Impact of Climate Variables on Paddy Production in Tamil Nadu

ABSTRACT

The significant reduction in agricultural production in Sri Lanka, compounded by the rising prices of fuel and basin food items followed by agricultural food shortages in Afghanistan and increase in food consumption worldwide carry our global concern towards food security and sustainability mere self-sufficient in production. Agriculture is extremely vulnerable to climate change. Extreme climate happens like heavy rainfall, high temperature and drought making heavy losses in agriculture regionally and significantly damaging the harnessing of better crop yields. As a major staple food crop, Paddy is selected for examining the impact of climate variability on paddy crop yield and variance thereof in Indian state of Tamil Nadu. Season and Crop Reports published by the Department of Agriculture, Government of Tamil Nadu and NASA Power Data are the secondary data sources were used for the study. Just-Pope yield function was used to determine the influence of climate variables on mean crop yield and variance. The results indicate that yield of paddy increases from the increase in temperature, however, are negatively associated with precipitation intensity. The variability in the yield of paddy also increases with increase in rainfall. The study has suggested weather-based crop insurance policy and climate-resilient farming techniques to reduce the losses to the farmers.

Keywords: Vulnerable, Food Security, Sustainability, NASA Power Data, Just-Pope yield function.

JEL Codes: C01, Q00, Q50

INTRODUCTION

Technology, genetics, climate, soil, field management practices and associated decisions such as fertilizer applications, tillage and crop hybrid selection, irrigation management, row spacing, planting date and depth, population density, and so on are global drivers of agricultural production and their variability. A significant share of agricultural productivity increases is the consequence of technological advances in genetics, agronomy, and resource use methods. (Kukal and Irmak., 2018). Weather and climate are key drivers or influencers of agricultural production systems, and it has been proved that current trends in climate variable change may be responsible for significantly affecting crop output trends despite advances in technology and other fronts.

Climate change has a higher impact on agricultural yield over crop output in countries like India, where agriculture is highly dependent on natural forces. Climate change scenarios such as higher temperatures and variations in precipitation will have a direct influence on agricultural output. (Joshi, 2011). According to previous studies, India is expected to experience one of the world's largest losses in agricultural productivity as a result of perceived climate change trends and projected scenarios. Climate change forecasts for India up to 2100 show an overall increase in temperature of 2-4 degrees Celsius, with no substantial change in rainfall magnitude (Kavikumar, 2009). Similarly, it is predicted that the average temperature would rise by 3-6 ° C., and precipitation will increase by 15-40% over India by the end of the twenty-first century (National Communication Project, 2004). In terms of temperature, the Intergovernmental Panel on Climate Change predicts an increase of 1.1-6.4 degrees Celsius by the end of the century. The yield loss of rice crop owing to increased temperature of 1 to 2°C could cause in 3–17% in different parts of the country (Aggarwal & Mall, 2002).

Likewise, Saravanakumar (2015) projected that by end-of-century impacts for rice output could decline 10% relative to the reference line yield (1971–2009). So, it may be noted that slight change in climate variables can bring major impact, primarily on the crop yield and lately to the income of the farmers (Kumari *et al*. 2001).

Therefore, in order to decrease the impact of climate change, the intervention used by the farmers increases the initial cost i.e. expenditure over inputs increases. It has been estimated that farmers experienced changes in the cold season was (59.4%), followed by hot season (56.5%) however for the rainy season it was observed maximum changes i.e. about 80.5%. It was also reported by the farmers that the period of rainy season has now became shorter than that of what it used to be few years ago (Johnsen and Aune 2011).

Therefore, it is essential for finding the association between climate variables and primary crop yield of major staple food crop (paddy) in Tamil Nadu over empirical analysis. Hence, the main objective of the present study is to empirically evaluate the effects of climate related variables on paddy yield in Indian state of Tamil Nadu. The residual part of the paper is structured as follows. Section 2 presents a brief literature review associated with climate and crop yields. The data sources and empirical methodology are described in Section 3. Section 4 provides the empirical findings and discussion. The last section presents summary and conclusions of the study.

