ANSF
APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
15(1), 178 - 193 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Climate change effects on Chickpea yield and its variability in Andhra Pradesh, India

K. Nirmal Ravi Kumar*
Department of Agricultural Economics, Agricultural College, Bapatla, Acharya NG Ranga Agricultural University (ANGRAU), (Andhra Pradesh), India
M. Jagan Mohan Reddy
Director, Extension Education Institute, Rajendranagar, Professor Jaya Shankar Telangana State Agricultural University (PJTSAU) (Telangana), India
Suresh Chandra Babu
Capacity Strengthening, The International Food Policy Research Institute (IFPRI), Washington, USA

*Corresponding author. Email: kn.ravikumar@angrau.ac.in

Article Info
https://doi.org/10.31018/jans.v15i1.4102
Received: November 6, 2022
Revised: January 30, 2023
Accepted: February 5, 2023

How to Cite

Kumar, K. N. R. *et al.* (2023). Climate change effects on Chickpea yield and its variability in Andhra Pradesh, India. *Journal of Applied and Natural Science*, 15(1), 178 - 193. https://doi.org/10.31018/jans.v15i1.4102

Abstract
Farmers usually do not know the precise output that is affected by climatic factors such as temperature and rainfall and are characterized by inter-annual variability, part of which is caused by global climate change. No study covers the influences of climate factors on yield and yield risk in the context of chickpea farming in Andhra Pradesh, India. In this context, this study aimed to investigate the trends in climate change variables during *Rabi* season (October to January, 1996-2020) and evaluated their variability on chickpea yields across different agro-climatic zones in Andhra Pradesh by employing Just and Pope production function. Four non-parametric methods-Alexandersson's Standard Normal Homogeneity Test, Buishand's Range Test, Pettitt's Test and Von Neumann's Ratio Test are applied to detect homogeneity in the data. Mann–Kendall (MK) test and Sen's slope (SS) method were employed to analyze monthly rainfall trends and minimum and maximum temperature trends. Results of Just and Pope (panel data) quadratic and Cobb-Douglas methods revealed that monthly minimum temperature positively influenced the mean yield of chickpea (0.22% and 0.16%, respectively). However, rainfall (-0.41% and -0.31%) and maximum temperature (-0.08% and -0.04%) negatively influenced the mean yield of chickpea under quadratic and Cobb-Douglas models, respectively. Accordingly, rainfall (0.08% and 0.06%) and maximum temperature (0.83% and 0.72%) positively influenced the yield variability and minimum temperature (-0.77% and -0.67%) reduced yield variability of chickpea under quadratic and Cobb-Douglas models respectively. In view of these findings, it is imperative to advocate the farmers about the importance of cultivating drought-tolerant chickpea varieties, drought-proofing and mitigation strategies, micro-irrigation practices and improving their access to agro-meteorological information towards sustainable chickpea cultivation in Andhra Pradesh.

Keywords: Chickpea, Climate, Just and Pope production function, Mann–Kendall test, Panel data, Sen's slope estimator, Trend analysis

INTRODUCTION

Climate change has a dire impact on the socio-economic sector and the environment and can lead to massive famines and migration, natural resource degradation, and weak economic performance. Agriculture bears much of the impact, and in developing countries like India, it is the most affected sector, absorbing up to 80 percent of all direct impacts with multiple effects on water availability, agricultural production, food security and rural livelihoods. They impact not only a particular region that experiences it but also every household, as agricultural production and water resources are integrally related to producing a wide range of goods and services (FAO, 2017). So, climate change is considered a potential threat to attaining sustainable agriculture development coupled with food security. Unfortunately, India is one of the most vulnerable countries to climate change and the forecasts from earlier studies (Chaturvedi *et al., 2012; Krishnan et al., 2020*). They highlighted increases in rainfall; and maximum and minimum temperatures, thus adversely influencing the timely sowing of crops, crop growth, crop yields, and food security. According to Chaturvedi *et al. (2012), at*

All-India level, mean warming over India is likely to be in the range 1.7 to 2.0^{0}C by 2030s and 3.3 to 4.8^{0}C by 2080s and precipitation is projected to increase from 4 per cent to 5 per cent by 2030s and from 6 per cent to 14 per cent towards the end of the century (2080s) compared to the 1961-1990 baseline.

Further, there is a consistent positive trend in the frequency of extreme precipitation days (e.g., greater than 40 mm/day) for decades 2060s and beyond. This calls for serious attention to analysing the impact of climate change and its variability on agriculture to plan for adaptation and mitigation strategies to combat the same. At the same time, it needs to enhance agricultural productivity through evolving climate-resilient crop varieties and technologies/innovations suiting changing climatic scenarios (Dagar *et al., 2017).*

Previous studies on impact of climate change on crop yields were carried out internationally (Carew *et al.* (2017); Mahdiyeh *et al.* (2018); Feroze *et al.* (2020); Samira *et al.* (2020); Agossou *et al* (2021); Mulungu *et al.* (2021)); through employing Just and Pope's (1978) stochastic production function approach. However, to the best of the researcher's knowledge, no study has been conducted so far applying the panel data approach in Andhra Pradesh. It is in this context there is a need to analyze the trends in climate change variables and their impact on mean chickpea yield and its variability in Andhra Pradesh using a panel data approach.

The present work differs and builds upon previous research, as it extends the existing literature by calculating the homogeneity or inhomogeneity to detect break points of climate change data (rainfall, maximum and minimum temperatures) over two and a half decades. The second difference is that no previous studies were conducted in Andhra Pradesh to analyse the impact of climate variability on chickpea yields, which helps to formulate climate resilient strategies for chickpea cultivation. The third difference is, we use a long panel spanning almost two and a half decades (1996-2020) and this is considered useful, since climate change unfolds over long timescales. This panel data is larger than earlier studies like Raju and Pratiti (2020) and Carew *et al.* (2017). Fourth, this study is at the granular level of districts majoring in chickpea cultivation across different agro-climatic zones in Andhra Pradesh. As a final point, this study covers only major chickpea-cultivating districts in Andhra Pradesh to overcome aggregation anomalies, as in the case of the country-level panel (Boubacar 2012 ; Haile *et al.* 2017). That is, as there is greater climate divergence across different States in India, it is not meaningful to consider country-level panel and generalize the findings at All-India level; hence, this study is limited to major chickpea cultivating districts in Andhra Pradesh only. This is also true for studies in other countries like Carew *et al.* (2017); Feroze *et al.* (2020); Raju and Pratiti (2020), and Agossou *et al.* (2021). Considering the importance, this study examines the impact of climate change variables on the mean and variability of chickpea yields in Andhra Pradesh by employing the widely used Just and Pope production function (Sarker *et al.*, 2019).

India is the leading producer of chickpeas, with 12.33 per cent of the share in global pulses production and is cultivated in around 10.94 m.ha with a production of 11.08 m. tonnes during 2020. India accounted for 74 per cent of the total area and 75 per cent of total production of chickpea in the world in 2020. Major chickpea-producing countries include India followed by Turkey (0.63 m. tonnes), Pakistan (0.50 m. tonnes), Myanmar (0.48 m. tonnes), Ethiopia (0.46 m. tonnes), Russia (0.29 m. tonnes), Australia (0.28 m. tonnes) and USA (0.19 m. tonnes) . China, mainland enjoy the highest productivity of chickpea (5356 kg/ha) and India ranked 18th position in the world in terms of productivity with 1012 kg/ha and which is less than the global average (1519 kg/ha) in 2020 (www.fao.org). Further, the chickpea is one of the major pulse crops cultivated during *Rabi* season. In India, Andhra Pradesh is one of the leading chickpea producing States under varied agro-climatic conditions with around 0.46 m. ha area and 0.56 m. tonnes production during 2019-20 (Statistical Abstract, 2020). This State comprises diverse agro-climatic zones viz., Scarce rainfall zone, Southern zone, Krishna zone, Godavari zone and North Coastal zone. As these zones were largely impacted by climate change (Komali *et al.*, 2020), it called for analysing of climate change variables' influence on chickpea yields. Therefore, this study employed cross-sectional time series data across major chickpea-cultivating districts in Andhra Pradesh to address the following research questions: i) Is there any difference in climate change variables and chickpea yields across the selected districts? ii) How do the changes in climate variables affect the mean and variability of chickpea yields ? iii) What will be the elasticities of climate change setups on future predictions of chickpea yields?

