005 and the average ET_c of (578.3 mm) displayed in Kalaburgi (Fig 4e). Similarly, the highest ET_c of (660.4 and 678.3 mm) was observed in 2018 at Sedam and Jewargi respectively, whereas the lowest of (450.5 and 483.7 mm) was observed in 2005 at Sedam and Jewargi respectively. The average value of ET_c of (534.4 mm) was reported at Sedam (Fig 4f) and (562 mm) at Jewargi (Fig 4g). Results indicated that ET_c of pigeonpea exhibited a decreasing trend at Afzalpur, Chincholi and Kalaburgi and increasing trend at Aland, Chittapur, Sedam and Jewargi in the past 35 years. Also, in the study area observed that decreasing in wind speed, relative humidity and solar radiations are influences the increasing of CWR (Kambale *et al*., 2017) at Aland, Chincholi, Chittapur. The study area consists of black soil and some extent of red soil, CWR depends on soil properties. The similar results were obtained by Trivedhi *et al*. (2018) who determined the actual evapotranspiration in the Shipra river basin. CROPWAT 8.0 Model was used to determine the potential evapotranspiration and subsequently actual evapotranspiration for the time series 1990 to 2010. The maximum average ETo (259.7 mm) was in the month of May due to highest temperature in this month and the minimum average ETo (90.5 mm) was in the month of December due to minimum temperature in this month. It can be concluded from the observation that the maximum average actual ET (288 mm) was in the month of May due to highest temperature in this month and the minimum average actual ET (34 mm) was in the month of November due to minimum temperature in this month. The overall long term crop water requirement data showed a positive trend in series for the last 35 years at Aland and Sedam. Similarly, statistical results for ET_c observed a negative trend in the series over Afzalpur, Chincholi, Chittapur, Jewargi and Kalaburgi (Table 4).

Predicted ET_c under different climate change scenarios

Predicted ET_c under different climate change scenarios with reference to average values of 35 years weather datasets is presented in Fig 5 and Table 4. The scenarios 1, 3, 4, 5, 6 and 2 based on IPCC and INCCA, respectively. For scenario 1, 2 and 3 observed the highest ET_c with (718.8 mm), (722.7 mm) and (728.5 mm) for Jewargi and the lowest with (705.6 mm), (709.4 mm) and (715.2 mm) for Aland. The ET_c for scenario 4 observed the highest with (734.5 mm) at Afzalpur and the lowest with (726 mm) at Chincholi. In case of scenario 5, the highest ET_c with (767.5 mm) was observedat Jewargi and the lowest with (753.8 mm) at Aland. In scenario 6, the highest ET_c (795.4 mm) observed at Afzalpur and the lowest (781.1 mm) was at Aland. Similar results were also obtained by Shahid (2011) and Fisher *et al*. (2007) in their conducted studies. In overall ET_c of pigeonpea observed an increasing trend in all the places under various climate change scenarios. A similar line of results was obtained by Kambale *et al*. (2017). The maximum and minimum of ET_c observed in scenario 6 and scenario 2, respectively. Under the INCCA and IPCC future prediction scenarios for climate change on the rise in temperature predicted by them an increase in the level of ET_c for all locations (Manasa and Anand, 2016). It is important to note that the predicted ET_c under IPCC and INCCA scenarios follows the trend of ET_c estimated for Aland, Chittapur, Sedam and Jewargi from long term weather data.

Spatial analysis

The spatial variability maps of crop water requirement prepared to display its spatial distribution in the study area. The spatial variability analysis of estimated crop water requirement of pigeonpea carried out in ArcGIS Vr.xx with spatial analyst tool by IDW interpolation technique. Spatial variability maps for the selected study area of crop water requirement (ET_c) under different climate change scenarios are presented in Fig 6 (a-e). The Fig 6(a) exhibited the spatial distribution of ET_c (Li *et al*., 2017) for the reference scenario of the study area with minimum values range of (530 to 535.27 mm) at Afzalpur, Jewargi and Chittapur and the highest of (581.5 to 599.9 mm) at Chincholi area. The ET_c predicted for scenario one displayed in Fig 6(b) and the lowest ET_c observed over the Aland with a range of (705.6 to 709.59 mm) and the highest with ranges (715 to 718 mm) distributed over the Afzalpur, Kalaburgi and Sedam for the case of Scenario-1. In scenario-2, the minimum ET_c range of (709 to 713 mm) distributed over Aland and the highest in the range of (719 to 722 mm) over Afzalpur, Kalaburgi and Sedam and is shown in Fig 6(c). The ET_c estimated