METHODOLOGY

To assess the impact of climate change on agriculture in Tamil Nadu, district level data on the yields of paddy and climate variables were used for the period 1980-81 to 2019-2020. The districts are compiled into seven agro-climatic zones of Tamil Nadu. The seven agro-climatic zones in Tamil Nadu were shown in Figure 1. The data were compiled from the Season and Crop Reports published by the Department of Agriculture, Government of Tamil Nadu; and the corresponding data on monthly temperature, and rainfall were obtained from the NASA Power Data.

Descriptive Statistics

Area and Yield

The paddy is an important crop in all the zones (Table 1), but is more prominent in the Cauvery Delta, Southern zone and North-Eastern zone. On an average, paddy occupies 48 per cent of the gross cropped area in Tamil Nadu. The paddy yield is highest in Western zone, followed closely by Southern zone. It may be noted that in the Western zone paddy occupies only 16 per cent of the gross cropped area.

Climate Variables

The summary statistics of the climate variables for each zone is given in Table 2. The mean temperature is higher in the Southern zone (29.2 °C) followed by Cauvery Delta (29.0 °C), while North-Eastern zone has a higher variability in temperature. The North-Eastern zone has recorded the highest annual precipitation (of 1091 mm) and highest variability. Cauvery Delta follows closely with annual precipitation of 980 mm and highest variability of 221 mm. The precipitation is lowest in Western zone (690 mm) with a standard deviation of 181 mm.

Method of Estimation: Just-Pope Yield Function

Just and Pope (1978) developed a stochastic production function specification that allows explicit estimation of the effects of independent variables on the probability distribution of output. An added advantage of the approach is that it does not impose dependence between an item's effect on yield variability and its effect on mean yield. Just and Pope (1978, 1979) described both a Maximum Likelihood (MLE) (1978) and a three step, feasible generalized least squares (FGLS) (1979) procedure for estimating the function. Following Chen *et al.* (2004) and Isik and Devadoss (2006), we have employed an estimation method based on the Just- Pope yield function (1978) that allows statistical determination of the influence of climate on mean yield and variance. The yield function is specified as:

$$Yi_t = f(X_{it}, \beta) + h(X_{it}, \delta)\omega_{it} \qquad \ldots (1)$$

where, y_{it} is the yield of crop I; $f(\cdot)$ is the average production function, and X is a set of independent variables (climate, location, and time period). The functional form $h(\cdot)$ for the error-term is an explicit form for heteroskedastic errors, allowing estimation of variance effects. Estimates of the parameters of $f(\cdot)$ give the average effect of the climate variables on yield, while $h(\cdot)$ provides the effect of each variable on variance of the crop yield. The interpretation of the signs on the parameters of $h(\cdot)$ is straight forward. If the marginal effect on yield variance of any variable is positive, then increases in that variable increase the standard deviation of yield, while a negative sign implies otherwise.

To estimate the Just-Pope function, the Feasible Generalized Least Squares (FGLS) has been used iteratively. The basic procedure is: (a) estimate the model by ordinary least squares (OLS) and get the residuals; (b) regress the logarithm of squared residuals against X as independent variables; (c) get the predicted values of the residuals, calculated as antilogarithm of predictions from step (b) (These are consistent estimates of the variances); and (d) estimate the original model by weighted least squares (WLS) with square root of the variance predictions as weights.

This study adopted the fixed effects model as it allows estimation of a unit-specific effect for each zone, and does not require restrictive assumption that zone specific effects are independent of the covariates, as in the case of random effects model (McCarl *et al.,* 2008). The zone dummies have been included in the regression equation to capture the zone-specific effects that are invariant over time.

In addition to the linear climate variables, the interactions of regions with temperature and precipitation have also been used in the regression equation as their effects may not be uniform across regions. The Just-Pope yield function was estimated with alternative specifications by including acreage, precipitation (in mm/year), temperature (mean and variance), standard deviation of temperature and precipitation intensity. The intensity ranges from 1/12 (uniformly intense) to 1 (one month gets entire annual precipitation). The linear and quadratic time trends were included to capture the effect of technological change.

The linear mean function, $f(X, \square)$ is:

$$f(X; \beta, d) = \beta_0 + \beta_1 \, Area + \beta 2 \, Maximum\ Temperature + \beta 3 \, Minimum\ Temperature + \beta 4 \, Precipitation + \sum_{i-1}^{i-R-1} d_i \, D_i \quad \ldots (2)$$

where, $d_i D_i$, (i=1, 2…) are the zone-specific dummies taking the values 1 and 0.