MATERIALS AND METHODS

Study area and data collection

As a large part of Southern India falls under arid and semi-arid regions, the State of Andhra Pradesh was purposively selected for the study. Ananthapuramu. Kadapa, East Godavari, Krishna and Visakhapatnam districts were also purposively selected, as chickpea is one of the major crops cultivated during Rabi season and these districts harbour the highest cultivated area under chickpea across different agro-climatic zones viz., Scarce rainfall zone, Southern zone, Krishna zone, Godavari zone and North Coastal zone respectively. Together, these five districts accounted for 39 per cent of the chickpea area and 23 per cent of chickpea production during Rabi season in Andhra Pradesh. Historical climate observations viz., monthly rainfall, maximum and minimum temperatures for October to January 1996-2020 were obtained from Statistical Abstracts of Andhra Pradesh, Hand Book of Statistics of selected districts. As there were no missing values in climate change variables, the yield data of chickpeas were also collected for the above reference period.

Descriptive statistics

Mean, Standard Deviation (SD) and Coefficient of Variation (CV) are employed to examine the variability for climate change variables viz., rainfall, maximum and minimum temperatures, area and yields of chickpea during Rabi season (October to January, 1996-2020).

Climate variables trend analysis

Homogeneity analysis: Pettitt's Test, Alexandersson's Standard Normal Homogeneity Test (SNHT), Buishand's Range Test and Von Neumann's Ratio Test were employed to assess the homogeneity of monthly time series of rainfall, maximum and minimum temperatures during Rabi season (1996-2020). In accordance with Agossou *et al*, 2021; Patakamuri *et al*, 2020; Ahmad and Deni, 2013; Wijngaard *et al.*, 2003; the classification was made based on the number of tests rejecting H_O (data are homogeneous) (Table 1).

Table 1. Classification based on the number of tests

Class	Category	Inference
Class A	Useful	When none or only one of the above four tests rejects H_O
Class B	Doubtful	When two of the four tests reject H_O
Class C	Suspect	When three or all the tests reject

Mann–Kendall (MK) Test and Sen's Slope Method: The MK test (Kendall, 1975; Mann, 1945) was employed to assess the trends in monthly rainfall, maximum and minimum temperatures during Rabi season (Koudahe *et al.*, 2018). The true slope (change per unit time) was predicted using Sen's slope estimator (Sen, 1968). As the results of MK test are likely to be affected by the presence of serial correlation in time series data, the following Trend-Free Pre-Whitening test (using R package "modifiedmk" (Patakamuri *et al.*, 2020; Ahmad *et al.*, 2015; Yue *et al.*, 2002)) was carried out before the MK test:

$$r_1 = \frac{\sum_{i=1}^{n-1}(X_i-\bar{X})(X_{i+1}-\bar{X})}{\sum_{i=1}^{n}(X_i-\bar{X})^2} \qquad \text{Eq. 1}$$

Where, r_1 = lag-1 serial correlation coefficient X_i = value of an observation of time series data, $\bar{X}$ = mean of the sample of time series data and n = sample size.

The autocorrelation coefficient values were tested against the following equation:

$$r_1(95\%) = \frac{-1 \pm 1.96\sqrt{(n-2)}}{n-1} \qquad \text{Eq. 2}$$

If r_1 lies between the upper and lower limits of the confidence interval, then the time series data were considered serially correlated.

Panel unit roots and stationary: The presence of unit roots for each variable was tested (with trend and without trend) by employing Fisher-type test (Maddala and Wu, 1999); Levin, Lin, Chu (LLC) test (Barnwal and Kotani, 2010) and Harris-Tzavalis test **(**Harris and Tzavalis 1999) (to ensure the robustness of the results), as non-stationary data set might yield spurious results (Chen and Chang, 2005; Granger and Newbold, 1974).

Just and Pope production function: To study the influence of climate variables on chickpea's mean yield and yield variability during Rabi season, Just and Pope (1978; 1979) production function was applied. It involves two components viz., estimation of mean yield and yield variability (risk) (Cabas *et al.*, 2010; Kim and Pang, 2009). The common form of the Just and Pope Production Function (Just and Pope, 1978) is:

$$y = (X) + h(X)\epsilon, \qquad \text{Eq. 3}$$

Based on Saha *et al.* (1997) and Chen *et al.* (2004) a production function of the form below is obtained:

$$y = (X) + u = (X, \beta) + h(X, \alpha)\epsilon, \qquad \text{Eq. 4}$$

where, y is chickpea yield; X is descriptive variables (rainfall, monthly maximum temperature, minimum temperature and time trend), and ϵ is the exogenous production shock with (ϵ)=0 and $Var(\epsilon)$ = δ_{ϵ}^{2} .

In this study, two functional forms of Just and Pope production function are considered viz., Quadratic and Cobb-Douglas forms (Tveteras, 1999; Tveteras and Wan, 2000; Chen *et al.*, 2004; Isik and Devadoss, 2006; Koundouri and Nauges, 2005; Kim and Pang, 2009) for the estimation of mean yield and yield variability functions for chickpea.

Mean function: This is specified as:

Linear-Quadratic form: $y = \alpha_0 + \alpha_t T + \sum_j \alpha_{1j} x_j + \sum_j \alpha_{2j} x_j^2 + \sum_j \sum_{(k \neq j)} \alpha_{jk}\, x_j x_k$ Eq. 5

Cobb-Douglas form: $y = \alpha + \alpha T + \prod_j x_j^{\alpha_j}$ Eq. 6

where, x_j *and* x_k are explanatory variables that include climate variables, 'T' represents time trend and $\alpha's$ imply coefficients to be estimated. The justification of including the time trend is that it can capture technological progress over the period under consideration.

Variance function: Following Just and Pope (1978, 1979), Kumbhakar and Tveteras (2003) and Koundouri and Nauges (2005), the variability function h(.) is modelled as a Cobb-Douglas form:

$$h(x) = \beta T \prod x\beta_j \quad \text{(or)} \quad h(x) = \beta T\ x\beta_1.\ x\beta_2.\ x\beta_3\ \ldots..\ x\beta_n \qquad \text{Eq. 7}$$

Logarithmic transformation of this function produces the linear function as follows:

$$lnh\ (x) = \ln\ (\beta T\ \beta t x\beta_1.\ x\beta_2.\ x\beta_3\ \ldots..\ x\beta_n)$$

$$lnh\ (x) = \ln\beta + ln\mathrm{T}\beta t + lnx\beta_1 + lnx\beta_2 + lnx\beta_3 + \cdots + lnx\beta n lnh(x) = \ln\beta_0 + \beta t lnT + \beta_1 lnx_1 +$$

$$\beta_2 lnx_2 + \beta_3\ lnx_3 + \cdots + \beta_n lnx_n \qquad \text{Eq. 8}$$

where $\beta's$ are parameters to be estimated.

Hausman test was conducted to decide, whether to employ random effects model or fixed effects model for analysing the panel data. Further, in this study, a three-step Feasible Generalized Least Squares (FGLS) estimator was considered over Maximum Likelihood Estimator (MLE), as the former yields better results considering the large sample size (n = 125) and the problems of heteroscedasticity and autocorrelation in panel data set can be better addressed from FGLS (Judge *et al., 1985;* Cameron & Trivedi, 2009).

Elasticities of climate change variables: The elasticities (marginal effects) of climate change variables will be computed through multiplying the coefficients of climate variables, like rainfall, maximum temperature and minimum temperature, with the average of respective climate change variables and dividing by average yield (Humayun, 2015).

Future predictions of chickpea yields: From the above estimated elasticities of climate change variables, future predictions of chickpea yields can be obtained through employing the following equation:

$$\Delta Y = [(\partial Y/\partial R) * \Delta R + (\partial Y/\partial MaxT) * \Delta MaxT + (\partial Y/\partial MinT) * \Delta Mint] * 100 \qquad \text{Eq. 9}$$

where, Y is the yield, R is the rainfall, MaxT is the maximum temperature and MinT is the minimum temperature; (∂Y/∂R), (∂Y/∂MaxT) and (∂Y/∂MinT) were identified by the equations of the model. Coordinated Regional Downscaling Experiment (CORDEX) South Asia multi- Regional Climate Model (RCM) reliability ensemble average estimate of projected changes in the annual mean of daily rainfall, maximum and minimum temperatures over India for the future periods: near-term (2016-2045), mid-term (2036-65) and long-term (2066-2095) changes in future climate over India under Representation Concentration Pathway (RCP) 4.5 scenario, relative to the base 1976-2005 were considered to project the changes in chickpea yields (Sanjay *et al*, 2017).

RESULTS AND DISCUSSION

Summary statistics of climate variables, area and yield of chickpea across selected districts: The findings (Table 2) revealed that Visakhapatnam received the highest mean rainfall of 107.3 mm followed by East Godavari (92.1 mm) during Rabi season, 1996-2020. The lowest mean rainfall was noticed in Ananthapuramu (74.7 mm), followed by Kadapa (80.5), as both these districts fall in the dry tract of Rayalaseema region in Andhra Pradesh. It was also evident from high CV values (>40%) that in both these districts, the rainfall is highly erratic compared to other districts. However, there is not much variation (CV) regarding maximum and minimum temperature across the selected districts (Humayun, 2015; Feroze, 2020; Samira *et al*., 2020).

