**The Vulnerability of Plantation Crops to Climate Change: Insights from India's Tea Production**

**ABSTRACT**

Climate change has emerged as a significant challenge for agriculture globally, with profound implications for plantation crops, which are economically vital for many developing countries, including India. Changes in temperature, unpredictable rainfall patterns, and increased frequency of extreme weather events have raised concerns about the sustainability and productivity of plantation crops. Plantation crops are particularly sensitive to climatic variations due to their long gestation period, dependence on stable environmental conditions, and vulnerability to extreme weather events. The study examines the impact of climate change on tea production by selecting the major tea producing state Assam from northern part of India, Kerala and Tamil Nadu from southern part of India. The data for the study is collected from Indiastat and Economic Review (2021) for the period 2011 to 2020. High humidity and rainfall increased year round tea production in Assam, while Kerala’s tea production is affected by a more seasonal climate, with a distinct dry season leading to fluctuation in tea production. Tea production in Kerala and Tamil Nadu is increasingly vulnerable to climate variability, especially changes in temperature and rainfall. While moderate deviations in rainfall can be managed, sustained high temperatures above the optimal threshold critically limit shoot growth and yield. Therefore, adaptive measures, including shade management, irrigation scheduling, and selection of heat-resilient cultivars, are essential to mitigate the adverse effects of climatic stress on tea production.

Keywords: Climate change, rainfall, temperature, tea production

1. **INTRODUCTION**

Agriculture has recently become more demand-driven, shifting from staple to cash crops and integrating into global markets pushing the sector into competition without adequate preparation for the resulting vulnerabilities. As the scientific consensus grows that significant climate change, in particular increased temperatures and precipitation, is very likely to occur over the 21st century (Christensen et al., 2007), economic research has attempted to quantify the possible impacts of climate change on society.

One of the most pressing climatic changes in recent times is the rise in atmospheric temperatures caused by increased levels of carbon dioxide and other greenhouse gases. Rainfall patterns have also become increasingly unpredictable, with many regions experiencing more frequent extremes such as droughts, floods, erratic rainfall, and early snowmelt. In addition to these climate-related shocks, farming faces other challenges, including fluctuating crop yields, volatile commodity prices, and shifting agricultural policies. Agricultural production remains highly uneven due to its heavy reliance on weather conditions. Farm incomes are particularly vulnerable to both covariate shocks like droughts, floods, and cyclones, and idiosyncratic shocks such as injuries, fire, theft, the use of fake seeds, and other human-induced disruptions

Climate change is affecting all aspects of agriculture globally. Plantation crops are particularly vulnerable to rising temperatures, increased CO₂ levels, shifting rainfall patterns, heightened pest and disease pressures, and the depletion of organic carbon pools. Modern inputs like fertilizers, which work best with adequate water, are heavily influenced by rainfall variability—especially in regions lacking reliable irrigation. In such areas, output fluctuations tend to increase with growth: in years of good rainfall, improved soil moisture and groundwater levels encourage greater fertilizer use, leading to a significant rise in crop yields. But, in a year of deficient rainfall, crop yields go down steeply because of a significant reduction in the use of inputs, thereby widening the year to year fluctuations in yields resulted to a rise in the sensitivity or elasticity of output with respect to variations in rainfall ( Rao *et al.,* 1988).

Plantation crops, particularly tea play a significant role in India's agricultural economy and rural livelihoods. Indian tea is renowned globally for its exceptional quality, driven by strong geographical indications, significant investments in processing facilities, on-going innovation, a diversified product range, and strategic market expansion The study found that North India produces about 80 per cent of tea in India, about 56 per cent of North Indian tea is exported to other countries and fetches a very high price when compared to South Indian tea (Economic Review, 2021). This crop is highly sensitive to climatic conditions, making them vulnerable to the on-going and intensifying impacts of climate change. Climate change is expected to decrease not only the quality of tea, but also the quantity of tea production; as a consequence of increased soil erosion, pests, and diseases that are becoming more resistant and the success of tea farming is closely tied to climatic variables (Jayasinghe et.al., 2020). Sudden shifts in climate have emerged as a major environmental concern for tea-growing regions, as tea plants, with their long lifespan, are particularly vulnerable to the long-term effects of climate change across the globe (Ochieng *et.al*., 2016). Changes in weather patterns along with the increased frequency of drought, storms, flood, etc. are likely to affect the tea industry adversely as tea production is reliant on the climate of the tea-growing region (Mallik and Ghosh, 2022). An excessive and sporadic rainfall and a combination of hotter and wetter weather condition during monsoon months had a detrimental effect on tea yield (Mallik and Ghosh, 2022).

