Climate Change

Comparative Assessment of Climate Variability and Change on Coffee and Tea Cultivation in India

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ABSTRACT

Climate variability poses a significant threat to India's coffee and tea sectors. Rising temperatures, erratic rainfall and recurring droughts reduce yields, deteriorate quality and endanger farmer livelihoods, making it essential to assess climatic impacts on crop productivity and long-term economic sustainability. The present paper attempts to study and compare the effects of climate variability on coffee and tea in India. For this purpose, secondary data from 1971 and 2022 are used. The Johanson co-integration test, the Granger causality test, and regression analysis are commonly used to assess how climate variability affects crop production. The study discovered that while doing the ADF, DF, and PP tests, both intercept and trend specification are utilised and the coefficients of temperature, rainfall and the production of coffee and tea are shown to be significant. The study found coffee and tea production increases by 6.423 per cent and 5.681 per cent change in yield for every 1 per cent increase in temperature and decreases by 1.87 per cent and 1.33 per cent for every 1 per cent increase in rainfall from 1971 to 2022. It is concluded that encouraging sustainable behaviours, such as subsidies for eco-friendly technologies and governments and industry players can promote certifications for sustainable products.

Keywords : - Climate, coffee, tea, variability

1. INTRODUCTION

India's diverse climates and landscapes create ideal conditions for growing some of the world's most valuable crops such as coffee and tea. These two iconic crops are not only important to India's agricultural economy, but they also provide a living for millions of farmers. However, as climate variability increases, these crops face new challenges. Over the past 60 years, rising temperatures, shifting rainfall patterns and heightened drought intensity have begun to threaten the productivity of these climate-sensitive crops (Biggs et al., 2018). For example, even a 1°C increase in average temperature can cause yields to drop by 5-10 per cent. Understanding how key climate factors such as temperature and precipitation influence the cultivation of coffee and tea is critical in predicting the future of these industries (Baruah and Handique, 2021). This paper explores how climate variability affects both crops are compared to examine the impacts on their production and broader economic implications in an era of climate change. Climate change influences tea production by changing rainfall patterns, raising temperatures and shifting seasonal cycles. In Assam, for example, heavy rainfall causes soil erosion and waterlogging, damaging plant roots and reduce yields. Prolonged droughts heighten vulnerability to pests while rising temperatures cause more frequent heatwaves that harm both tea plants and plantation workers. Climate shifts shorten growing periods, reducing the valuable first and second harvests. Additionally, pests are thriving due to warmer winters. Climate variations also affect tea's chemical makeup, with higher elevation tea containing more beneficial compounds than lower elevation tea.

Climate is a key factor for successful coffee production. Drought, salt, high temperature, storms and strong winds decrease flower production and increase the risk of small beans production. These climate changes show a direct impact on coffee quality and productivity levels (Acharya, 2018). Similarly, drought and salt stress limit the coffee production. Drought causes the water deficit in plants and reduces the cell turgor to fall at its maximum value, and during drought stress, plant's physiological structure gets disturbed, so that coffee production will decrease. Sufficient water availability is a very crucial aspect for coffee plants to give a high yield. As a result of heavy rains and excess moisture, many plantations have experienced black rot incidents, bean droppings, and the threat of ripe cherries turning blackish in colour as well as some cherries cracking. This type of bean has a less pleasant taste and will cost significantly less on the market.

In light of this, the current study looks into how India's production of tea and coffee is impacted by climate change. It is set up as follows. Methods and materials are presented in the second section. Section III presents the results and discussion, and Section IV presents the conclusion and policy recommendations.

2. METHODOLOGY

India's tea-growing regions include Tamil Nadu, Kerala and Karnataka in the South, Dooars, Terai and Darjeeling in West Bengal and Cachar in Assam. These regions possess deep, fertile soils that drain well and are rich in organic matter and humus. All year long, there is a warm, humid climate free from frost. It rains roughly 1500 millimetres along with less than 15 degrees Celsius is the temperature. India's historic coffee-growing regions including Karnataka, Kerala and Tamil Nadu, are home to various states that produce coffee. Karnataka produces more than 70 percent of India's total coffee production, followed by Kerala, which produces around 21 per cent, Tamil Nadu, which produces 5 per cent along with Odisha and Andhra Pradesh. A hot, humid climate with temperatures between 15 and 28 degrees Celsius and 150 to 250 cm of rainfall is necessary for coffee plants.