The mean area of chickpea (Table 3) is highest in Ananthapuramu (0.649 lakh ha), followed by Kadapa (0.667 lakh ha). However, the area is very much meagre in all three coastal districts viz., Krishna (1000 ha), East Godavari (400 ha) and Visakhapatnam (100 ha). The lack of adequate irrigation facilities in Ananthapuramu and Kadapa districts has prompted farmers to allocate more area to chickpea (Hand Book of Statistics, Ananthapuramu, 2020). The area under chickpea cultivation in these two districts has gained momentum in the past two and a half decades and increased by 237 and 580 percent, respectively, during 1996-2020. However, chickpea cultivation in coastal districts has gained more popularity in the recent decade (2011-2020), especially in East Godavari and Krishna districts, with 296 and 389 percent, respectively. This is due to the late release of canal water from Godavari and Krishna perennial rivers, respectively, during Kharif season (up to 2nd week of August) and this prompted the farmers to go late sowings of staple food crops, rice and consequently preferred to cultivate chickpea during Rabi season. Even in Visakhapatnam, there is a slow increase in chickpea cultivated area by 37 per cent during the above reference period, as oil palm cultivation is gaining momentum in this district.

Regarding productivity of chickpea, it is highest in Krishna (1720 kg/ha), followed by East Godavari (1637 kg/ha) and Visakhapatnam (1430 kg/ha) and it is lowest in Ananthapuramu with only 646 kg/ha. The higher variability (CV%) in rainfall during *Rabi season (47.2*%) and lack of adequate irrigation facilities in Ananthapuramu are mainly responsible for lower chickpea yields (Hand Book of Statistics, Ananthapuramu, 2020). It is interesting that yield risk was higher in Kadapa (152%) and Ananthapuramu (44%) districts compared to coastal districts viz., East Godavari (20%), Krishna (25%) and Visakhapatnam (26%), as the rainfall varia-

Table 2. Mean rainfall, maximum and minimum temperatures in selected districts during *Rabi* season, 1996-2020

District	Variables	Mean	CV(%)	Minimum	Maximum
Ananthapuramu	Rainfall (mm)	74.7	47.2	26.5	184.4
	Max. Temp (^{O}C)	30.6	1.0	29.1	33.1
	Min. Temp (^{O}C)	19.1	2.1	17.4	22.5
Kadapa	Rainfall (mm)	80.5	44.5	32.1	208.4
	Max. Temp (^{O}C)	30.3	1.0	19.1	31.6
	Min. Temp (^{O}C)	20.6	2.0	18.7	23.6
East Godavari	Rainfall (mm)	92.1	27.1	76.8	101.5
	Max. Temp (^{O}C)	30.2	0.9	27.6	31.8
	Min. Temp (^{O}C)	21.1	1.6	20.3	23.4
Krishna	Rainfall (mm)	91.6	29.7	76.6	132.7
	Max. Temp (^{O}C)	29.9	1.3	28.3	32.3
	Min. Temp (^{O}C)	22.6	1.2	20.7	24.1
Visakhapatnam	Rainfall (mm)	107.3	15.6	81.6	287.1
	Max. Temp (^{O}C)	29.2	1.0	27.1	31.6
	Min. Temp (^{O}C)	20.7	1.8	19.5	23.1

Table 3. Summary statistics of area and yield of chickpea in selected districts during *Rabi* season, 1996-2020

Variable	Ananthapuramu		Kadapa		East Godavari		Krishna		Visakhapatnam	
	Area (‘00ha)	Yield (kg/ha)	Area (‘00ha)	Yield (kg/ha)	Area (‘00ha)	Yield (kg/ha)	Area (‘00ha)	Yield (kg/ha)	Area (‘00ha)	Yield (kg/ha)
Mean	649	646	667	1198	4	1637	10	1720	1	1430
CV (%)	38	44	44	152	163	20	116	25	59	26
Minimum	229	230	142	168	0	1078	0	951	0	185
Maximum	945	1154	1120	9694	19	2428	40	2500	2	3000

bility is higher during Rabi season in Ananthaputramu (47.2%) and Kadapa (44.5%). However, cultivation of chickpea was inevitable in these two districts because of low and erratic rainfall, lack of adequate irrigation facilities and coincidence of rainfall patterns with the Critical Moisture Sensitive Stages (CMSS) of this crop. However, in three coastal districts viz., Krishna, East Godavari and Visakhapatnam, due to late release of canal irrigation water during Kharif season, the farmers could not sow rice in right time during Rabi season and this prompted them to go for chickpea cultivation. The area under chickpea cultivation is gaining momentum in these three districts due to its lucrative prices in the market. The findings also indicated that though these three coastal districts were the forerunners in terms of yield for chickpea (on account of good irrigation facilities), the mean area is significantly higher among Ananthapuramu and Kadapa (Statistical Abstract, 2020).

Homogeneity of rainfall and temperature data: The findings (Table 4) indicated that rainfall during Rabi season across all the districts was labelled “useful”. That is, the findings from Pettitt’s test, SNHT, Buishand's test and von Neumann's test detected no breakpoint (inhomogeneity) across all the districts, implying no recession in rainfall during the reference period. Regarding maximum temperature, all the districts, except Visakhapatnam revealed “useful” (Ahmad and Deni, 2013). Like rainfall, the time series data for minimum temperature during Rabi season was classified as “useful” across all the selected districts.

Again, the homogeneity tests were performed for month-wise rainfall; and maximum and minimum temperatures during Rabi season ie., October to December of the selected reference period (Table 5). A total of 60 series (12 months, 5 districts and 3 climate variables) were tested and among them, 58 series were labelled “useful”, and only two were classified as “Doubtful” regarding homogeneity, viz., October for rainfall and maximum temperature for Visakhapatnam district. Low temperatures and high wind speed during cyclonic rains made it difficult for observers to record the climate data of different stations from Visakhapatnam. However, as 58 series out of 60 are recorded “useful”, it implies the data are of good quality and less erroneous for the study.

Serial correlation analysis: A total of 60 time series (4 months×3 climate change variables×5 districts) were subjected to serial correlation test and the findings (Table 6) showed that only two series were serially correlated. This represents only 3.33 per cent of the total number of time series assessed. So, as in homogeneity tests, the monthly minimum temperature data revealed no serial correlation across all the districts; however, rainfall and maximum temperature data for January were found to be serially correlated in Visakhapatnam. So, for these two climate change variables of Visakhapatnam, a modified version of the MK test (Pre-Whitening) was employed along with Sen's slope estimator to analyse the trends in climate change variables.

Trends in climate variables, area and productivity of chickpea: In all the selected districts, monthly rainfall during Rabi season exhibited non-significant increasing trends ($p > 0.05$), unlike Visakhapatnam district (Table 7). The slope is highest for Kadapa (0.05 mm/year) and lowest for Visakhapatnam district (-0.054 mm/year). Interestingly, the pattern of rainfall in these districts and its coincidence with the CMSS of the crops decide the cropping pattern. When the vegetative stage of crops coincides with dry spells, it leads to a decline in productivity. Due to the single rainy season in Ananthapuramu and Kadapa, there is no chance for farmers to go for crop diversification. Further, the rainfall pattern in these two districts coincides with the CMSS of groundnut and chickpea and, thereby, compels the farmers to cultivate these two crops during Rabi season. Regarding temperature, in all the selected districts, maximum temperatures exhibited significant increasing trends ($p<0.05$). On the contrary, monthly minimum temperatures showed significant declining trends in East Godavari (-0.185**), Krishna (-0.123**) and Visakhapatnam (-0.133**) districts, unlike Ananthapuramu (0.150**) and Kadapa (0.081^{NS}).

