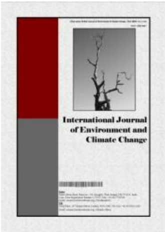

International Journal of Environment and Climate Change

12(11): 125-130, 2022; Article no.IJECC.88759
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Impact of Precipitation over the Productivity of Sugarcane in Major Agro-climatic Zones of Tamil Nadu

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2022/v12i1130953

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/88759

Original Research Article

Received 26 April 2022
Accepted 02 July 2022
Published 06 July 2022

ABSTRACT

Sugarcane is one of the traditional crops grown abundantly across the state of Tamil Nadu due to the lengthening of the period of monsoon and its diversified uses in different agro-based industries. Precipitation, a significant factor for sugarcane cultivation, has an impact on its productivity differs for different agro-climatic zones. A secondary data of district wise precipitation and sugarcane productivity of Tamil Nadu for the 30 years (1985 - 2014) were also collected. The impact of precipitation over the productivity of various crops can be explained by using the Standard Precipitation Indices (SPI) data and applying Principal Component regression (PCR) technique. Initially, SPI, A drought monitoring index, represents a Z-Score, was calculated seasonally for different agro-climatic zones. As there was a severe collinearity between the SPI values of seasons, Principal component regression analysis was used to study the impact of precipitation on the sugarcane productivity by considering the SPI values of four seasons along with time as regressor variables. The study showed that the productivity of sugarcane in Cauvery Delta zone and Western Zone mainly depended upon the precipitation during South west monsoon and North East monsoon periods. However, the productivity of sugarcane in North East zone was mostly dependent on the precipitation of Cold Weather period when compared to all other seasons. Unlikely, North west and Southern zones are not significantly influenced by the precipitation.

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Keywords: Standardized precipitation index; principal component regression; variance inflation factor; tolerance; KMO test; Bartlett's test of Sphericity.

1. INTRODUCTION

Sugarcane is one of the traditional crops grown abundantly across the state of Tamil Nadu. Currently, 0.263 million hectares are under cane cultivation and this is increasing annually due to the increased consumption of sugar and also the growing demand from mills for sugar cane as a raw material. Tamil Nadu's yield of 106 tonnes per hectare is the second highest among all Indian states next to West Bengal (118.754 tonnes/hectare) [1]. Sugarcane requires minimum 1000 mm to 1750 mm precipitation for its ideal production. Based on the rainfall pattern, cropping pattern and administrative units, Tamil Nadu has been classified into seven distinct agro-climatic zones namely, North Eastern zone, North Western zone, Western zone, Cauvery Delta zone, Southern zone, High Rainfall zone and Hilly zone. Since the state is entirely dependent on rainfall for recharging its water resources [2]. Climate change and monsoon failures lead to acute water scarcity and severe drought. Uneven distribution of rainfall during the monsoon seasons may affect the crop physiology leads to reduction in the crop productivity [3,4]. The sugarcane and sugar yields have fluctuated with extreme climate events such as drought and tropical cyclones [5]. From the above justified facts, it is evident that there is a considerable scope to assess the impact of seasonal precipitation on productivity of sugarcane in Tamil Nadu.

2. MATERIAL AND METHODS

2.1 Study Area and Data

The present study is conducted with the overall objective of analyzing the impact of precipitation over the productivity of sugarcane in different agro-climatic zones of Tamil Nadu. For this study, A secondary data of productivity of sugarcane for the period of 30 years from 1990 to 2019 and district wise precipitation data of Tamil Nadu for the corresponding years were collected from the Department of Economics and Statistics, Government of Tamil Nadu.

2.2 Standardized Precipitation Index

Using the precipitation data, Standardized Precipitation Indices were calculated using the [6] procedure. Gawander (2007) [7] found the gamma distribution to fit climatological precipitation time Series well.

The gamma distribution is defined by its frequency or probability density function

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \qquad for \;\; x>0,$$

$\alpha > 0, \beta > 0$

where, α is a shape parameter, β is a shape parameter, x is the precipitation amount.

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y}\, dy$$

$\Gamma(\alpha)$ is the gamma function

From Thom (1966), the maximum likelihood solutions are used to optimally estimate α and β:

$$\hat{\alpha} = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right); \quad \hat{\beta} = \frac{\bar{x}}{\hat{\alpha}}$$

where, $A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}$

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given months and time scale for the station in question. The cumulative probability is given by:

$$G(x) = \int_0^x g(x)\,dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})}\int_0^x x^{\hat{\alpha}-1} e^{\frac{-x}{\hat{\beta}}}\, dx$$

Letting $t = \frac{x}{\hat{\beta}}$, this equation becomes the incomplete gamma function:

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})}\int_0^x t^{\hat{\alpha}-1} e^{-t}\, dt$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$H(x) = q + (1- q)\ G(x)$

where q is the probability of a zero. If m is the number of zeros in a precipitation time series, Thom (1966) [8] states that q can be estimated by m/n. Thom (1966) uses tables of the incomplete gamma function to determine the cumulative probability $G(x)$. The cumulative probability, $H(x)$, is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI [5].

$$Z = \text{SPI} = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for } 0 < H(x) \le 0.5$$

$$Z = \text{SPI} = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for } 0.5 < H(x) < 1$$

where,

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \quad \text{for } 0 < H(x) \le 0.5$$

$$t = \sqrt{\ln\left(\frac{1}{(1-H(x))^2}\right)} \quad \text{for } 0.5 < H(x) < 1$$

The SPI values are categorically classified as shown in the following Table 1 on drought basis.