There is growing evidence that climate change will significantly impact tea cultivation, posing a major challenge for tea plantations in Assam, India. Tea yield is negatively influenced by temperature anomalies, indicating that rising temperatures are unfavourable for tea cultivation, while rainfall anomalies have a positive but comparatively weaker impact, suggesting that variations in rainfall cannot fully mitigate the adverse effects of warming, thereby underscoring the sensitivity of tea production to climate change ( Baruah & Handique, 2021).

Tea cultivation is increasingly threatened by climate change, which is affecting growth, yield, and quality and climate has always been a decisive factor in agriculture and crop production, respectively (Sahu et al 2025). Changes in weather patterns, including the increased frequency of droughts, storms, and floods, are likely to adversely affect the tea industry, as tea production is highly dependent on regional climate conditions, with excessive and sporadic rainfall combined with hotter and wetter monsoon weather shown to have a detrimental impact on yield (Mallik & Ghosh, 2022). Observing at trends in temperature and rainfall between 1991 and 2023, it identifies significant trends in climatic factors and their relationship to tea productivity, the study revealed a positive growth trend in rainfall in the production of Darjeeling tea (Sahu *et al*. 2025).

 Accordingly the major research questions are: whether there is any sign of climate change impact on tea production in India? Impacts if any, which states affects the most. Hence, this study examines how climate change affects agricultural production, especially cash crops like Tea in India. Given this backdrop, the present study focuses on the impact of climate change on the production of major crop like tea in India.

1. **THE VULNERABILITY OF PLANTATION CROPS TO CLIMATE CHANGE**

The focus of previous empirical studies has been on the developed countries like US, but vulnerability to climate change may be greater in the developing world, where agriculture typically plays a larger economic role. Climatic shocks such as excess rainfall, deficit rainfall, delayed onset of the monsoon, crop damage due to pest and insects always pose barriers to crop yields ( Nepal and Shrestha, 2015) and this climatic variability and occurrence of extreme events are major concerns for the Indian subcontinents. In India, the analysis of seasonal and annual surface air temperatures (Pant & Kumar, 1997) has shown a significant warming trend of 0.57◦C per hundred years and the warming is found to be mainly contributed by the post-monsoon and winter seasons. The monsoon temperatures do not show a significant trend in any major part of the country and similar warming trends have also been noticed in Pakistan, Nepal, Sri Lanka and Bangladesh (Warrick and Ahmed, 2012).

Rainfall patterns in India over the past century have shown largely random fluctuations, with no consistent trend in the summer monsoon; however, localized trends have emerged. Increasing rainfall has been observed along the West Coast, North Andhra Pradesh, and Northwest India, while East Madhya Pradesh, Odisha, and Northeast India have experienced a decline (Kumar and Parik,2001). Extreme situations like floods, droughts, cyclones, etc. pose direct threats to crops, while more subtle weather shifts during critical growth stages can also significantly affect yields. Agricultural productivity is further shaped by market conditions, input costs, and water availability. Rainfall deficits often reduce irrigation supplies, which may lead to a shift from irrigated to rain-fed crops in subsequent seasons (Kumar et al., 2004).