The results displayed in Table 8 showed declining trends in month-wise rainfall during the growing (Rabi) season of chickpea in all the districts viz., Ananthapu-

Table 4. Summary of homogeneity results of the rainfall (mm) and temperature during *Rabi* season (1996-2020)

District	Pettitt's Test		SNHT		Buishand's test		von Neumann's test		Remarks
	K	p-value (Two-tailed)	T_O	p-value (Two-tailed)	Q	p-value (Two-tailed)	N	p-value (Two-tailed)	
Rainfall (mm)									
Ananthapuramu	32.000	0.128	10.067	0.059	3.196	0.685	1.651	0.184	Useful
Kadapa	35.000	0.213	4.260	0.283	2.467	0.897	2.321	0.786	Useful
East Godavari	43.000	0.515	2.080	0.756	3.115	0.700	2.538	0.922	Useful
Krishna	58.000	0.769	2.631	0.615	3.717	0.486	2.156	0.649	Useful
Visakhapatnam	52.000	0.971	2.446	0.675	3.831	0.466	2.439	0.871	Useful
Maximum Temperature (^{O}C)									
Ananthapuramu	86.000	0.124	7.459* (2015,2017)	0.036	5.952	0.068	1.395	0.057	Useful
Kadapa	90.000	0.091	7.128	0.047	6.627	0.026	1.304	0.036	Useful
East Godavari	126.000* (2015,2017)	0.001	9.793	0.017	7.978	0.002	1.023	0.004	Useful
Krishna	134.000* (2003,2009,2015)	0.000	13.012	0.000	9.197	0.000	0.826	0.000	Useful
Visakhapatnam	136.000* (1996,2005)	0.000	11.575* (1996,2005)	0.003	8.674	0.000	1.034	0.006	Doubtful
Minimum Temperature (^{O}C)									
Ananthapuramu	76.000	0.261	4.326	0.268	4.760	0.220	1.728	0.246	Useful
Kadapa	86.000	0.135	5.634	0.132	5.336	0.126	1.733	0.246	Useful
East Godavari	64.000	0.575	4.398	0.306	4.812	0.209	2.008	0.504	Useful
Krishna	54.000	0.940	4.025	0.371	3.592	0.542	1.759	0.270	Useful
Visakhapatnam	86.000	0.128	5.507	0.198	5.771	0.077	1.875	0.366	Useful

K, T_O, Q and N stand for the resulting coefficients of the respective tests, * indicates the inhomogeneous districts at 5% significance level and values in the parentheses represent the break point years (von Neumann's Test gives no information about the break point)

Table 5. Summary of homogeneity results of the month-wise rainfall and temperature data during *Rabi* season

Districts	October	November	December	January
Rainfall (mm)				
Ananthapuramu	Useful	Useful	Useful	Useful
Kadapa	Useful	Useful	Useful	Useful
East Godavari	Useful	Useful	Useful	Useful
Krishna	Useful	Useful	Useful	Useful
Visakhapatnam	Doubtful	Useful	Useful	Useful
Maximum Temperature (^{O}C)				
Ananthapuramu	Useful	Useful	Useful	Useful
Kadapa	Useful	Useful	Useful	Useful
East Godavari	Useful	Useful	Useful	Useful
Krishna	Useful	Useful	Useful	Useful
Visakhapatnam	Doubtful	Useful	Useful	Useful
Minimum Temperature (^{O}C)				
Ananthapuramu	Useful	Useful	Useful	Useful
Kadapa	Useful	Useful	Useful	Useful
East Godavari	Useful	Useful	Useful	Useful
Krishna	Useful	Useful	Useful	Useful
Visakhapatnam	Useful	Useful	Useful	Useful

Table 6. Summary of serial correlation results of rainfall and temperature data during *Rabi* season

Districts	October	November	December	January
Rainfall (mm)				
Ananthapuramu	False	False	False	False
Kadapa	False	False	False	False
East Godavari	False	False	False	False
Krishna	False	False	False	False
Visakhapatnam	False	False	False	True
Maximum Temperature (^{O}C)				
Ananthapuramu	False	False	False	False
Kadapa	False	False	False	False
East Godavari	False	False	False	False
Krishna	False	False	False	False
Visakhapatnam	False	False	False	True
Minimum Temperature (^{O}C)				
Ananthapuramu	False	False	False	False
Kadapa	False	False	False	False
East Godavari	False	False	False	False
Krishna	False	False	False	False
Visakhapatnam	False	False	False	False

Note: ‘False’ = absence of serial correlation; ‘True’ = presence of serial correlation ramu (October, (-1.104 mm/season)), Kadapa (October, (-2.038 mm/season)), East Godavari (October, (-1.444 mm/ season)), Krishna (October, (-0.999 mm/season)) and Visakhapatnam (October, (-1.333 mm/season), November, (-0.774 mm/year) and January, (-0.108 mm/year)), though non-significant. Only in Kadapa, the rainfall during January recorded positive and significant trend (0.0001 mm/year). Further, across all the districts, the maximum temperatures recorded positive trends, though non-significant, during the chickpea's vegetative phase, and it turned significant during October for Kadapa (0.077^{O}C). The minimum temperatures showed significant declining trends during the chickpea sowing season, i.e., November and December in Ananthapuramu and Kadapa; October and November in East Godavari; November in Kadapa and October, November and December in Visakhapatnam. This implies that during the sowing and vegetative phase of chickpea, rainfall and maximum temperature showed increasing trend, while minimum temperature showed declining trends across the selected districts. In Ananthapuramu, rainfall during rabi season accounts for around 30 per cent of annual rainfall (1996-2020); the mean maximum and minimum temperatures are around 30.6^{O}C and 19.1^{O}C. This compels the farmers to adopt pulses like chickpea during this season (Hand Book of Statistics, Ananthapuramu, 2020). The same is the case for Kadapa with respect to mean rainfall, its pattern and mean temperature values during Rabi season, as these two districts are located in similar agro-climatic conditions of Rayalaseema region in Andhra Pradesh. In both these districts, the yields of chickpea showed inter-annual fluctuations primarily because of rainfall variability in both these districts. However, East Godavari and Krishna districts are blessed with higher mean rainfall and irrigation from perennial rivers viz., Godavari and Krishna, respectively and thus, permit the farmers to practice diversified crops during Rabi season like rice, maize, black gram, chillies etc. So, the area under chickpea remained low and stable up to 2006, with short-term fluctuations between 2007 to 2014 and later showed a continuous increasing trend in both districts. This is because of two major reasons viz., higher Minimum Support Prices (MSPs) offered by the Government and improved local marketing facilities. In the Visakhapatnam district, because of higher mean annual rainfall (ranging from 808 mm to 1617 mm with a mean of 1111 mm during 1996-2020), the farmers prefer to cultivate sugar cane and rice as major crops in the district. During Rabi season, farmers cultivate chickpea, green gram, horse gram and black gram, etc., from October/November under restored soil moisture conditions, as rainfall distribution exceeds November with longer dry spells. Further, the declining trends in minimum temperatures from October to November facilitate the farmers to take up chickpea cultivation. However, there is a slow pace in the increase in area and yields of chickpea compared to the above four districts, as its sowings are delayed due to frequent cyclonic rains during October and November in the Visakhapatnam district.

Pre-estimation specification tests*:* Prior to applying the data for Just-Pope model, the data on climate change variables and yields of chickpea are examined for stationarity by employing the ADF-Fisher-type, LLC test and Harris-Tzavalis test (Poudel and Kotani, 2013; Sarker *et al.* 2019). These (unit root) tests are carried out with constant and trend specifications for the respective series. The outcomes of these tests (Table 9) implied that the variables are stationary for all equations. These results are consistent with McCarl *et al*, 2008 for rainfall and temperature in USA, Kim and Pang, 2009 for rainfall in Korea.

Then, the Modified Wald test, Breusch-Pagan/Cook-Weisberg test, Breusch-Pagan-Godfrey (BPG) and White heteroscedasticity tests are used to determine whether the variance of residuals is dependent on the values of independent variables. The findings (Table 10) indicate that the H_O of homoscedasticity is rejected and

Table 7. Modified MK test and Sen's Slope test (Trend-Free Pre-Whitening) of rainfall (mm), maximum and minimum temperatures (˚C) in selected districts during *Rabi* season

Districts	**First year**	**Last year**	**October to December**					
			Rainfall		**Max. Temp**		**Min. Temp**	
			MK	**SS**	**MK**	**SS**	**MK**	**SS**
Ananthapuramu	1996	2020	0.006	0.001	0.086*	0.016	0.150**	0.022
Kadapa	1996	2020	0.009	0.050	0.152**	0.021	0.081	0.012
East Godavari	1996	2020	0.005	0.001	0.206**	0.034	-0.185**	-0.028
Krishna	1996	2020	0.034	0.001	0.232**	0.057	-0.123**	-0.012
Visakhapatnam	1996	2020	-0.019	-0.054	0.207**	0.037	-0.133**	-0.017

Note: ** - Significant at 1% level, * - Significant at 5% level

Table 8. Modified MK test and Sen's Slope test (Trend-Free Pre-Whitening) of the month-wise (n = 25) rainfall (mm), maximum and minimum temperatures (˚C) in selected districts during *Rabi* season