The current study is based on secondary data that the Indian Metrological Department and the RBI Statistical Handbook have provided. For the study, annual data on temperature, precipitation and the production of coffee and tea from 1971 to 2022 are gathered. The analysis uses a log value that has been created from the 53 years of data. (This study based on secondary information and data were extracted from Indian Metrological Departmental site and The RBI Statistical Handbook with year 1971 to 2022. Year of experiment is 6 Months with year January 2025 to June 2025).

Verifying the unit root, or stationarity, of the data is crucial before beginning any analysis of the time series data. The study uses the DF test and the Phillips Perron test to test the identical ADF test. Furthermore, a variety of criteria, such as the Sequential modified LR test statistic, Final Prediction Error (FPE), Akaike information criterion (AIC), Schwarz information (SC), and Hannan-Quinn information criterion (HQ), are used to determine the optimal lag duration. The correlation between climate variability and agricultural production efficiency is investigated using the Johansen Co-integration test. In addition, the Granger causality test is used to ascertain the direction of the relationship between two series of agricultural production and meteorological variables like temperature and rainfall. Furthermore, linear regression analysis found that the impact of climate variability on productions during the periods. In this paper, we were used Econometrics Views (E-VIEWS) software for statistical analysis. These segmentation techniques are described below.

By analyzing the long-term relationship between the time series, the effects of climate change on the production of tea and coffee are evaluated (Vasisht et al., 2018). Johansen's co-integration test is used for this, and its general form is as follows:

$$\Delta Yt = \mu + \sum_{i=1}^{p-1} \Gamma i \Delta Yt - 1 + \prod Yt - 1 + \varepsilon_t$$

Johansen proposed two likelihood ratio tests, where Γ and $\prod$ are matrices of parameters, ε_t is a $(n \times 1)$ vector of innovations to determine the number of co-integrating vectors, and p is the number of lags chosen by lag length selection criteria. The maximum eigen value test statistic and trace test can be expressed as follows:

$$\int \text{trace} = -T\sum_{i=r+1}^{n} \ln(1-\lambda_i)$$
$$\int \max = -T \ln(1-e_r+1)$$

where λ_i is the i^{th} largest canonical correlation and T is the sample size. The trace test compares the alternative hypothesis of n cointegrating vectors with the null hypothesis of r cointegrating vectors. According to Beag and Singla (2017), the alternative hypothesis for the maximum eigenvalue test is r+1 cointegrating vectors, while the null hypothesis is r cointegrating vectors.

By calculating the percentage of a variable's current value that can be explained by previous values of other variables, the Granger method seeks to enhance the explanation by adding lagged values of earlier variables. Thus, to analyse the direction of relationship among parameters, the Granger causality test (Ghosh, 2019) is used, which can be presented as follows:

$$X_t = C_0 + \sum_{i=1}^{p} a_i X_{t-i} + \sum_{j=1}^{p} b_j Y_{t-j} + \varepsilon_t$$
$$Y_t = \gamma_0 + \sum_{i=1}^{p} a_i Y_{t-i} + \sum_{j=1}^{p} \beta_j X_{t-j} + \mu_t$$

Where, p is the number of lags of both variables in the system. If the null hypothesis i.e. $b_1=b_2=......=b_p=0$, is accepted, then Y_{t-1} does not granger cause X_t. According to Ali and Gupta, (2019), if $H_0 : \beta_1 = \beta_2=....\beta_p=0$ is accepted, it means that X_{t-1} does not granger cause X_{t-1}.

This study used a log-linear regression model. The dependent variable is coffee (model-1) and tea (model-2) while the independent variables include rainfall and temperature.

$$\text{Logcoffee}_{\text{production}} = \beta_0 + \beta_1 \log \text{rainfall} + \beta_2 \log \text{temperature} \dots \text{(model-1)}$$
$$\text{Logtea}_{\text{production}} = \beta_0 + \beta_1 \log \text{rainfall} + \beta_2 \log \text{temperature} \dots \text{(model-2)}$$