Climate change, marked by erratic rainfall and more frequent natural disasters, disproportionately affects developing countries due to their dependence on climate-sensitive sectors like agriculture, fisheries, and forestry (Delbiso *et al*., 2017). Decreases in solar radiation and rising minimum temperatures reduce net crop productivity by increasing maintenance respiration requirements (Aggarwal, 2003). Climatic variables such as rainfall and temperature act as exogenous factors in crop production, while farmer-controlled inputs—like fertilizers, pesticides, and irrigation—vary across space and time (Rao et al., 1988). Specifically, tea yield and shoot expansion are highly sensitive to environmental conditions including light, CO₂ levels, temperature, and water availability (Carr, 1972)

Tea growth and productivity is mainly controlled by water availability. Drought is responsible for a 14-20 per cent reduction in yield and 6-19 per cent mortality of tea plants (Cheruiyot et al. 2008). In addition, under drought conditions, photo inhibition could reduce source capacity and thereby impose a source- limitation on tea yield (Mohotti and Lawlor, 2002). Although the total annual rainfall in most rain-fed tea-growing areas is generally sufficient, its uneven, bimodal distribution due to monsoonal seasonality often limits annual tea yield, leading to a continuous dry period of about 2–3 months (Jaetzold and Schmidt, 1982).

In temperate regions with insufficient rainfall, tea plantations require supplementary irrigation to meet their water needs. In addition, tea cultivation areas are expanding rapidly and a large proportion of this expansion is taking place in areas whose major limitation is soil moisture and therefore, water deficit is, and will continue to be, a major limiting factor in tea production (Cheruiyot *et al*. 2008). High transpiration rates from extensive tea canopies cause significant soil water deficits which are responsible for decreased leaf expansion rates (Stephens and Carr 1993). Transpiration is closely linked to photosynthesis, which is responsible for the growth of young leaves and forms the economic yield of tea (Anandacoomaraswamy *et al*. 2000).

In well-watered plants, young leaves show a significantly lower diffusion resistance than old leaves, while in water-stressed plants young leaves always exhibit a higher diffusion resistance than old leaves (Sandanam *et al.* 1981). Interestingly, in the young leaves of greenhouse-grown tea which had developed under water stress, acclimation to drought conditions occurred that was well reflected in their more stable photochemistry, water relations and an efficient antioxidant defence system compared with the mature leaves (Hajiboland and Bastani 2012).

The global weather change has become unpredictable, creating uncertainty in agricultural production, with the production of tea being no exception (FAO, 2016). Changes in temperature, rainfall, and the occurrence of extreme weather events such as drought and high-intensity rainfall have adversely affected yield and production of tea in recent decades (De Costa *et al.* 2007, Wijeratne *et al*. 2007). Drought events in the region are primarily due to a weak south- west monsoon on the Indian sub-continent, leading to a failure of wet season rainfall (FAO, 2016). Drought affects both the quantity and quality of tea, leading to a considerable loss of export earnings and production costs also increase during drought due to the need for additional inputs (Wijeratne and Fordham 1996). Temperature increases of 0.4 to 3.0°C are also predicted while rainfall is expected to increase with an uneven pattern of distribution (FAO, 2016). The intensity of these climate impacts on tea production will likely vary across the major tea growing regions, in low-, up- and mid-country areas (Wijeratne *et al*. 2007).

The reviewed literature highlights that climate variability, particularly changes in rainfall patterns and temperature, poses significant risks to agricultural productivity in India. While some regions show increasing rainfall trends, others face declining patterns, leading to uneven impacts across the country. Both extreme weather events and subtle climatic shifts can adversely affect crop yields, especially during critical growth stages. As climate-induced uncertainties continue to rise, understanding and mitigating these impacts through adaptive practices and policy interventions becomes increasingly important for sustaining agricultural livelihoods, particularly in vulnerable developing region.

1. **DATA SOURCE AND METHODOLOGY**

The study seeks to examine the impact of climate variables like rainfall and temperature on tea production of selected states in India. Recent findings reveal that climate change poses a significant threat to agricultural crop production, badly affecting food security and rural livelihoods. In a way that many studies have gone through it, it is necessary to check which variable is severely affecting the production of these crops in India.

Here, tea production, rainfall, temperature in India studied using secondary data sources like the publications from Tea Board, Indiastat, and Economic Review (2021). As this work focus on the effect of changes in climate on tea production, the study employed time series data of different states independently. The study selected major tea producing states like Assam from northern part of India, Kerala and Tamil Nadu from southern part of India for the period 2011 to 2020. Assam accounts for over half of India's total tea production, Kerala and Tamil Nadu produces major share among southern part of India. The study considered rainfall deviation and average temperature data to examine the impact of climate variables on yield for tea in sample states. Here it is chosen the percentage deviation of rainfall, which is calculated by

Actual Rainfall -Normal Rainfall \*100

Normal Rainfall

The line graph is employed to show the trends in production and to find the relation between production and climate variables. Karl Pearson’s correlation coefficient is employed to analyse the association between tea production and rainfall.