Month	**First year**	**Last year**	**Ananthapuramu**			**Kadapa**			**East Godavari**			**Krishna**			**Visakhapatnam**		
			Rainfall	**Max. Temp**	**Min. Temp**	**Rainfall**	**Max. Temp**	**Min. Temp**	**Rainfall**	**Max. Temp**	**Min. Temp**	**Rainfall**	**Max. Temp**	**Min. Temp**	**Rainfall**	**Max. Temp**	**Min. Temp**
Oct	1996	2020	-0.080 (-1.104)	0.225 (0.038)	0.145 (0.017)	-0.113 (-2.038)	0.428** (0.077)	-0.007 (-0.002)	-0.105 (-1.444)	0.188 (0.035)	-0.413** (-0.048)	-0.018 (-0.999)	0.246 (0.083)	-0.174 (-0.027)	-0.058 (-1.333)	0.051 (0.010)	-0.326* (-0.034)
Nov	1996	2020	0.007 (0.066)	0.058 (0.006)	-0.022* (0.003)	0.058 (0.188)	0.261 (0.033)	-0.138* (-0.033)	0.022 (0.143)	0.094 (0.016)	-0.087** (-0.018)	0.073 (0.280)	0.239 (0.047)	-0.116* (-0.022)	-0.134 (-0.774)	0.065 (0.013)	-0.087* (-0.022)
Dec	1996	2020	0.161 (0.130)	0.261 (0.032)	-0.159* (0.021)	0.074 (0.141)	0.109 (0.015)	-0.159* (0.024)	0.159 (0.059)	0.145 (0.037)	0.167 (0.030)	0.160 (0.057)	0.239 (0.040)	0.072 (0.024)	0.105 (0.108)	0.217 (0.037)	-0.203* (-0.041)
Jan	1996	2020	0.228 (0.0001)	0.116 (0.018)	-0.007 (-0.003)	0.384* (0.0001)	0.326* (0.041)	-0.036 (-0.010)	0.004 (0.0001)	0.319 (0.066)	-0.145 (-0.030)	0.016 (0.0001)	0.384** (0.057)	-0.181 (-0.027)	-0.222 (-0.108)	0.326* (0.069)	0.145 (0.027)

Note: Figures in parentheses indicate Sen's slope values, ** - Significant at 1% level, * - Significant at 5% level

will permit the Just-Pope model to proceed. Breusch-Pagan LM test of independence and Wooldridge test also rejected the presence of Aggregation bias or Contemporaneous Correlation and autocorrelation of error terms, respectively. Finally, the results of the Hausman test revealed that the fixed effect model is better than the random effect model.

Just and Pope production function: This model is performed to estimate parameters of mean yield and yield variability functions under quadratic and Cobb-Douglas functional forms. Regional dummy variables are included in the mean yield functions, but not in the yield variance functions. In order to avoid the dummy variable trap, four dummy variables are considered, one less than the number of categories (districts) (Damodar, 2004). The outcomes of mean yield and its variance estimations for chickpea under both quadratic and Cobb-Douglas functional forms are shown in Table 11.

Quadratic model: Findings from Table 11 indicate that minimum temperature is positive and significantly ($p<0.01$) related to the mean yield of chickpea. This shows that minimum temperature during sowing and crop growth periods positively influenced chickpea yield. On the contrary, maximum temperature ($p<0.01$) significantly negatively influenced the mean yield of chickpea. This is because the increasing temperature can lead to decreased leaf area and increased senescence rate, a shortened growing period, and, consequently, a decrease in chickpea yield. The negative relation between yield and maximum temperature is in tune with the results of Resop *et al.* (2014); Kumar *et al.* (2015); Vashisht *et al.* (2015); Srivastava *et al.* (2019). The time trend variable is significant ($p<0.00$) in the mean function and implies that technological progress in the form of improved varieties, better seed, agronomic practices and plant protection measures has positive influence on chickpea yield, which is evident from increased chickpea yield in the study area over the reference period. This finding on the positive influence of time trend on yields is in agreement with the works of Isik and Devadoss (2006) in Idaho, USA; Sarker *et al.* (2014) in Bangladesh; and Sinnarong *et al.* in Thailand (2019). However, the low magnitude of the time trend could have arisen from factors other than technological advances, such as low input use, poor management, and low adoption of improved varieties that might have slightly shadowed the effect of technological advances. Quadratic terms for rainfall, maximum temperature and minimum temperature are insignificant with positive effects on mean yield. As these coefficients are positive, it implies a threshold beyond which these variables positively influence the mean yield. The

Table 9. Panel unit root test results (1996-2020)

Variables	Fisher-ADF (Modified inv. chi-squared)		LLC (Adjusted t*)		Harris-Tzavalis (rho)	
	Trend	Without trend	Trend	Without trend	Trend	Without trend
Yield (t/ha)	11.8182**	14.2978**	-4.5262**	-4.1277**	-0.0859 (-10.3236)**	-0.0496 (-17.3927)**
Rainfall (mm)	22.5124**	28.5362**	-6.0421**	-2.0638*	-0.2336 (-12.2097)**	-0.2306 (-20.7619)**
Maximum Temp (^{O}C)	9.5791**	7.3925**	-1.8538*	-3.3059**	0.1214 (-7.6748)**	0.4108 (-8.8210)**
Minimum Temp (^{O}C)	15.5437**	18.5568**	-1.9928*	-3.2133**	-0.0221 (-9.5087)**	0.0701 (-15.1637)**

Note: Figures in parentheses indicate 'Z_{cal}' value, ** - Significant at 1% level, * - Significant at 5% level (indicating rejection of unit root hypothesis)

interaction of rainfall and minimum temperature is positive and significantly associated with mean yield, while the other interaction terms are negative and insignificantly related to mean yield. All four district dummies enjoy a positive and significant influence on mean yield, implying that yield of chickpea in these districts significantly differs from the mean yields of the benchmark, i.e., Ananthapuramu.

In yield variability/risk function, the influence of minimum temperature was found to be negative and significant ($p<0.01$) whereas, the maximum temperature was positive and significant ($p<0.01$) implying that minimum temperature was the variance decreasing factor whereas, the maximum temperature is a variance increasing factor. Squared rainfall ($p<0.05$) and maximum temperature ($p<0.01$) had a positive and significant influence on yield variability, implying that

There is a threshold beyond which these factors increases the yield variability in chickpea. Time trends were also found to be positive and significantly ($p<0.01$) related to yield variability. That is, the variability in chickpea yield is increasing over time (years) and minimum temperature is expected to decrease the same. These findings are in line with the results of Chen *et al.* (2004) in USA; and Kumar *et al.* (2015) in major agricultural intensive states of India such as Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal due to more adaptation towards modern technology.

Cobb-Douglas model: The results in Table 11 indicate that maximum temperature have a negative and significant association ($p<0.01$) with the mean yield of chickpea. This is because chickpea cannot withstand heat stress, as it will affect both phenological and physiological mechanisms. On the contrary, minimum temperature showed a positive and significant ($p<0.01$) influence on the mean yield of chickpea. The trend variable again showed positive and significant contribution to the mean yield of chickpea. As in quadratic model, all the district dummies have exerted positive and significant association with the mean yield compared to the benchmark district, Ananthapuramu.

Regarding yield (risk) variability function, the impacts of rainfall (insignificant) and maximum temperature (significant, $p<0.05$) were positive, implying that these two are risk-increasing factors. On the contrary, the minimum temperature was a significant ($p<0.01$) risk-decreasing factor. The trend variable exerted a positive and significant ($p<0.01$) influence on yield variability of chickpea due to technological progress over a period of

Table 10. Panel data model specification tests

Heteroscedasticity				Aggregation bias (Contemporaneous Correlation (CC))	Autocorrelation	Fixed effect vs Random effect
Modified Wald test for group-wise heteroskedasticity	Breusch-Pagan / Cook-Weisberg test	Breusch-Pagan-Godfrey (BPG) Test	White test	Breusch-Pagan LM test of independence	Wooldridge test	Hausman test
χ2 (5) = 1037.52**	χ2(1) = 4.69*	F(4, 120) = 3.28*	F(9, 115) = 2.62**	χ2(10) = 11.378^{NS}	F(1, 4) = 2.252^{NS}	χ2(3)= 19.58* (Fixed effect is appropriate)

Note: ** - Significant at 1% level, * - Significant at 5% level, NS – Non-Significant time. These results are in line with the findings of Chen *et al.* (2004) in USA; and Kumar *et al.* (2015) in India. The estimates from these two studies revealed that applying more technological progress would risk decreasing crop input. Minimum temperature and adoption of improved varieties, better seeds, good agricultural practices, etc., reduce chickpea yield variability (risk).

Elasticities (Marginal effects) of climate variables*:* From the earlier Table 11, the impact of climate parameters ie., rainfall, maximum temperature and minimum temperature in either production function were translated into elasticities (Sarker *et al*, 2014). This is a good way to interpret the elasticities because, the coefficients in quadratic model (both mean yield and yield variability) are not easily readable due to non-linearity and interaction between climate change variables.

Table 12 reports the elasticities for minimum temperature are positively related to the mean chickpea yield in both models. Elasticity for minimum temperature is computed as 0.16~0.22; thus, one per cent rise in minimum temperature increases the average chickpea yield by 0.16~0.22 per cent. Maximum temperature has a negative effect on the average chickpea yield in both models. It's elasticity is estimated as —0.08~—0.05, i.e., a one per cent rise in maximum temperature reduces the average chickpea yield by 0.05~0.08 per cent. Regarding rainfall, its elasticity for rainfall is computed as —0.41~ —0.31 and this implies that one per cent increase in rainfall reduces the average chickpea yield by 0.31~ 0.41 per cent.