3. RESULTS AND DISCUSSION

The stationarity of the data is evaluated using the Augmented Dicky Fuller (ADF), Dicky Fuller (DF), and Pearson Paul (PP) test results, which are displayed in Table-1. Because the coefficients for temperature, rainfall, and the production of tea and coffee are found to be significant, the intercept and trend specification is used when doing the ADF test. Three tests' findings showed that the null hypothesis that the four parameters have unit roots and are non-stationary is accepted at this level. Furthermore, looking over the Table 1 shows that in the case of the ADF, DF and PP tests, the null hypothesis that there is a unit root is not accepted for any of the production series at the first difference. Consequently, the first parameter differences are discovered to be stationary. Stationarity of the parameters is also presented graphically in Figures 1 and 2 represent the CUSUM test, which indicates that during 1970-2022 the data set is highly acceptable, and the line inside the box fits the model and is statistically significant.

Table 1: Stationarity test

Parameters	**ADF**		**DF**		**PP**	
	Intercept	**Trend and intercept**	**Intercept**	**Trend and intercept**	**Intercept**	**Trend and intercept**
Coffee	21.43	8.93	9.96	7.08	24.44	27.40
Tea	8.71	8.67	8.47	8.80	10.79	10.77
Rainfall	9.25	9.20	14.48	8.93	28.76	28.08
Temperature	5.46	5.39	6.35	7.14	15.93	16.23

Source: Author's calculation; ADF, DF and PP tests are statistically significant at P=0.05 level of probability along with data at first difference of stationarity.

