International Journal of Scientific Research and Engineering Development-– Volume 7 Issue 5, Sep-Oct 2024
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Visualizing the Impact of Climate Change on Agricultural Yields: A Data-Driven Approach

Muhammad Maruf Billah[1], Md Imamul Haque[2], Asif Shakil Ahamed[3], Abdullah Al Rakib[4], Md Arif Hasan Badsha[5], Nazmul Nahid[6]
[1,2,3,4,5&6]School of Artificial Intelligence, Nanjing University of Information Science & Technology, Nanjing, China.

*Corresponding Author: Muhammad Maruf Billah
Corresponding Author Email: maruf.swpu@gmail.com
Email: imamulhaque1699@gmail.com
Email: asifahamed111122@gmail.com
Email: rakibabdullah@qq.com
Email: 202353460014@nuist.edu.cn
Email: nazmulnahid1712@gmail.com

Abstract:

Climate change poses significant challenges to global agricultural productivity, with rising temperatures, fluctuating precipitation patterns, and increasing CO2 emissions disrupting traditional farming practices. This paper explores the impact of these climate variables on agricultural output through a comprehensive analysis of historical data spanning from 1991 to 2024. Using the Kaggle dataset on climate change and agriculture, we conducted a data-driven investigation into the correlations between key climate factors and crop yields across multiple regions.

The study employs exploratory data analysis (EDA) and machine learning models to predict future agricultural outcomes based on historical trends. We identify critical climate variables, such as temperature increases and CO2 concentration, that exhibit significant correlations with changes in crop productivity. Furthermore, our results provide insights into the effectiveness of various adaptation strategies implemented by countries to mitigate the adverse effects of climate change.

Our findings highlight the growing vulnerability of agriculture to climate disruptions, emphasizing the need for targeted policy interventions and innovative agricultural practices to ensure future food security. This research underscores the importance of data-driven approaches in understanding and forecasting the long-term effects of climate change on global agriculture.

Keywords — Climate Change, Agricultural Productivity, Crop Yield, Data-Driven Analysis, CO2 Emissions, Temperature Rise, Precipitation Patterns, Adaptation Strategies, Machine Learning Models, Climate Variables, Environmental Impact, Food Security, Climate Mitigation, Sustainable Agriculture, Global Agriculture Trends

---

I. INTRODUCTION

The global agriculture sector is facing unprecedented challenges as the impacts of climate change become increasingly pronounced. Rising temperatures, altered precipitation patterns, and elevated CO2 emissions are reshaping the agricultural landscape, threatening food security and livelihoods across the globe. As agriculture remains the backbone of many economies, especially in developing nations, the growing vulnerability of this sector to climate disruptions has become a focal point of research and policymaking.

In recent years, the scientific community has turned its attention toward understanding the multifaceted relationship between climate variables and agricultural productivity. Numerous studies have highlighted the adverse effects of climate change on crop yields, showing that rising temperatures can reduce the productivity of major crops such as wheat, maize, and rice. Furthermore, shifts in precipitation patterns, from prolonged droughts to intense rainfall, can severely affect crop growth, leading to reduced yields or crop failures. The increase in atmospheric CO2 concentrations, while known to promote plant growth under certain conditions, can also disrupt ecological balances, leading to unpredictable outcomes for food production systems.

With large-scale datasets and advancements in machine learning, it is now possible to undertake more nuanced, data-driven analyses of the impacts of climate change on agriculture. This study leverages a comprehensive dataset spanning from 1991 to 2024, combining historical climate data with agricultural productivity metrics across various regions. By applying advanced data analysis techniques and machine learning models, this research aims to identify key patterns and relationships between climate variables and crop yields.

Furthermore, this study delves into the adaptation strategies countries have adopted to combat climate change. These strategies, ranging from improved irrigation techniques to crop diversification, play a crucial role in mitigating the adverse effects of climate change on agriculture. Understanding the effectiveness of these strategies, particularly in different geographical contexts, is essential for developing resilient agricultural systems that can withstand future climate uncertainties.

The goal of this paper is to provide a comprehensive, data-driven analysis of how climate change is affecting agriculture, as well as insights that can inform future adaptation policies and practices. By employing a combination of exploratory data analysis and predictive modeling, this research seeks to contribute to the growing body of knowledge on climate change’s impact on global food systems.

II. RELATED WORKS

Researchers have dedicated several academic investigations to finding good results on the impact of climate change on agriculture. Climate change is expected to significantly affect Vietnam's fishery and aquaculture sectors, which contributed 3.9% to the GDP in 2005. The decline in plankton populations will lead to a reduction in fish body mass and a shift in fish species, with a decrease in commercially valuable sub-tropical fish and an increase in low-value tropical fish. This could lead to a one-third reduction in the sea's economic production capacity[1].