It is noteworthy that minimum temperature reduces yield variability. The coefficient for minimum temperature is negative and statistically significant in both yield variability (risk) equations. The findings revealed that a one per cent rise in minimum temperature would induce the chickpea yield variability to decline by 0.68 ~ 0.78 per cent. However, one per cent increase in maximum temperature and rainfall will cause the rice yield varia-

Table 11. Estimates of the impact of climatic variables on mean yield and yield variability of chickpea using the Just and Pope quadratic and Cobb-Douglas models

S. No	Variables	Quadratic model				Cobb-Douglas model			
		Mean Yield		Yield Variability		Mean Yield		Yield Variability	
		Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
1	Rainfall	-0.0062	0.0819	0.0013	0.0011	-0.3123	0.2119	0.0612	0.0421
2	Max. Temp	-1.9699**	0.5362	0.0351**	0.0088	-0.0459**	0.0148	0.7238*	0.2878
3	Min. Temp	3.3307**	1.0882	-0.0510**	0.0122	0.1571**	0.0462	-0.6762**	0.2411
4	Time trend	0.0045**	0.0012	0.0163**	0.0056	0.0416**	0.0173	0.0171**	0.0064
5	Rain^2	0.0001	0.0016	0.1376*	0.0678	--	--	--	--
6	Max.Temp^2	0.0762	0.0821	0.1802**	0.0132	--	--	--	--
7	Min.Temp^2	1.0797	0.8553	1.4317	1.1228	--	--	--	--
8	Rain* Max. Temp	-0.7206	1.2473	0.4226	0.3214	-0.3635	3.7310	-25.0812	26.9230
9	Rain* Min. Temp	0.3515**	0.0872	-0.4379**	0.1566	4.6578	3.8102	-21.2157	15.8359
10	Max. Temp * Min. Temp	-0.5833	0.4613	0.1283	0.1738	106.2391*	52.0421	175.7141	313.9339
11	D2-Kadapa	0.4968*	0.2445			0.6101**	0.2241		
12	D3-Visakhapatnam	0.9807**	0.2457			1.1745**	0.2710		
13	D4-Krishna	1.1838**	0.4928			1.3737**	0.3106		
14	D5-East Godavari	1.0889**	0.2787			1.4023**	0.2698		
	Constant	74.4787	20.4803	940.96	343.21	1.2496	0.5621	1.0825	3.3584
	Model statistics								
	Observations	125		125		125		125	
	F test (14, 110)	9.88**		F(14, 110) = 1.93**		F test (11, 113) = 11.98**		F(11, 113) = 4.98**	
	Prob > F	0.0000		0.0306		0.0000		0.0000	
	R^2 Adj	0.7841				0.8122			

Note: ** - Significant at 1% level, * - Significant at 5% level bility to increase by 0.72 ~ 0.83 per cent and 0.06 ~ 0.09 per cent, respectively. So, both rainfall[1] and maximum temperature together will increase chickpea yield variability by 0.78 ~ 0.92 per cent. It is to be noted that rainfall may not necessarily be a risk-increasing input because it is not statistically significant. However, considering the sign of impact, it is considered a risk-increasing input on average. The increased chickpea yield variability can result in a wide fluctuation of its production, make price unstable, and in turn increase the market risk. Thus, these two climate change variables are risk-increasing inputs in this sense and these findings are in line with Man and Arwin (2009) with respect to rice yields in Korea for rice.

The elasticities for minimum temperature ranged between -0.7763 and 0.2189 in the quadratic model and between -0.6762 and 0.1571 in Cobb-Douglas model with respect to yield (risk) variability and mean yield functions, respectively. These results also showed that an increase in minimum temperature increases the mean yield of chickpea and decreases the yield variability both in quadratic and Cobb-Douglas functions. Further, the estimated elasticities of minimum temperature for both mean yield and yield variability of chickpea in either production functional form are lesser than unity and, thus, are considered less elastic. These findings imply that minimum temperature is mostly a yield-increasing and risk-decreasing factor. On the contrary, the elasticity values of rainfall range between -0.4094 and 0.0858 and between -0.3123 and 0.0612 with respect to mean yield and yield (risk) variability functions in quadratic and Cobb-Douglas models, respectively. This indicates that rainfall is yield decreasing and risk-increasing factor and it is also considered less elastic. Similar findings are obtained regarding the elasticities of maximum temperature in both quadratic and Cobb-Douglas production functions, inferring that it adversely influenced both mean yield and yield variability that too with a less elastic response, as shown in Min *et al.* (2005) and Boo *et al.* (2005). So, these findings indicated that the minimum temperature change largely drives the influence of climate variations on chickpea yield compared to rainfall and maximum temperature.

Effects of future climate change: From the obtained elasticities, the influences of future scenarios of climate

Table 12. Elasticities of climate change variables

Yield function	Climate variables	Quadratic model	Cobb-Douglas model
Mean yield	Rainfall	-0.4094	-0.3123
	Maximum Temperature	-0.0835	-0.0459
	Minimum Temperature	0.2189	0.1571
Yield variability	Rainfall	0.0858	0.0612
	Maximum Temperature	0.8283	0.7238
	Minimum Temperature	-0.7763	-0.6762

Table 13. Projected change for chickpea yields during 2030, 2040, 2050 and 2080s

Years and Climate projections	Quadratic Model		Cobb-Douglas model	
	Mean Yield (%)	Yield Variability (%)	Mean Yield (%)	Yield Variability (%)
2030 [Δ R = 5%; Δ MaxT = 1.26^{O}C; Δ Mint = 1.36^{O}C]	17.20	-0.79	14.03	-0.46
2040* [Δ R = 7%; Δ MaxT = 1.50^{O}C; Δ Mint = 1.75^{O}C]	22.91	-11.01	18.43	-9.34
2050 [Δ R = 10%; Δ MaxT = 1.81^{O}C; Δ Mint = 2.14^{O}C]	27.63	-15.36	22.20	-13.09
2080 [Δ R = 12%; Δ MaxT = 2.29^{O}C; Δ Mint = 2.63^{O}C]	33.53	-13.47	27.07	-11.36

*Surendra *et al* (2020)

variations on chickpea yield and variability are estimated (Surendra *et al*, 2020). CORDEX South Asia multi-RCM Reliability Ensemble Average (REA) estimates of projected changes in the annual mean of daily rainfall, maximum and minimum temperatures over India for four-time slices viz. 2030, 2040, 2050 and 2080 are employed to predict changes in chickpea yields (Sanjay *et al.*, 2017). Accordingly, by 2080, the annual rainfall may rise by 12 per cent, maximum temperature may rise by 2.29°C and minimum temperature may rise by 2.63°C. The projected results (Table 13) revealed that the chickpea yields would increase up to 33.53 percent and 27.07 per cent in 2080 with reference to quadratic and Cobb-Douglas models respectively. That is, the mean yield increase in the quadratic model is well above the value for the Cobb-Douglas model. However, both the findings indicated that by the year 2080, with a significant change in climate, chickpea yields will be increased compared to the current yield. On the other hand, future climate changes would reduce yield variability in both functional forms over the four periods. The interesting aspect is that the decrease in variability increases overtime. However, the percentage variability changes are again higher for quadratic model compared to Cobb-Douglas model (Humayun, 2015).

The analysis presented in this study has important policy implications. It is known that India has been a net importer of chickpea (www.fao.org) from the global market till 2019 (www.fao.org) and the per capita consumption of pulses is 47.3 grams per day—is marginally higher than what is recommended for people with a sedentary lifestyle by the Indian Council of Medical Research (40 grams per capita per day), but it is much lower than the recommendation for working men and women viz., 60 and 50 grams, respectively (Agricultural Statics at a Glance, 2020). In view of this, adopting climate-resilient strategies to sustain chickpea production is important to address nutrition-related issues. This further calls for location-specific studies on climate variations and chickpea productivity to develop micro-level adaptation practices, reduce yield variability and improve nutrition security. Further, the research institutions in Andhra Pradesh should produce high-yielding and climate-resilient chickpea varieties to mitigate the effects of climate change so as to ensure twin benefits, viz., increase in mean yield and reduce the production risks.

The limitation of this study is that the employed Just and Pope production function should also include non-climate variables such as edaphic conditions, cropped area, irrigation, fertilizer, adoption of high yielding variety seeds, extreme natural events etc., to make the findings more comprehensive. It is also important to control for non-climate variables to draw realistic conclusions because these variables may ameliorate or exacerbate the production risk of chickpea (Rosegrant and Roumasset 1985; Roumasset 1989; Ramaswami 1992; Di Falco *et al.,* 2006; Guttormsen and Roll 2013; Samira *et al.*, 2020).