Table 4: Yearly highest, lowest values, Long term average, Mann-Kendall trend (Z) and Sen's slope value (Q of crop water requirement.

Places/	Crop water requirement, mm			Test statistics	
Indices	Highest	Lowest	Average	Z	Q
Aland	690.8 (2013)	280.4 (1984)	550.0	0.795	0.850
Afzalpur	785.7 (1988)	533.0 (2007)	533.0	-0.071	-0.183
Chincholi	881.1 (2000)	509.8(1998)	608.2	-0.966	-0.933
Chittapur	660.7 (2018)	450.4(2004)	531.2	-0.014	-0.071
Kalburgi	857.9 (2001)	483.4 (2005)	578.3	-0.582	-0.632
Sedam	660.4 (2018)	450.5 (2005)	534.4	0.511	0.324
Jewargi	678.3 (2018)	483.7 (2005)	562	-0.540	-0.467

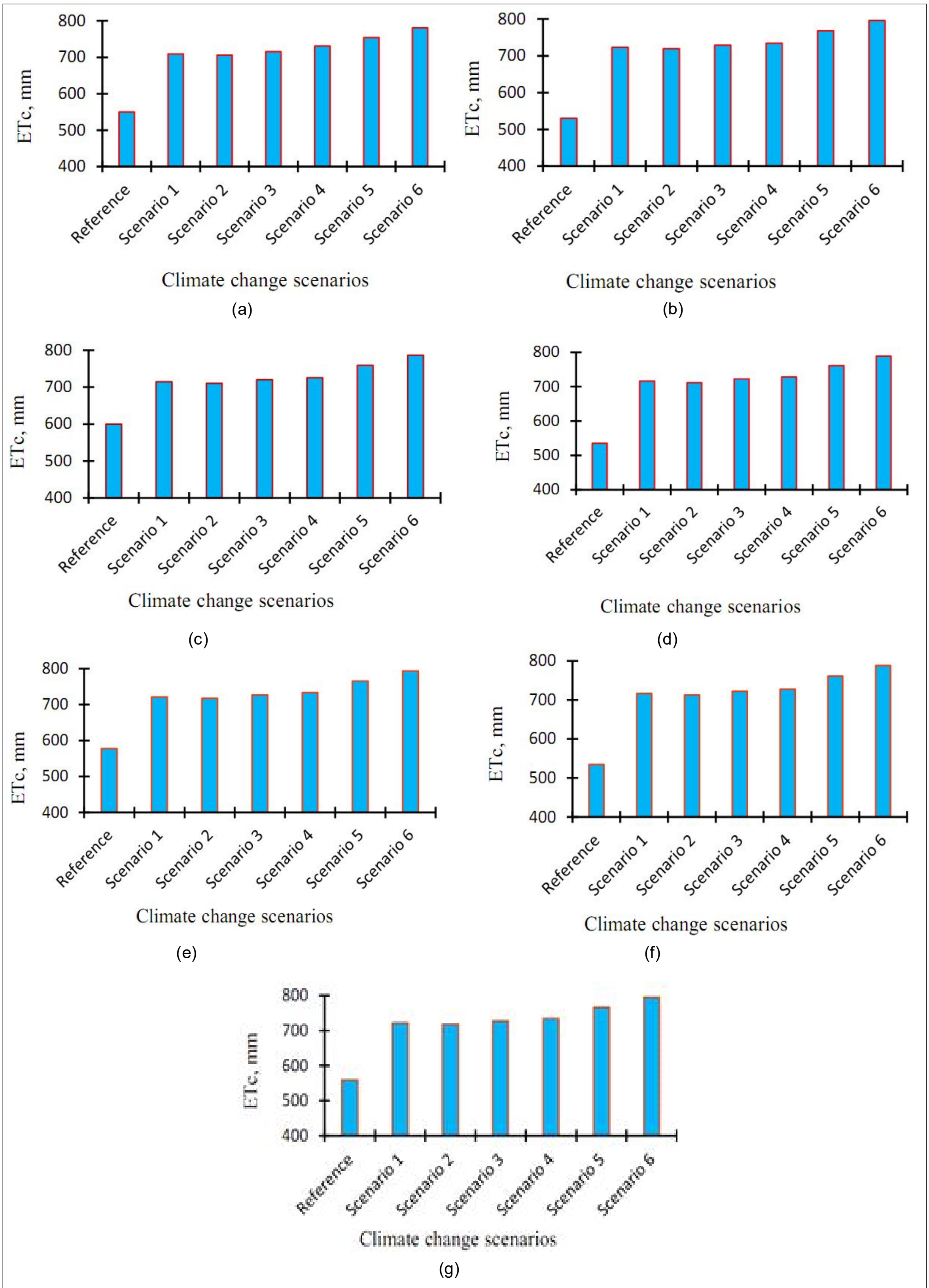

Fig 5: Crop water requirement of pigeonpea under different climate change scenarios for locations a) Aland, b) Afzalpur, c) Chincholi, d) Chittapur, e) Kalburgi, f) Sedam and g) Jewargi.