The variance function $\sigma^{\square}\omega \ln h^2(x; \delta, \eta)$ with $\sigma^2\omega=1$ was assumed to have the following semi-log linear form:

$$\ln h^2(x; \delta, \eta) = (\delta X + \eta D) = \{\delta_0 + \delta_1 \, Area + \delta_2 \, Maximum\ Temperature + \delta_3 \, Minimum\ Temperature + \delta_4 \, Precipitation + \sum_{i-1}^{i-R-1} d_i \, \eta_i \} \quad \ldots (3)$$

where, [ln $h2\ (X; \beta,\eta)$], logarithm of squared residuals from the first stage OLS, is the dependent variable, and the independent variables are the same as from the first stage OLS; η_i is the coefficient of dummy variables.

An underlying assumption of this model is that the variables included in it are stationary. Accordingly, before estimating the Just-Pope yield function, a panel unit root test was performed to test the stationarity of the variables.

RESULTS AND DISCUSSION

Descriptive Statistics

Table 1 presents the area, production and productivity of the paddy crop of seven agro-climatic zones of Tamil Nadu. Rice is the major staple food crop of Tamil Nadu, which is cultivated in three different seasons taking up around 40 percent of the total cropped area and around 55 percent of the total area of food crops. The average yield of rice was 3.57 tonnes per hectare. The study area covered the State of Tamil Nadu in southern peninsular India which lies between 7.91°N to 13.65°N latitude and 76.17°E to 80.82°E longitude.

The table provides a comprehensive overview of the Paddy crop cultivation across various geographic zones, each characterized by distinct climatic and geographical conditions. The data underscores the significant differences in paddy cultivation metrics, including area, production, and productivity, across these zones.

In the North Eastern Zone (NEZ), paddy cultivation covers an extensive area of 612,129 hectares. This vast expanse contributes to a total production of approximately 2,194,890 tonnes, reflecting a productivity rate of 3.58 tonnes per hectare. The relatively high productivity suggests that the conditions in this zone are conducive to efficient paddy cultivation. Moving to the North Western Zone (NWZ), although the area under paddy cultivation is comparatively smaller at 79,894.7 hectares, the productivity here is notably higher, with 4.01 tonnes per hectare. This zone achieves a total production of 320,886 tonnes, which is a remarkable feat given the limited cultivation area.

In the Western Zone (WZ), paddy cultivation encompasses 126,444 hectares, yielding a total production of 498,621 tonnes. The productivity rate of 3.94 tonnes per hectare places this zone in a favourable position in terms of paddy cultivation efficiency. The Cauvery Delta Zone (CDZ) displays a large cultivation area of 627,840 hectares, contributing significantly to the total production of

1,888,005 tonnes. However, the productivity rate in this zone is relatively lower at 3.00 tonnes per hectare, potentially indicating room for improvement in optimizing yields.

Moving southward, the Southern Zone (SZ) covers 373,425 hectares for paddy cultivation, resulting in a production of 1,020,454 tonnes. The productivity rate of 2.73 tonnes per hectare suggests that there could be potential for enhancing yields through improved agricultural practices. In the High Rainfall Zone (HRZ), which covers a relatively smaller area of 18,910.4 hectares, the productivity is particularly high at 4.24 tonnes per hectare. Consequently, this zone contributes 80,228.3 tonnes to the total paddy production.

In the Hilly Zone (HZ), the limited cultivation area of 968.682 hectares still manages to achieve a noteworthy productivity rate of 3.49 tonnes per hectare, resulting in a production of 3,385.59 tonnes. In summation, the table's data provides insights into the diverse paddy cultivation landscape across these distinct zones, emphasizing varying levels of productivity and production. Such information can serve as a foundation for agricultural decision-making, resource allocation, and targeted improvements in each zone to enhance overall paddy crop yield and contribute to food security.

The Table 2 presents a comprehensive overview of summary statistics for key climate variables across various geographic zones. These variables include Maximum Temperature (Max. Temp) and Precipitation, with the data showcasing the Mean, Standard Deviation (SD), Maximum (Max), and Minimum (Min) values for each variable in different zones.