Conclusion

This study investigated the trends in monthly rainfall; and maximum and minimum temperatures during *Rabi* season using the MK test and Sen's slope method. It also studied the influence of climate change variables on chickpea yields and its variability across agro-climatic zones in Andhra Pradesh by employing Just-Pope stochastic production function. The MK test and Sen's slope findings revealed that both month-wise rainfall and the maximum temperature had recorded positive trends (though non-significant); however, minimum temperature showed declining trends during Rabi season in all the selected districts. Further, monthly minimum temperatures showed significant declining trends in East Godavari (-0.185**), Krishna (-0.123**) and Visakhapatnam (-0.133**) districts, unlike Ananthapuramu (0.150**) and Kadapa (0.081^{NS}). The results from Just and Pope production function showed that the monthly minimum temperature during chickpea sowing and growing seasons had a positive and significant impact on mean chickpea yield. However, these beneficial impacts tend to get reversed with higher temperatures. Similarly, excess rainfall during the vegetative phase of the crop has an adverse impact on the crop. The findings from Just and Pope (quadratic) function revealed that monthly minimum temperature has significantly reduced the yield variability, unlike rainfall, maximum temperature and their respective squared terms. This calls for practising adaptation measures such as using drought-tolerant varieties, drought-proofing and mitigation strategies, micro-irrigation practices, development and access to agro-meteorological information and their incorporation in farmers' decision-making processes for sustainable chickpea production in Andhra Pradesh. Further, collecting reliable climate data and their regular updating is essential in the study area.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Agossou Gadedjisso-Tossou, Komlavi Adjegan & Armand Ketcha Malan Kablan (2021). Rainfall and temperature trend analysis by Mann–Kendall test and significance for rainfed cereal yields in Northern Togo. *Sci*, 3, 17. https://doi.org/10.3390/sci3010017
2. Agricultural Statistics at a Glance (1951-2020). Various

issues; Ministry of Agriculture and Farmers' Welfare; Government of India

3. Ahmad, I., Tang, D. Wang, T., Wang, M. & Wagan, B. (2015). Precipitation trends over time using Mann-Kendall and Spearman's Rho tests in Swat river basin, Pakistan. *Adv. Meteorol.* 431860. Article ID 431860 | https://doi.org/10.1155/2015/431860
4. Ahmad, N.H. & Deni, S.M. (2013). Homogeneity Test on daily rainfall series for Malaysia. *Matematika*, 29, 141–150. .https://doi.org/10.11113/matematika.v29.n.586
5. Barnwal, P. & Kotani, K. (2010). Impact of variation in climate factors on crop yield: A case of rice crop in Andhra Pradesh, India. *Economics & Management Series*, *https://www.iuj.ac.jp/workingpapers/index.cfm?File=EMS*_2010_17.pdf
6. Boo, K.O., Kwon, W.T., Oh, J.H. & Baek, H.J. (2004). Response of global warming on regional climate change over Korea: An experiment with the MM5 model." *Geophysical Research Letters,* 31(21), L21206. https://doi.org/10.3741/JKWRA.2012.45.10.1069
7. Boubacar, Inoussa (2012). The effects of drought on crop yields and yield variability: An economic assessment. *International Journal of Economics and Finance,* 4(12): 51-60. https://doi.org/10.5539/ijef.v4n12p51
8. Cabas, J., Weersink, A. & Olale, E. (2010). Crop yield response to economic, site and climatic variables. *Climatic Change*, 101, 599-616. https://doi.org/10.1007/s10584-009-9754-4
9. Cameron, A.C. & Trivedi, P.K. (2009). Microeconometrics using stata. Stata Corp LP, Texas
10. Carew, R., Meng, T., Florkowski, W.J., Smith, R. & Blair, D. (2018). Climate change impacts on hard red spring wheat yield and production risk: Evidence from Manitoba, Canada*, Can. J. Plant Sci,* 98: 782–795 dx.doi.org/10.1139/cjps-2017-0135
11. Chaturvedi Rajiv Kumar, Jaideep Joshi, Mathangi Jayaraman, Bala, G. & N. H. Ravindranath. (2012). Multi-model climate change projections for India under representative concentration pathways. *Current Science,* 103, 7, https://www.researchgate.net/publication/279896993
12. Chen, C.C., & Chang, C.C. (2005). The impact of weather on crop yield distribution in Taiwan: Some new evidence from panel data models and implications for crop insurance. *Agricultural Economics,* 33, 503 11. https://doi.org/10.1111/j.1574-0864.2005.00097.x
13. Chen, C.C., McCarl, B.A. & Schimmelpfennig, D.E. (2004). Yield variability as influenced by climate: A statistical investigation. *Climatic Change,* 66, 239-61. https://doi.org/10.1023/B:CLIM.0000043159.33816.e5
14. Dagar, J.C., Sharma, P.C., Chaudhari, S.K., Jat, H.S. & Sharif Ahamad. (2016). Climate change vis-a-vis saline agriculture: Impact and adaptation strategies. Springer India. *Innovative Saline Agriculture*, https://doi.org/10.1007/978-81-322-2770-0_2
15. Damodar, N. (2004). Basic Econometrics; Mc-Graw Hill publishing, Co.: New York, NY, USA.
16. Di Falco, S., Chavas, J.P. & Smale, M. (2006). Farmer management of production risk on degraded lands: The role of wheat genetic diversity in Tigray region, Ethiopia. Environmental and Production Technology Division. Discussion Paper 153 IFPRI, Washington DC, USA. http://dx.doi.org/10.1111/j.1574-0862.2007.00194.x
17. FAO. International Seminar on Drought and Agriculture. (2017), https://www.fao.org/land-water/water/drought/droughtandag/en/
18. Feroze, S.M., Singh, R., Aheibam, M. & Singh, K.L. (2020). Climate change effects on crop yields are evident in North Eastern hills states of India. *Indian Journal of Hill Farming*, 33 (2), 209-215
19. Granger, C.W.J., & Newbold, P. (1974). Spurious regressions in Econometrics. *Journal of Econometrics*, 2, 111-120. http://dx.doi.org/10.1016/0304-4076(74)90034-7
20. Guttormsen, A. G. & Roll, K.H. (2013). Production risk in a subsistence agriculture. *Journal of Agricultural Education and Extension,* 20(1), 133-145. https://doi.org/10.1080/1389224x.2013.775953
21. Haile, Mekbib, G., Tesfamicheal Wossen, Kindie Tesfaye. & Joachim von Braun. (2017). Impact of climate change, weather extremes, and price risk on global food supply. *Economics of Disasters and Climate Change,* 1 (1), 55-75. https://doi.org/10.1007/s41885-017-0005-2
22. Hand Book of Statistics, Ananthapuramu. (2020). Government of Andhra Pradesh
23. Harris, R.D.F., & Tzavalis, E. (1999). Inference for unit roots in dynamic panels where the time dimension is fixed. *Journal of Econometrics*,91 (2), 201–26. https://doi.org/10.1016/S0304-4076(98)00076-1
24. Humayun, K.M.D. (2015). Impacts of climate change on rice yield and variability - An analysis of disaggregate level in the southwestern part of Bangladesh especially Jessore and Sathkhira districts. *J Geogr Nat Disast*, 5,3. https://doi.org/10.4172/2167-0587.1000148
25. Isik, M., & Devadoss, S. (2006). An analysis of the impact of climate change on crop yields and yield variability. *Applied Economics*, 38, 835-844. https://doi.org/10.1080/00036840500193682
26. Judge, G. G., Griffiths, W.E., Hill, R.C., Lutkepohl, H. & Lee T.C. (1985). The theory and practice of Econometrics. 2nd ed. New York: Wiley. https://doi.org/10.2307/1240726
27. Just, R.E. & Pope, R.D. (1978). Stochastic specification of production functions and economic implications. *Journal of Econometrics*, 7, (1)67–86. https://doi.org/10.1016/0304-4076(78)90006-4
28. Just, R.E. & Pope, R.D. (1979). Production function estimation and related risk considerations. *American Journal of Agricultural Economics*, 61, (2),276–84. https://doi.org/10.2307/1239732
29. Kendall, M.G. (1975). Rank Correlation Methods; Griffin: London, UK, ISBN 9780852641996.
30. Kim, M.K. & Pang, A. (2009). Climate change impact on rice yield and production risk. *Journal of Rural Development*, 32: 17-29. https://doi.org/10.22004/ag.econ.90682
31. Komali Kantamaneni, Louis Rice, Komali Yenneti. & Luiza, C. Campos. (2020). Assessing the vulnerability of agriculture systems to climate change in coastal areas: A Novel Index. *Sustainability*, *12*, 4771; https://doi.org/10.3390/su12114771
32. Koudahe, K., Djaman, K.,, Kayode, J.A.,, Awokola, S.O. & Adebola, A.A. (2018). Impact of climate variability on crop yields in southern Togo. *Environ. Pollut. Clim. Chang*, 2, 148. [CrossRef]. https://doi.org/10.4172/2573-458X.1000148
33. Koundouri, P. & Nauges, C. (2005). On production function estimation with selectivity and risk considerations.