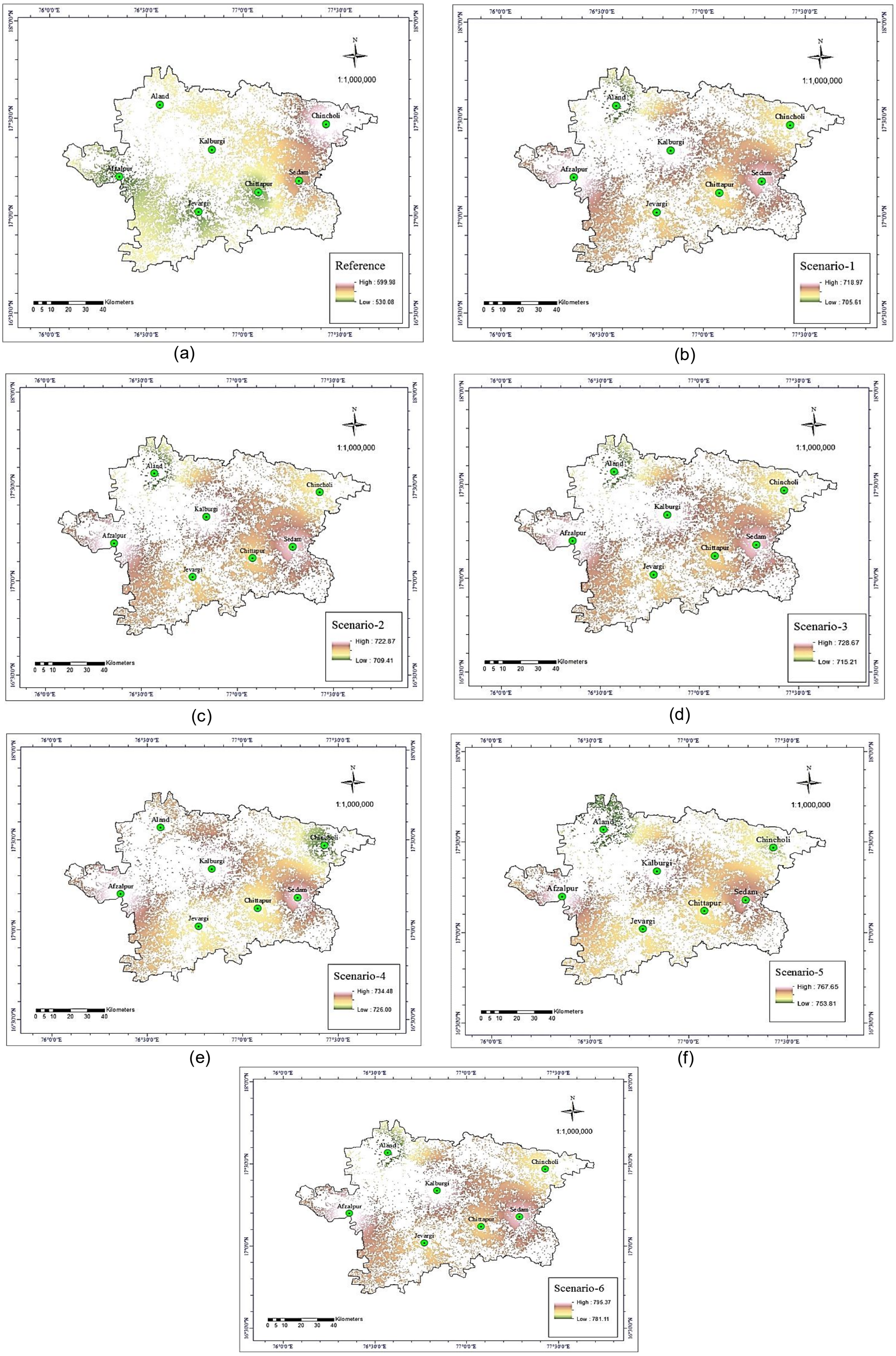

Fig 6: Spatial variability maps of crop water requirement, mm under different climate change scenarios.

under scenario-3 shown in Fig 6 (d). The spatial variability of ET_c found less of (715 to 719 mm) at Aland and the highest found with a range of (725 to 728 mm) at Afzalpur, Kalaburgi and Sedam. The spatial distribution of scenario-4 ET_c is shown in Fig 6 (e) and found less of (726 to 728 mm) at Chincholi and part of Jewargi and Chittapur and the highest with a range of (732 to 734 mm) was found at Afzalpur, Kalaburgi and Sedam. The spatial distribution of scenario-5 ET_c shown in Fig 6 (f) the spatial distribution of scenario-6 ET_c is shown in Fig 6 (g) and found less (781 to 785 mm) at Aland and the highest with a range of (791 to 795 mm) at Afzalpur, Kalaburgi and Sedam. The spatial distribution maps reveal that the distribution of ET_c is found an increasing trend in all the scenarios to reference scenarios ET_c. In all the scenarios ET_c is less at Aland, except scenario-4, the highest at Afzalpur, Kalaburgi and Sedam.

CONCLUSION

The net impact of climate change on crop water requirement would depend on two important climatic factors, namely rainfall and temperature. This may be due to the controlling of other climatic parameters. The major conclusions drawn from the study are;

- The ET_c of pigeonpea estimated and exhibited an increasing trend at Afzalpur, Jewargi and Kalburg and a decreasing trend at Aland, Chittapur, Sedam and Chincholi in the past 35 years.
- ET_c of pigeonpea observed an increasing trend at all the places under various climate change scenarios. Under the INCCA and IPCC future prediction scenarios, the maximum and minimum of ET_c observed in scenario 6 and scenario 2, respectively.
- It is important to note that the predicted ET_c under IPCC and INCCA scenarios follows the trend of ET_c estimated for Aland, Chittapur, Sedam and Jewargi from long term weather data.
- The spatial distribution maps reveal that the distribution of ET_c is found an increasing trend in all the scenarios to reference ET_{cc}. In all the scenarios ET_c is less at Aland, except scenario 4 and the highest at Afzalpur, Kalaburgi and Sedam.
- Looking at the impact of the variability of climate on crop water requirement on pigeonpea there is need to promote adoption measures *viz*. rainwater harvesting, soil and water conservation and increase groundwater recharge in the study area to minimize the risk of yield reduction due to climatic variability.

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