1. **RESULT AND DISCUSSIONS**

**4.1 Tea Production and Climate Change in India: An Inter- state Analysis**

Indian tea is globally renowned for its quality, attributed to strong geographical indications, substantial investments in infrastructure, innovation, a diversified product mix, and market expansion. However, tea cultivation is highly sensitive to climatic conditions. Temperature fluctuations and rainfall patterns significantly influence tea growth, with sustained increases in average monthly temperatures leading to reduced yields. Among climatic factors, water availability plays a dominant role in controlling tea productivity. Table 1 explains production of tea in five selected states in India.

|  |
| --- |
| **Table.1 : Tea production in India (million kg)**  |
| States  | 2011-12  | 2012-13  | 2013-14  | 2014-15  | 2015-16  | 2016-17  | 2017-18  | 2018-19  | 2019-2020  |
| Assam  |  501.4  | 588.14 | 629.05 | 606.80 | 631.0  | 669.52 | 653.53 | 676.98 | 716.49 |
| Karnataka |  5.28  |  6  |  5.52  |  6.74  |  6.46  |  5.10  |  5.37  |  5.10  |  4.86  |
| Kerala  |  66.90  |  63.76  |  63.48  |  67.20  |  57.97  |  61.40  |  62.33  |  58.02  |  59.26  |
| Tamilnadu  |  164.6  |  171.9  | 174.71 |  167.42 | 163.09 | 146.04 | 164.40 | 155.32 | 155.31 |
| W.Bengal  | 225.69 | 287.32 | 312.10 | 324.26 | 324.70 | 356.39 | 367.86 | 385.22 | 424.89 |

Source: Indiastat, 2021

The northern part of India is the biggest producer at about 80 per cent of the total country’s annual tea production with the majority of the production coming from Assam followed by West Bengal (Tandane & Kaur, 2020). State wise growth rate of production was positive and significant in Assam, West Bengal, Tamil Nadu and Karnataka whereas positive but non-significant in Kerala (Tandane & Kaur, 2020). Table 1 shows a comparative static analysis of five major tea producing states in India. Tea production in Assam is high mainly due to its warm and humid climate, heavy rainfall, and fertile alluvial soil along the Brahmaputra River valley, which provide ideal conditions for tea cultivation. The region’s misty mornings and long tradition of tea farming further enhance both the quantity and quality of tea produced. Kerala’s tea production is affected by a more seasonal climate, with a distinct dry season leading to fluctuation in tea production.

**4.2 Tea Production and Climate Change in Assam**

Assam tea has earned an international reputation and holds a substantial share in the global tea market. The total area under tea cultivation in Assam is accounting for more than half of the country’s total area under tea and the estimated annual average production of tea in Assam is about 630- 700 million kg (Gaonkhowa, 2023)

 **Figure1: Trends in tea production in Assam from 2011-12 to 2019-2020**.



 Source: Indiastat, 2021

India is one of the world’s biggest tea producers and more than half of country’s production comes from Assam. Figure1 shows the increasing trends in tea production of Assam from 2011- 2012 to 2019-2020. Climate variables like rainfall and low temperature paved the way for high productivity of tea. Assam tea now costs more and is becoming increasingly challenging because of changing weather.

It is clear from the Table 2 that even though they experience dry periods is longer and it rains heavily within short span of time, several large tea gardens have started using irrigation systems to get better yields. It is found that there are fluctuations in the production of tea at all levels due to failure of monsoon. Similarly, increasingly frequent hot spells are harming yield in Assam. Exposure of tea plants to sunlight, which can damage crops, is also increasing in Assam.