Table 1. Drought classification for SPI value

SPI values	Intensity
2.0 +	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

The mean (SPI) equal to zero for the location and desired period because of the time series fitting to a probability distribution, which the probability density function is transformed into a normal distribution. For this study, based on the seasons of Tamil Nadu viz, Cold Weather Period (CWP) from January to February, Hot Weather Period (HWP) from March to May, South West Monsoon (SWM) from June to September and North East Monsoon (NEM), SPI was calculated.

2.3 Methodology

While regressing the SPI values of four seasons and time as predictors with productivity as response, there is a need to test the multicollinearity i.e., approximate linear relationship among the independent variables. Correlation, Variation Inflation Factor (VIF) and Tolerance are the tools used to detect Multicollinearity. Due to presence of multicollinearity between regressor variables, principal component regression (PCR) [9] analysis was carried out.

Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of Sphericity was used to test the appropriateness of the PCR analysis and to test the original correlation matrix is an identity matrix respectively.

Kaiser-Meyer-Olkin test [10] is given by

$$r_{x,y} = \frac{\sum_{j=1}^{m}\sum_{j\neq k}^{m} r_{jk}^2}{\sum_{j=1}^{m}\sum_{j\neq k}^{m} r_{jk}^2 + \sum_{j=1}^{m}\sum_{j\neq k}^{m} p_{jk}^2}$$

where r^{jk} is correlation between j^{th} and k^{th} variables, p^{jk} is Partial correlation between j^{th} and k^{th} variables, m is Number of pairs of observations. It varies between 0 and 1. A value of 0 indicates that the sum of partial correlation is large relative to the sum of the correlation, indicating diffusion in the pattern of correlation.

The test statistic of Bartlett's Sphericity test is given by

$$\chi^2 = \left[\frac{1-n+(2p+5)}{6}\right] \log|r| \sim \chi^2_{\alpha,\ \frac{p(p-1)}{2}\ df}$$

where n is Number of observations and p is number of parameters (variables).

After testing, the eigenvalues associated with each linear component before and after extraction was explained. Fixnally, the principal component regression was fitted using the principal component values along with time and SPI values as regressors and productivity as response.

3. RESULTS AND DISCUSSION

To analyze the rainfall impact on the productivity of sugarcane, regression analysis was carried out by using sugarcane productivity as response and time (*t*), SPI values of CWP (X_1), HWP (X_2), SWM (X_3) and NEM (X_4) as regressor variables. The Collinearity statistics such as VIF and Tolerance for the selected agro-climatic zones showed the presence of multicollinearity. The Collinearity statistic values for the selected zones are given in the Table 2. Since, there is multicollinearity, the Principal component Regression (PCR) analysis was carried out for the selected agro-climatic zones.

Kaiser-Meyer-Olkin measure of sampling adequacy and Bartlett's test of sphericity for all the selected agro-climatic zones of Tamil Nadu are showed in the Table 3. The KMO value for the agro-climatic zones are acceptable i.e. PCR analysis yields distinct and reliable factor. And also, Bartlett's test values are highly significant at 1 per cent level of significance. So, there is a significant relationship between regressors. It tells that the correlation matrix is not an identity matrix. Hence, PCR analysis was highly appropriate.

The eigenvalues associated with each principal component and the percentage of variability explained by the eigenvalues for the agro-climatic zones are given in the Table 4. Table 4 shows that, The PC_1 and PC_2 of the selected zones explained the most variability. So, only PC_1 and PC_2 scores were used to perform regression analysis.

The R^2 value of the models ranged from 0.016 to 0.251 which was clear that the variability in productivity can't be explained by SPIs and time alone (Table 5). Though, for certain zones, the precipitation showed some impact on the productivity of sugarcane.

For Cauvery Delta zone, Since the coefficient of time and PC_2 is significant, South west monsoon and North East monsoon have an impact on the productivity of sugarcane in Tamil Nadu. Similarly, for North East zone, Cold weather period rainfall plays significant positive role in the productivity. In western zone, South west monsoon and North East monsoon have positive impact and Cold Weather rainfall have negative impact on the Sugarcane productivity. Unlike other zones, North west and Southern zones are not significantly disturbed by the precipitation as per the data.