Across the different zones, the highest mean maximum temperatures are observed in the North Eastern Zone (NEZ) at 40.1°C, the North Western Zone (NWZ) at 40.38°C, and the Western Zone (WZ) at 39.92°C. Comparatively, the Southern Zone (SZ) experiences a slightly lower mean maximum temperature of 38.96°C, and the High Rainfall Zone (HRZ) and Hilly Zone (HZ) record even lower means at 37.78°C and 37.27°C respectively. The Cauvery Delta Zone (CDZ) exhibits the lowest mean maximum temperature at 39.17°C.

The Standard Deviations in maximum temperature are relatively consistent among the zones, ranging from 6.14 to 6.66, indicating similar levels of variability in temperature across the regions. The highest recorded maximum temperatures for each zone are noteworthy. The North Western Zone (NWZ) records the highest maximum temperature of 43.29°C, followed closely by the Western Zone (WZ) at 42.46°C. These figures suggest that these zones experience extreme temperature conditions at times.

In terms of precipitation, the North Eastern Zone (NEZ) experiences the highest mean amount at 951.502 mm, followed by the Southern Zone (SZ) at 1127.79 mm, the High Rainfall Zone (HRZ) at 1394.13 mm, and the Hilly Zone (HZ) at 868.605 mm. The North Western Zone (NWZ) and the Western Zone (WZ) both have mean precipitation values around 800 mm. The variability in precipitation, as indicated by the Standard Deviations, is more pronounced across the zones, ranging from 181.581 mm to 436.269 mm. This highlights the diversity in precipitation patterns among the regions.

The maximum recorded precipitation values are substantial, with the North Eastern Zone (NEZ) experiencing the highest at 1587.14 mm and the Southern Zone (SZ) following closely at 1951.93 mm. These values suggest the potential for heavy rainfall events in these zones. Conversely, the minimum precipitation values range from 419.24 mm to 495.7 mm, indicating relatively consistent lower limits across the zones.

The data presented in Table 2 underscores the substantial variability in climate variables across different geographic zones. These variations in temperature and precipitation are likely to impact various sectors, including agriculture, water resources, and infrastructure. Such insights are crucial for understanding the unique challenges and opportunities posed by the climate in each zone, aiding in the formulation of effective strategies for climate adaptation and mitigation measures.

Results of Panel Unit Root Tests

It is essential to investigate the presence of unit roots for each variable before estimation of the Just Pope Yield function. The test results show that the null hypothesis of the unit root is rejected for each variable with trend (area, production, productivity, Maximum Temperature, Minimum Temperature and Precipitation) at the one percent significance level. Since the panel unit root results reject the null hypothesis of non-stationary, each variable is stationary. Thus, there is no need to first-difference the data to eliminate unit roots (McCarl et al., 2008; Kim and Pang, 2009;) and we can estimate the model. Table 3 presents the results of unit root test. Chen et al. (2004) found that the results were similarity.

Table.3: Unit Root Test of Variables

Variables	DF	p-value
Area	-4.13***	0.014
Production	-4.12***	0.015
Productivity	-4.11***	0.015
Tmax	-3.83***	0.028
Tmin	-3.96***	0.021
Precipitation	-4.17***	0.013

After estimating the panel data model, we used Breusch-Pagan and White test to detect heteroscedasticity. Table 4 presents results of the test. The null hypothesis of homoscedasticity (H_0) is rejected at the 5 percent significance level. Thus, the White test indicates the existence of panel heteroscedasticity. This warrants the use of a suitable econometric estimation procedure that takes into account the panel heteroscedasticity of the error term. As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H_0, and accept the alternative hypothesis $H_{a.}$

Table 1: Area, production and productivity of Paddy crop

Variables	Zones						
	NEZ	NWZ	WZ	CDZ	SZ	HRZ	HZ
Area (ha)	612129	79894.7	126444	627840	373425	18910.4	968.682
Total Production (tonnes)	2194890	320886	498621	1888005	1020454	80228.3	3385.59
Productivity (t/ha)	3.58	4.01	3.94	3	2.73	4.24	3.49

NEZ – North Eastern Zone; NWZ-North Western Zone; WZ-Western Zone; CDZ-Cauvery Delta Zone; SZ-Southern Zone; HRZ-High Rainfall Zone; HZ-Hilly Zone