 **Table 2. Tea production and climate variable in Assam**

|  |  |  |  |
| --- | --- | --- | --- |
| Year  | Production(million kg)  | Rainfall deviation (%)  | Temperature(centigrade) |
| 2011-12  |  501.4  | -11.54  |  34  |
| 2012-13  |  588.14  | -30.98  |  26  |
| 2013-14  |  629.05  | -17.22  |  20  |
| 2014-15  |  606.8  |  -4.36  |  24  |
| 2015-16  |  631.0  |  -13  |  19  |
| 2016-17  |  669.52  |  3.34  |  20  |
| 2017-18  |  653.53  |  -27.4  |  23  |
| 2018-19  |  676.98  |  -5.52  |  25  |
| 2019-20  |  716.49  | 17.58  |  27.2  |

 Source: Indiastat, 2021

Climate variables such as temperature and rainfall significantly influence tea production in Assam. Research indicates that tea yields increasing at decreasing rate when monthly average temperatures increases, highlighting the crop's sensitivity to higher temperatures. Previously, rainfall was evenly distributed, but recent data indicate concentrated precipitation within short periods, leading to topsoil erosion in tea gardens. This not only hampers productivity but also increases vulnerability to pests during dry spells, thereby raising dependency on pesticides and production costs. The Karl Pearson correlation coefficient between rainfall and tea production in Assam is 0.49, indicating a moderate to strong positive relationship. This empirical evidence supports the theoretical linkage between rainfall and tea yield in Assam.

* 1. **Tea Production and Climate Change in Kerala**

Kerala is a significant tea-producing state in India, Idukki and Wayanad account for nearly 87% of the total area under tea cultivation in the state. Tea production in Kerala is increasingly affected by climate change, manifesting through prolonged droughts, intense precipitation over short periods, temperature extremes, higher incidence of disease infestations, weed growth, and stronger wind velocities. These factors have contributed to fluctuating tea yields in recent years. For instance, production dropped from 66.9 million kg in 2012 to 63.76 million kg in 2013, showed a recovery to 67.2 million kg in 2015, and declined again to 57.97 million kg in 2016.

 **Table 3.Tea production and climate variable in Kerala**

|  |  |  |  |
| --- | --- | --- | --- |
| Year  | Production(million kg)  | Rainfall deviation (%)  | Temperature(centigrade)  |
| 2011-12  | 63  | -25.7  | 29  |
| 2012-13  | 66.9  | 11.3  | 29  |
| 2013-14  | 63.76  | 4.1  | 28  |
| 2014-15  | 63.48  | 2.3  | 28  |
| 2015-16  | 67.2  | -11  | 28  |
| 2016-17  | 57.97  | -36  | 30  |
| 2017-18  | 61.4  | -8.1  | 29  |
| 2018-19  | 62.33  | 20.3  | 29  |
| 2019-20  | 58.02  | 6.11  | 28  |

 Source: Indiastat, 2021

Table 3 conveys tea production in the state is increasingly vulnerable to climate variability, especially changes in temperature and rainfall. Analysis of tea production trends over the past decade reveals clear links between climatic fluctuations and yield levels. Tea production is particularly sensitive to both minimum temperatures and rainfall. Optimal growth occurs within a moderate temperature range of 18–25°C, yet in recent years, average temperatures in Kerala have frequently exceeded this, reaching up to 30°C. Such elevated temperatures, when combined with deficient rainfall, have been associated with noticeable declines in yield. For example, years with both high temperatures and significant rainfall shortfalls recorded the lowest levels of production, indicating compounded climatic stress on tea crops.

Conversely, when temperature conditions remained within the tolerable threshold, even moderate rainfall deficits did not severely impact yields, suggesting some resilience under favourable thermal conditions. Moreover, years with above-average rainfall generally supported better yields, underlining the critical role of water availability in sustaining tea productivity. The floods in 2018, for instance, led to a significant drop in production despite overall adequate rainfall levels, emphasizing that extreme weather events can negate the benefits of improved averages. In summary, the data underline the complex interplay between rainfall and temperature in determining tea productivity. While moderate deviations in rainfall can be managed, sustained high temperatures above the optimal threshold critically limit shoot growth and yield. Therefore, adaptive measures, including shade management, irrigation scheduling, and selection of heat-resilient cultivars, are needed to mitigate the adverse effects of climatic stress on production.

Climate change has increasingly exposed tea plantations in Kerala’s high-range districts to extreme weather events, notably frost, resulting in significant crop damage. Such climatic stressors have led to lower yields and compromised quality, driving up the cost of production per kilogram. This, in turn, creates an unstable market scenario for both producers and buyers. Reduced productivity, coupled with declining quality, often leads to price volatility, further affecting the sustainability of production.