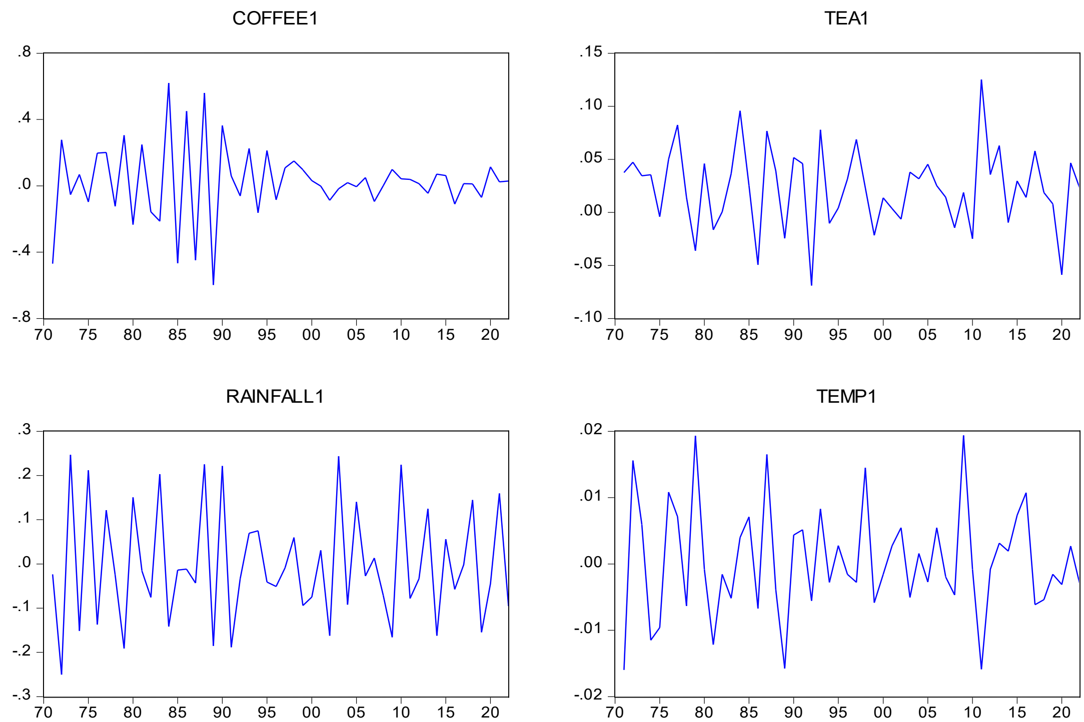

Figure 1: First differences of the parameters

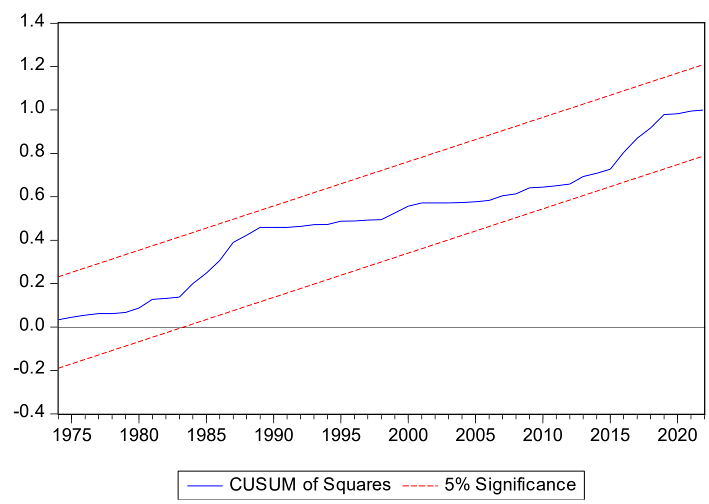

Figure 2: CUSUM test

The co-integration test can begin after the variables stabilize and integrate to the same order, or the lag length. Table-2 displays the outcomes of the VAR lag order selection criteria. The findings showed that the five criteria -LR, FPE, AIC, SC and HQ are used to determine the lag order of two. To test the co-integration, the lag order of two is chosen, following the majority.

The co-integration between two climatic factors (temperature and rainfall) is examined to learn more about the production of coffee and tea. Table-3 displays the findings of the Johansen co-integration test. The results of Johansen's two tests the trace and the maximum Eigen value are shown in the Table. If the non-co-integrating equations null hypothesis is accepted, it means that there is no co-integrating relationship between the variables. The trace and eigenvalue tests reject the null hypothesis at the five percent significance level. It suggests that there is a long-term relationship between the climatic conditions of coffee and tea.

Table 2: VAR Lag order selection criteria

Lag	Log L	LR	FPE	AIC	SC	HQ
0	238.47	NA	8.20	9.57	9.41	9.51
1	348.84	198.21	1.75	13.42	12.64	13.12
2	383.23	56.15*	8.36*	14.17*	12.78*	13.64*
3	392.42	13.51	1.14	13.89	11.88	13.13
4	406.47	18.34	1.33	13.81	11.18	12.81

Source: Author's calculation; * Indicates lag order selected by the criterion, each test at P=0,05 level; LR: Sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike Information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion

Table 3: Johansen-co-integration test

Hypothesised No. of CE (s)	Trace Test		Maximum Eigen Value Test	
	Trace Statistic	P=0.05 Critical value	Max-Eigen Statistic	P=0.05 Critical value
None*	191.82	47.85	69.80	27.58
At most 1*	122.01	29.79	47.50	21.13
At most 2*	74.50	15.49	42.99	14.26
At most 3*	31.51	3.84	31.51	3.84

Source: Author's calculation; Trace test & Eigen statistics indicate 4 co-integrating equation(s) at P=0.05 level; *: Denotes rejection of the hypothesis at P=0.05 level.

The pairwise Granger Causality test is displayed in Table-4. It is discovered that coffee does not significantly affect temperature or rainfall at the 5 per cent and 1 per cent probability levels in coffee production. Nonetheless, it is discovered that tea does not significantly affect temperature or rainfall at the five percent probability level in tea production. Rainfall is not caused by temperature.

Table 4: Pair-wise Granger causality tests

Coffee Production	Observation	F- Statistics	Probability
Coffee does not Granger cause rainfall	53	5.63799	0.02***
Coffee does not Granger cause temperature	53	13.2418	0.000***
Tea Production	Observation	F- Statistics	Probability
Tea does not Granger cause rainfall	53	5.99905	0.01***
Tea does not Granger cause temperature	53	21.6090	0.000***

Source: Author's calculation; This causality is based on lag 1; *: D denotes rejection of the hypothesis at P=0.01 level.