From the view of above, precipitation have no significant impact on the productivity of sugarcane in North West and Southern zones. But for the other zones, the precipitation has significant impact on the sugarcane productivity. For the Cauvery Delta zone and Western zone, precipitation during the South West monsoon and North east monsoon have significant impact on the productivity whereas for North Eastern Zone, precipitation during the Cold Weather period have significant impact on the productivity. Because of the climatological differences of the zones, the precipitation during a specific season have a reasonable influence on the productivity.

Table 2. Collinearity Statistics for different agro-climatic zones of Tamil Nadu

Parameters	**Cauvery Delta**		**North East**		**North Western**		**Southern**		**Western**	
	T	***VIF***	***T***	***VIF***	***T***	***VIF***	***T***	***VIF***	***T***	***VIF***
CWP (X1)	0.89	1.13	0.92	1.08	0.99	1.01	0.23	4.44	0.98	1.02
HWP (X2)	0.04	28.72	0.02	43.82	0.02	57.24	0.02	63.84	0.02	42.26
SWM (X3)	0.04	25.00	0.07	15.01	0.01	114.03	0.02	58.23	0.02	43.76
NEM (X4)	0.03	33.79	0.04	23.15	0.01	77.00	0.03	32.70	0.02	43.40
Year (t)	0.05	20.69	0.04	28.30	0.04	23.95	0.03	40.36	0.05	19.51

T - Tolerance; VIF- Variance Inflation Factor

Table 3. KMO and Bartlett's Test for different agro-climatic zones of Tamil Nadu

Statistic	**Cauvery Delta**	**North East**	**North Western**	**Southern**	**Western**
KMO measure of sampling adequacy	0.801	0.780	0.788	0.853	0.792
Bartlett's sphericity test (*df* = 6)	1475.574**	964.336**	956.313**	921.001**	1249.971**

*** Significant at 1% level*

Table 4. Factor loadings, Eigen values and percentage of variance for different agro-climatic zones of Tamil Nadu

Parameter	Cauvery Delta Factor Loadings		North East Factor Loadings		North Western Factor Loadings		Southern Factor Loadings		Western Factor Loadings	
	PC$_1$	***PC$_2$***	***PC$_1$***	***PC$_2$***	***PC$_1$***	***PC$_2$***	***PC$_1$***	***PC$_2$***	***PC$_1$***	***PC$_2$***
CWP (X_1)	0.888	-0.459	0.337	**0.941**	0.060	0.998	0.861	0.508	0.097	**0.995**
HWP (X_2)	0.703	0.695	0.981	-0.081	0.996	-0.017	0.986	-0.130	0.993	-0.019
SWM (X_3)	0.698	**0.703**	0.976	-0.126	0.997	-0.024	0.984	-0.146	**0.994**	-0.038
NEM (X_4)	0.702	**0.702**	0.983	-0.117	0.997	-0.018	0.977	-0.170	**0.994**	-0.039
Eigenvalue	3.22	1.66	3.00	0.92	2.98	1.00	3.64	0.33	2.97	0.99
% of Variance	65.41	33.75	74.88	23.06	74.56	24.94	90.92	8.14	74.29	24.85
Cumulative percentage	65.41	99.15	74.88	97.94	74.56	99.50	90.92	99.06	74.29	99.14

Table 5. PCR coefficients of productivity and SPIs of different agro-climatic zones in Tamil Nadu

Zones	Constant	Coefficients	Year(t)	PC1	PC2	R^2	RMSE
Cauvery Delta	124.113*	Coefficient	**-1.279***	-7.189	**2.869***	0.116	16.619
		Standard Error	-0.564	-4.85	-1.17		
		Standardized	-0.634	-0.411	0.164		
North East	117.879*	Coefficient	-0.899	-4.614	**9.915***	0.216	41.55
		Standard Error	0.904	7.693	1.564		
		Standardized	-0.355	-0.21	0.451		
North West	117.238*	Coefficient	-0.901	-3.266	-2.342	0.061	19.728
		Standard Error	1.398	12.1	2.486		
		Standardized	-0.286	-0.119	-0.086		
Western	95.118*	Coefficient	1.227	**15.27***	**-7.578***	0.148	27.728
		Standard Error	0.899	7.785	1.776		
		Standardized	0.422	0.605	-0.3		
Southern	87.91*	Coefficient	1.244	14.369	-3.005	0.062	24.366
		Standard Error	1.633	14.072	2.24		
		Standardized	0.439	0.584	-0.122		

** Significance at 5% level; ** Significance at 1% level*

4. CONCLUSION

As there was a severe collinearity between the SPI values of seasons, Principal component regression analysis was used to study the impact of precipitation on the sugarcane productivity by considering the SPI values of four seasons along with time as regressor variables. The study showed that the productivity of sugarcane in Cauvery Delta zone and Western Zone mainly depended upon the precipitation during South west monsoon and North East monsoon periods. However, the productivity of sugarcane in North East, was mostly dependent on the precipitation of Cold Weather period when compared to all other seasons. Unlikely, North west and Southern zones are not significantly influenced by the precipitation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/88759