 **Figure 2 Tea production and climate variable in Kerala**

 Source: Indiastat, 2021

Analysis of climate data reveals that temperature has shown relatively minor fluctuations over the years, whereas rainfall exhibits considerable variability. Among climatic parameters, rainfall emerges as a more decisive factor influencing tea yield. As reflected in Figure 2, the year 2016 recorded both low productivity and markedly low rainfall, reinforcing the positive correlation between adequate precipitation and tea output.

**4.4 Tea Production and Climate Change in Tamil Nadu**

Amongst the tea producing states in south India, the share of Tamil Nadu is impressive when compared to the share of Kerala and Karnataka, the total tea production of Tamil Nadu is 131.83 million kg and it has increased to 163.09 million Kg. in 2015 (Sivakumar et al., 2018).

**Figure 3 .** **Tea productions in Tamil Nadu**

 Source: Indiastat, 2021

Tamil Nadu has experienced the most significant decline in area under tea cultivation in 2016-17. This decline is largely attributed to economic pressures faced by small and marginal cultivators who, unable to cope with recurrent losses and low market prices, are opting to sell their land to the construction sector. This shift in land use not only reduces the total area available for cultivation but also adversely impacts overall production and productivity in the region. The trend implies the need for institutional support and market stabilization mechanisms to sustain tea cultivation in economically vulnerable areas.

 **Table 4. Tea production and climate variable in Tamil Nadu**

|  |  |  |  |
| --- | --- | --- | --- |
| Year  | Production(million kg)  | Rainfall Deviation (%)  | Temperature(centigrade |
| 2011-12  |  164  | -22.42  | 26 |
| 2012-13  | 171.93  | -20.1  | 24 |
| 2013-14  | 174.71  | -18.9  | 25 |
| 2014-15  | 167.42  | -0.1  | 25 |
| 2015-16  | 163.09  | 31.12  | 25 |
| 2016-17  | 146.04  | -41.4  | 25 |
| 2017-18  |  164.4  | 6.4  | 26 |
| 2018-19  | 155.32  | -12.2  | 26 |
| 2019-20  | 155.31  | -0.32  | 26 |

 Source: Indaistat, 2021 and Timeanddate, 2020

 An analysis of tea production and rainfall deviation data from 2011–12 to 2019–20 reveals a complex but significant relationship between climatic variability and tea yield. While tea production remained relatively stable during years of moderate rainfall deficits, such as 2011–12 to 2013–14, with production exceeding 164 million kg despite deviations above -18%, it sharply declined during 2016–17 to 146.04 million kg, coinciding with the highest negative rainfall deviation of -41.4%. This suggests a threshold effect, where beyond a certain level, rainfall deficiency substantially impacts yield. Conversely, in 2015–16, even with a positive rainfall deviation of +31.12%, production remained low at 163.09 million kg, indicating that excess rainfall may also adversely affect output due to factors such as waterlogging or timing mismatches. Tea production is slightly recovered in 2017–18 with improved rainfall (+6.4 per cent), the stagnation in 2018–19 and 2019–20 with near-normal rainfall highlights the influence of additional variables like temperature extremes, pest outbreaks, and management practices. Overall, the data emphasises that both the quantity and distribution of rainfall critically influence tea productivity.

 **Figure 4 Tea production and rainfall deviation in Tamil Nadu**

 Source: Indiastat, 2021

Figure 4 manifest the impact of climatic variable like rainfall on tea production in Tamil Nadu. It is clearly perceived that, in the year 2016 production decreased drastically. Tamil Nadu hit by severe drought in the year 2016-17 which in turn severely affected the production of tea. Production has an increasing trend over rainfall in Tamil Nadu. Still it is found that there are fluctuations in the production of tea at all levels due to failure of monsoon, heavy frost during winter, trade policies of the government, unreasonable price for tea leaf, labour unrest and other (Sivakumar, 2018).