Table 5: Linear regression analysis

Coffee Production				Tea Production			
Variables	Coefficient	Standard Error	t Statistics	Variables	Coefficient	Standard Error	t Statistics
Rainfall	-1.876	0.535	-3.506***	Rainfall	-1.339	0.374	-3.577***
Temperature	6.423	1.163	5.522***	Temperature	5.681	0.813	6.983***
R-squared (0.68)				R-squared (0.72)			
Adjusted R-squared (0.60)				Adjusted R-squared (0.64)			
Durbin-Waston Statistics (2.15)				Durbin-Watson Statistics (2.22)			

Source: Author's calculation

The results of regression estimates are displayed in Table-5, where the production of tea and coffee is designated as the dependent variable and the remaining factors are identified as the explanatory variables. For both crops, the R^2 and modified R^2 indicate highly significant results (about 68 & 60 per cent for coffee and approximately 72 per cent & 64 per cent for tea, respectively). The adjusted R^2

indicates the proportion of the production fluctuations that can be accounted for by the explanatory variables (temperature and rainfall). The Durbin-Watson Statistic (1.5 < DW < 2.5) indicates that there is no autocorrelation between production and the explanatory factors, and is in the vicinity of the optimal level of 2.

The production of coffee and temperature are positively correlated. The coefficient of 6.423 shows that, on average, coffee production improves by 64 per cent for every 1 per cent increase in temperature. Rainfall and coffee output have an inverse connection, as indicated by the coefficient of -1.87. Rainfall has therefore been found to be significantly adverse at the one per cent probability level, with a coefficient of -1.87 showing that, on average, coffee production falls by 18 per cent for every 1 per cent increase in rainfall.

Too much rain can harm coffee plants by increasing fungal diseases like coffee leaf rust. This disease stops the plants from flowering and producing fruits. In Indian coffee regions such as Kerala and Karnataka, coffea arabica is especially affected by CLR, an important economic problem (Legesse, 2019). Coffee leaf rust grows well in warm and humid conditions, which help its spores germinate and spread quickly. It is estimated to cause dollar 1 to 2 billion in losses worldwide every year. As global temperatures and humidity rise, future climate models predict an intensification of CLR, particularly during wet, hot months, further threatening coffee production (Thanuja, 2017). This fungal infection leads to both qualitative and quantitative losses in coffee crops, especially during the monsoon, when prolonged wet conditions worsen the disease's spread and impact on coffee berries (Tadesse et al. 2021).

In the case of tea, we see a positive relationship between tea production and temperature. The coefficient of 5.681 indicates that for every one per cent increase in temperature, tea production increases by 56 per cent on average. There is an inverse relationship between rainfall and tea production, as denoted by a coefficient is -1.33. Thus, rainfall shows a negative and statistically significant effect at the 1 per cent level of probability. On average, a 1 per cent increase in rainfall results in a 13 per cent decrease in tea production, according to the coefficient of -1.33.

Heavy rainfall causes waterlogging, which washes away nutrients and slows the growth of good quality leaves. It also makes the leaves grow faster but this rapid growth reduces important flavour compounds like methylxanthines and catechins which give tea its taste and health benefits. These compounds can drop by up to 50 per cent during the monsoon season. High humidity during heavy rains also increases pests like tea mosquito bugs and diseases such as blister blight and grey blight. Grey blight results in leaf drop, blister blight decreases photosynthesis, and pests like red spider mites and tea mosquito bugs cause premature leaf loss and discoloration (Lehmann-Danzinger, 2000; Shrestha, 2020). These problems could be made worse by unpredictable weather patterns and climate change, which would lower tea production and quality.

4. CONCLUSION

The study show that temperature, rainfall and the production of tea and coffee are closely linked. The Johansen Co-integration test confirmed a long-term relationship among these variables. Regression results indicated that higher temperatures increase the production of both crops while too much rainfall has the inverse effect. It increases fungal diseases and pests in coffee and tea, reducing plant health, crop quality and overall productivity. Following are some suggestions that we would like to make focus on developing climate resilient crop varieties, improving pest and disease management and strengthening water management through better drainage and efficient farming methods. Reliable weather forecasting and early warning systems can help farmers make timely decisions. Promoting sustainable farming practices and adopting climate adaptation strategies are also essential for protecting long term tea and coffee production in vulnerable regions.

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Authors contributions

Dr. Urmi Pattanayak, was conceptualization of research; designing of the experiments; execution of data collection, analysis of data and interpretation along with preparation of the manuscript.

Dr. Amrita Nath, Miss. Milinda Mishra and Miss. Sonali Sahoo were help conceptualization of research, designing of the experiments, contribution of experimental materials and editing of the manuscript.

Dr. Jyotirmayee Acharya giving the overall instruction, reading and approved the final manuscript.

Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of interests

The authors declare that they have no conflicts of interests, competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data and materials availability

All data associated with this study are present in the paper.

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