Journal of Agricultural and Resource Economics, 30(3), 597-608. https://doi.org/10.22004/ag.econ.30977

34. Krishnan, R., Sanjay, J., Chellappan Gnanaseelan, Milind Mujumdar, Ashwini Kulkarni. & Supriyo Chakraborty. (2020). Assessment of climate change over the Indian region - A report of the Ministry of Earth Sciences (MoES), Government of India, ISBN 978-981-15-4327-2 (eBook) https://doi.org/10.1007/978-981-15-4327-2
35. Kumar, A., Sharma, P. & Ambrammal, S.K. (2015). Effects of climatic factors on productivity of cash crops in India: Evidence from state-wise panel data. *Glob. J. Res. Soc. Sci.*, 1, 9–18.
36. Kumbhakar, S. C. & Tveteras, R. (2003). Risk preferences, production risk, and firm heterogeneity. *The Scandinavian Journal of Economics*, 105(2), 275-293. https://doi.org/10.1111/1467-9442.t01-1-00009
37. Maddala, G.S. & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, 61, 631-652. https://doi.org/10.1111/1468-0084.0610s1631
38. Mahdiyeh Saei, Hamid Mohammadi, Saman Ziaee. & Sajjad Barkhordari Dourbash. (2019). The impact of climate change on grain yield and yield variability in Iran. *Iranian Economic Review,* 23, No.2, /511. DOI: http://dx.doi.org/10.15666/aeer/1605_66916707
39. Man-Keun Kim. & Arwin Pang. (2009). *Climate change impact on rice yield and production risk. Journal of Rural Development, 32(2), 17～29. https://doi.org/* 10.22004/ag.econ.90682
40. Mann, H.B. (1945). Nonparametric tests against trend. *Econometrica*, 13, 245. http://dx.doi.org/10.2307/1907187 [CrossRef]
41. McCarl, B. A., Villavicencio, X. & Wu, X. (2008). Climate change and future analysis: Is stationary dying? *American Journal of Agricultural Economics*, 90(5), 1241-1247. https://doi.org/10.1111/j.1467-8276.2008.01211.x
42. Min, S.K., Legutke, S., Hense, A. & Kwon, W.T.. (2005). Internal variability in a 1000-yr control simulation with the coupled climate model ECHO-G. PartI: Near surface temperature, precipitation, and mean sea level pressure. *Tellus A: Dynamic Meteorology and Oceanography*, 57 (4), 605-621 https://doi.org/ 10.3402/tellusa.v57i4.14712
43. Mulungu, K., Tembo, G., Bett, H. & Ngoma, H. (2021). Climate change and crop yields in Zambia: Historical effects and future projections. *Environ Dev Sustain*, 23, 11859–11880. https://doi.org/10.1007/s10668-020-01146-6
44. Patakamuri, S.K., Muthiah, K. & Sridhar, V. (2020). Long-term homogeneity, trend, and change-point analysis of rainfall in the arid district of Ananthapuramu, Andhra Pradesh State, India. *Water*, 12, 211. https://doi.org/10.3390/w12010211 [CrossRef]
45. Poudel, S. & Kotani, K. (2013). Climatic impacts on crop yield and its variability in Nepal: Do they vary across seasons and altitudes? *Clim. Change*, 116, 327–355. DOI: 10.1007/s10584-012-0491-8 [CrossRef]
46. Raju Mandal. & Pratiti Singha. (2020). Impact of climate change on average yields and their variability of the principal crops in Assam. *Indian Journal of Agricultural Economics,* Vol.75, No.3, July-September
47. Ramaswami, Bharat. (1992). Production risk and optimal input decisions. *American Journal of Agricultural Economics,* 74(4): 860-869. https://doi.org/10.2307/1243183
48. Resop, J.P., Fleisher, D.H., Timlin, D.J. & Reddy, V. (2014). Biophysical constraints to potential production capacity of potato across the US eastern seaboard region. *Agron. J.*, 106, 43–56. doi:10.2134/agronj2013.0277 [CrossRef]
49. Rosegrant Mark, W. & James A. Roumasset. (1985). The effect of fertiliser on risk: A heteroscedastic production function with measurable stochastic inputs. *Australian Journal of Agricultural Economics,* 29(2), 107-121. https://doi.org/10.1111/j.1467-8489.1985.tb00651.x
50. Roumasset, J. A. 1989. Fertilizer and crop yield variability: A review. Variability in Grain Yields: 223-233.
51. Saha, A., Havenner, A. & Talpaz, H. (1997). Stochastic production function: Small sample properties of ML versus FGLS. *Applied Economics*, 29(4), 459-469. https://doi.org/10.1080/000368497326958
52. Samira Shayanmehr, Shida Rastegari Henneberry, Mahmood Sabouhi Sabouni. & Naser Shahnoushi Foroushani. (2020). Drought, climate change, and dryland wheat yield response: An Econometric Approach. *Int. J. Environ. Res. Public Health*, 17, 5264; https://doi.org/10.3390/ijerph17145264
53. Sanjay, J., Krishnan, R., Ramarao, M.V.S., Mahesh, R., Bhupendra Singh, Jayashri Patel, Sandip Ingle, Preethi Bhaskar, Revadekar, J.V., Sabin, T.P. & Mujumdar M. (2017). Future climate change projections over the Indian Region, https://doi.org/10.48550/arXiv.2012.10386
54. Sarker, M.A.R, Alam, K. & Gow, J. (2014). Assessing the effects of climate change on rice yields: An econometric investigation using Bangladeshi panel data. *Econ. Anal. Policy*, 44, 405–416. http://dx.doi.org/10.1016/j.eap.2014.11.004 [CrossRef]
55. Sarker, M.A.R., Alam, K. & Gow, J. (2019). Performance of rain-fed Aman rice yield in Bangladesh in the presence of climate change. *Renew. Agric. Food Syst.*, 34, 304–312. https://doi.org/10.1017/S1742170517000473[CrossRef]
56. Sen, P.K. (1968). Estimates of the regression coefficient based on Kendall's Tau. *J. Am. Stat. Assoc.*, 63, 1379–1389. http://dx.doi.org/10.1080/01621459.1968.10480934 [CrossRef]
57. Sinnarong, N., Chen, C.C., McCarl, B. & Tran, B.L. (2019). Estimating the potential effects of climate change on rice production in Thailand. *Paddy Water Environ.*, 4, 1–9. https://doi.org/10.1007/s10333-019-00755- [CrossRef]
58. Srivastava, R., Talla, A., Swain, D. & Panda, R. (2019). Quantitative approaches in adaptation strategies to cope with increased temperatures following climate change in potato crop. *Potato Res.*, 62, 175–191, https://doi.org/10.1007/s11540-018-9406-z [CrossRef]
59. Statistical Abstract (2020). Government of Andhra Pradesh
60. Surendra Singh, Alka Singh. & Sanatan Nayak. (2020). Future climate change impacts on crop productivity in coastal regions of India: A panel estimation. *Climate Change,* 6(21), 100-108. http://www.discoveryjournals.org/climate_change/current_issue/v6/n21/TOC21.pdf
61. Tveteras, R. (1999). Production risk and productivity growth: Some findings for Norwegian Salmon Aquaculture. *Journal of Productivity Analysis*, 12(2), 161-179.

https://www.jstor.org/stable/41770884

62. Tveteras, R., & Wan, G. H. (2000). Flexible panel data models for risky production technologies with an application to Salmon Aquaculture. *Econometric Reviews*, 19(3), 367-389.
63. Vashisht, B., Nigon, T., Mulla, D., Rosen, C., Xu, H., Twine, T. & Jalota, S. (2015). Adaptation of water and nitrogen management to future climates for sustaining potato yield in Minnesota: Field and simulation study. *Agric. Water Manag*, 152, 198–206. https://doi.org/10.1016/j.agwat.2015.01.011 [CrossRef]
64. Wijngaard, J.B., Klein Tank, A.M.G., & Können, G.P. (2003). Homogeneity of 20th century European daily temperature and precipitation series. *Int. J. Clim*, 23, 679–692. https://doi.org/10.1002/joc.906 [CrossRef]
65. www.fao.org
66. Yue, S., Pilon, P., Phinney, B., & Cavadias, G. (2002). The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrol. Process*, 16, 1807–1829. https://doi.org/10.1002/hyp.1095 [CrossRef]