As this analysis get into a conclusion that, in Assam even though they experience long dry spells followed by heavy rainfall in short periods, many large tea gardens have adopted irrigation systems to improve yields. Assam acquired favourable climate for tea production which made it to produce large share. On the other, Kerala shows drastic decline in the tea production, as the temperature and rainfall is becoming unfavourable. Uneven rainfall and high temperature affects the tea production. Area under production also decreased so far in recent years. It is clear that among the tea producing states in south India, the area under tea cultivation has fallen at higher rate in Tamil Nadu because of the reason that there are cultivators who are unable to bear loss, not fetching good price for the produce selling their lands for construction industry (Sivakumar, 2018). This has led to a decline not only in the area under tea cultivation but also in overall production and factor productivity.

**5. CONCLUSION**

The study focuses on the significant role of climatic factors like temperature and rainfall in determining the productivity of tea in India. Tea cultivation exhibits higher vulnerability to climate fluctuations. Rainfall remains the primary determinant of tea production, and any failure in the monsoon results in noticeable declines in yield. The study highlights that adequate water availability and moderate temperatures contribute to higher productivity, whereas prolonged dry spells and extreme heat conditions, as observed in Assam, adversely affect crop health. The increasing frequency of heat waves and excessive sun exposure in tea-growing regions pose long-term risks to both yield quantity and quality, necessitating adaptive agricultural practices. Given these findings, it is imperative to undertake further research using long-term datasets that incorporate additional climatic and environmental variables. A more detailed understanding of climate variability, including shifts in seasonal patterns and extreme weather events, will be crucial in developing mitigation strategies for tea cultivation.

The finding of this study implies the need for climate-resilient agricultural policies to safeguard the sustainability of tea cultivation in India. Policymakers should promote climate-resilient practices, such as drought-resistant crops, and improved irrigation measures like rainwater harvesting and micro-irrigation. Expanding cultivation to emerging favorable regions while providing financial incentives and institutional support, including crop insurance and low-interest credit, will help farmers adapt to climate change. Sustainable land management, afforestation, and soil conservation efforts should be prioritized to mitigate extreme weather effects. By implementing these measures, India can strengthen the resilience of its tea industries, ensuring economic stability and long-term productivity in the face of climate change.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**References**

Aggarwal, P. K. (2003). Impact of climate change on Indian agriculture. *Journal of Plant Biology-New Delhi*, *30*(2), 189-198.

Anandacoomaraswamy, A., De Costa, W. A. J. M., Shyamalie, H. W., & Campbell, G. S. (2000). Factors controlling transpiration of mature field-grown tea and its relationship with yield. *Agricultural and Forest Meteorology*, *103*(4), 375-386.

Baruah, P., & Handique, G. (2021). Perception of climate change and adaptation strategies in tea plantations of Assam, India. *Environmental Monitoring and Assessment*, *193*(4), 165.

Carr, M. K. V. (1972). The climatic requirements of the tea plant: A review. *Experimental Agriculture*, *8*(1), 1-14.

Cheruiyot, E. K., Mumera, L. M., Ng'etich, W. K., Hassanali, A., & Wachira, F. N. (2008). Threshold soil water content for growth of tea [Camellia sinensis (L.) O. Kuntze]. Pp 29-38

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., ... & Whetton, P. (2007). Regional climate projections. Chapter 11.

Delbiso, T. D., Rodriguez-Llanes, J. M., Donneau, A. F., Speybroeck, N., & Guha-Sapir, D. (2017). Drought, conflict and children’s undernutrition in Ethiopia 2000–2013: a meta-analysis. *Bulletin of the World Health Organization*, *95*(2), 94.

De Costa, W. A., Mohotti, A. J., & Wijeratne, M. A. (2007). Ecophysiology of tea. *Brazilian Journal of Plant Physiology*, *19*, 299-332.

Economic Review (2021), Kerala State Planning Board, Thiruvananthapuram

FAO (Food And Agriculture Organization of The United Nations), 2016. Report of the Working Group on Climate Change of the FAO Intergovernmental Group on Tea. FAO, Rome, Italy.

Gaonkhowa, J. (2023). An analytical study on growth of tea industry in Assam. *International Journal for Multidisciplinary Research*, *5*(6), 1-9.