Table 2: Summary statistics of the climate variables

		Zones						
	Variables	**NEZ**	**NWZ**	**WZ**	**CDZ**	**SZ**	**HRZ**	**HZ**
Mean	**Max. Temp**	40.1	40.38	39.92	39.17	38.96	37.78	37.27
	Precipitation	951.502	769.282	803.776	836.842	1127.79	1394.13	868.605
SD	**Max. Temp**	6.6	6.66	6.57	6.44	6.41	6.22	6.14
	Precipitation	225.347	181.581	184.079	221.254	317.375	436.269	192.613
Max	**Max. Temp**	42.65	43.29	42.46	41.62	41.47	40.4	40.26
	Precipitation	1587.14	1261.77	1373.49	1548.4	1951.93	2510.16	1382.91
Min	**Max. Temp**	0.85	0.84	0.81	0.81	0.99	1.21	0.84
	Precipitation	624.609	419.24	444.946	471.095	470.087	495.7	464.06

Table 4: Testing Heteroscedasticity for Yield Response Functions

	Breusch-Pagan test / Residuals:	White test
LM (Observed value)	34.444	94.591
LM (Critical value)	16.919	72.153
DF	9	54
p-value (Two-tailed)	**<0.0001**	**0.001**
alpha	0.05	0.05

*Signification codes: 0 < "***" < 0.001 < "**" < 0.01 < "*" < 0.05 < "." < 0.1 < " " < 1*

Regression Results

The climate change may alter the assumption of stationarity of variance. Evidence exists that climate change will shift the mean and variance of crop yields (Chen *et al.,* 2004). The estimated parameters are presented in Table 5. The standard errors have been adjusted appropriately to account for the first-stage variation. The response and stimulus variables appear logarithmically for stationarity of the data which is found non stationarity through unit-root test.

The coefficient of the precipitation is negative but significant effect on paddy yield. This suggests that holding other variables constant, increase in precipitation will decrease the yield of paddy. Maximum temperature has negative effect on paddy yield but significant at 5 per cent level. While, the minimum temperature has positive effect on paddy yield but no significant effect which indicates that the increase in minimum temperature will increase the paddy yield. North west zone has significant positive effect on paddy yield. South zone has significant negative effect whereas the Cauvery delta zone has negative effect on paddy yield. North east zone has no effect on paddy yield. The earlier research also supported the present finding (Arumugam *et al.,* 2014).

Table.5: Log Yield Variance Regression

Independent variables	Paddy	
	Coef.	Std. error
Area	0.43***	0.04
Maximum Temperature	-1.02**	0.37
Minimum Temperature	0.14	0.18
Precipitation	-0.12**	0.04
Zone specific ´D1	0	0.02
Zone specific ´D2	0.06*	0.02
Zone specific ´D3	0.02	0.02
Zone specific ´D4	-0.04	0.02
Zone specific ´D5	-0.05*	0.02
Constant	5.14***	0.7
Number of observations	240	
F(10,229)	37.49	
Prob>F	0	

Notes: *, **, *** denote significance at 10 per cent, 5 per cent and 1 per cent levels, respectively.
a Dependent variables: Logarithm of squared residuals from first-stage OLS. Independent variables: area, production, maximum temperature, minimum temperature, precipitation
b Regional interaction dummies: D1- North-East zone, D2-North-West zone, D3-Western zone, D4-Cauvery Delta zone, D5-South zone, D6-Southern zone.

SUMMARY AND CONCLUSIONS

The impact of historical climate variability on crop yield distribution has been explored in this study, with crop yield as a dependent variable and area, temperature, and precipitation as indicators. Changes in average climate conditions induce changes in agricultural output over time, as shown by the regression results. Temperature swings and precipitation, in particular, were found to influence crop yield variability. The maximum temperature has indeed been discovered to have opposing impacts on the level and variability of paddy output. Precipitation variability has had a considerable detrimental influence on agricultural yield across the area.

To reduce the uncertainty and risk associated with crop-yield variability caused by climate change, an insurance schemes and climate-resilient farming techniques may be taken by the Government. To boost agricultural production and productivity, government institutions must implement schemes based on scientific results. Federal regulations should ensure that farmers have better access to low-cost or subsidized inputs, helping them to modify production tactics in accordance to expected climatic circumstances. Crop lines that are resistant to various stresses must be created in collaboration with stakeholders in order to achieve the desired productivity benefits.

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Fig 1: Seven Agro-Climatic Zones of Tamil Nadu