Hajiboland, R., & Bastani, S. (2012). Tolerance to water stress in boron-deficient tea (Camellia sinensis) plants. *Folia Horticulturae*, *24*(1), 41.

Jaetzold, R., & Schmidt, H. (1982). *Farm management handbook of Kenya*. Ministry of Agriculture.

Jayasinghe, S. L., Kumar, L., & Hasan, M. K. (2020). Relationship between environmental covariates and Ceylon tea cultivation in Sri Lanka. *Agronomy*, *10*(4), 476.

Krishna Kumar, Kanikicharla, Rupa K. Kumar, R. G. Ashrit, N. R. Deshpande, and James W. Hansen (2004). "Climate impacts on Indian agriculture." *International Journal of climatology* 24, no. 11: 1375-1393.

Kumar, K., & Parikh, J. (2001). Socio-economic impacts of climate change on Indian agriculture. *International Review for Environmental Strategies*, *2*(2).

Mohotti, A. J., & Lawlor, D. W. (2002). Diurnal variation of photosynthesis and photoinhibition in tea: effects of irradiance and nitrogen supply during growth in the field. *Journal of Experimental Botany*, *53*(367), 313-322.

Nepal, S., & Shrestha, A. B. (2015). Impact of climate change on the hydrological regime of the Indus, Ganges and Brahmaputra river basins: a review of the literature. *International Journal of Water Resources Development*, *31*(2), 201-218.

Ochieng, J., Kirimi, L., & Mathenge, M. (2016). Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. *NJAS-Wageningen journal of life sciences*, *77*, 71-78.

Pant, G. B., & Rupa Kumar, K. (1997). Climates of South Asia, John Wiley and Sons. *Chichester, 320p*.

Piyashee Mallik, Tuhin Ghosh. (2023)Sub-regional variation in atmospheric and land variables regulates tea yield in the Dooars region of West Bengal, India, *International Journal of Biometeorology 67 (10), 1591-1605,*

Rao, C. H., Ray, S. K., & Subbarao, K. (1988). *Unstable agriculture and droughts: implications for policy* (No. 47, pp. vii+-192pp).

Rao, G.S.L.H.V.P. 2009. Climate change and horticulture. In: Basics in Horticulture (Ed.) K.V.Peter. New India publishing company. New Delhi. pp 47-70

Sahu, Netrananda, Rajiv Nayan, Arpita Panda, Ayush Varun, Ravi Kesharwani, Pritiranjan Das, Anil Kumar, Suraj Kumar Mallick, Martand Mani Mishra, Atul Saini,( 2025). "Impact of Changes in Rainfall and Temperature on Production of Darjeeling Tea in India" *Atmosphere* 16, no. 1: 1.

Stephens W., Carr M.K.V., 1993. Responses of tea (*Camellia sinensis*) to irrigation and fertilizer. III. Shoot extension and development. Exp. Agric. 29: 323-339.

Sandanam S., Gee G.W., Mapa R.B., (1981). Leaf water diffusion resistance in clonal tea (*Camellia sinensis L.*): Effects of water stress, leaf age and clones. Ann. Bot. 47: 339-349.

Sivakumar, S., Saravana, N., Velmurugan, G., & Subashini, R. (2018). Performance of tea industries in South India–a comparative analysis. *International Journal of Pure and Applied Mathematics*, 119, 3549-3568.

Tandane, H., & Kaur, M. (2020). Growth and instability in area, production and yield of tea in India. *Journal of Agricultural Development and Policy*, *30*(1), 56-62.

Warrick, R. A., & Ahmad, Q. K. (2012). The implications of climate and sea-level change for Bangladesh Libro electrónico.

Wijeratne M.A., Fordham R., 1996. Effects of environmental factors on growth and yield of tea (*Camellia sinensis L*.) in the low-country wet zone of Sri Lanka. Sri Lanka J. Tea Sci. 64: 21-34.

Wijeratne, M. A., Anandacoomaraswamy, A., Amarathunga, M. K. S. L. D., Ratnasiri, J., Basnayake, B. R. S. B., & Kalra, N. (2007). Assessment of impact of climate change on productivity of tea (*Camellia sinensis L*.) plantations in Sri Lanka. *Journal of the National Science Foundation of Sri Lanka*, *35*(2).