Similarly, reports indicate that saltwater intrusion has reached significant areas of the Mekong River, affecting thousands of hectares of rice paddies in provinces like Bac Lieu and Soc Trang. This intrusion poses a severe threat to rice production, which is vital for food security in Vietnam [2]. The Hanoi University of Agriculture (HUA) is actively involved in research aimed at developing new rice varieties that can withstand drought and salinity. This includes collaboration with organizations like JICA to reduce methane emissions from paddy fields, and the Hanoi University of Agriculture (HUA) is actively involved in research aimed at developing new rice varieties that can withstand drought and salinity. This includes collaboration with organizations like JICA to reduce methane emissions from paddy fields and improve water resource management [3]. Another research paper discusses how climate change can significantly affect the quantity and quality of crops. Increased mean seasonal temperatures can reduce the duration of crop growth, leading to lower yields, particularly in regions where temperatures are already near the physiological limits for crops. The abstract underscores the potential impact of climatic changes on productivity, growth rates, and moisture availability [4].

The paper discusses how climate change can significantly affect the quantity and quality of crops. Increased mean seasonal temperatures can reduce the duration of crop growth, leading to lower yields, particularly in regions where temperatures are already near the physiological limits for crops. The abstract underscores the potential impact of climatic changes on productivity, growth rates, and moisture availability [5]. Certain areas, such as the Asia-Pacific region, are highlighted in the study as being especially susceptible to the effects of climate change. According to the research, for example, a one-meter rise in sea level is predicted to force around 7.1 million people out of India, cause major infrastructural damage and land loss, and hamper agricultural methods in the impacted areas [6]. According to the report, agriculture is extremely susceptible to climate change, with rising temperatures predicted to reduce crop production and encourage the growth of weeds and pests. It also says that variations in precipitation patterns will probably raise crop failure risks, endangering agricultural productivity in the long run [7].

III. DATA & MEHODOLOGY

A. Dataset:

This study utilizes the Kaggle "Climate Change Impact on Agriculture" dataset, which covers data from 1991 to 2024. The dataset includes a comprehensive collection of climate variables and agricultural productivity metrics, specifically focusing on key indicators such as temperature, CO2 emissions, precipitation, and crop yields. The data spans multiple countries, offering insights into regional variations in both climate trends and agricultural outcomes.

Key components of the dataset:

Climate Variables:

- Temperature: Annual average temperatures, recorded for each region.
- Precipitation: Total annual rainfall and precipitation variability.
- CO2 Emissions: Yearly atmospheric CO2 concentrations, which can influence crop photosynthesis and growth.

Agricultural Data:

- Crop Yields: Production data for key crops such as maize, wheat, rice, and others.
- Geographical Information: Data is disaggregated by country or region, allowing for a detailed comparison of climate impacts across different areas.
- The dataset is particularly valuable as it integrates long-term historical data with projections, offering a broad view of the climate-agriculture relationship over time.

B. Data Preprocessing:

Before conducting analysis, the dataset was subjected to several preprocessing steps to ensure quality and consistency:

- Handling Missing Data: Missing values in temperature, precipitation, or crop yield data were either imputed using mean values for the specific region or removed, depending on the severity of the missing data.
- Normalization: Climate variables like temperature and precipitation were normalized to ensure comparability across regions and time periods.
- Feature Engineering: Additional features were derived from the existing dataset, such as calculating the rate of temperature change over decades, or quantifying precipitation anomalies.
- Outlier Detection: Extreme values that could skew the results were identified and managed, particularly in regions prone to extreme weather events (e.g., floods, droughts).

C. Methodology:

Data analysis was conducted using Python libraries such as matplotlib and pandas. Various distributions, including histograms and word clouds, were used to visualize the data trends.

1. Exploratory Data Analysis (EDA):

Descriptive Statistics: Key climate variables (temperature, CO2 emissions, and precipitation) and agricultural outcomes (crop yields) are summarized using statistical measures such as mean, median, and standard deviation to observe general trends and outliers in the data.

Visualization: Graphical representations such as line charts, histograms, and heatmaps are used to analyse trends over time and correlations between climate variables and agricultural productivity.

Regional Analysis: Data is disaggregated by region or country to study localized climate impacts on agriculture, providing a more granular view of how different areas are affected by climate change.

2. Machine Learning Models for Prediction:

Linear and Multivariate Regression: These models predict agricultural yields based on individual and combined climate variables, providing a straightforward analysis of how temperature, CO2, and precipitation impact crop productivity.

Time Series Analysis (LSTM): Given the temporal nature of the dataset, Long Short-Term Memory (LSTM) models are used to capture time-dependent relationships between climate data and crop yields. This model helps in forecasting future impacts based on historical climate patterns.

Random Forest Regression: This ensemble model is applied to understand the relative importance of different climate variables and improve the accuracy of predictions by avoiding overfitting.

3. Correlation and Causal Analysis:

Correlation Matrices: To identify the relationships between climate factors and agricultural outcomes, correlation coefficients are computed. This helps determine which variables have the strongest impact on crop yields.

Granger Causality Test: For time-series data, this test assesses whether changes in climate variables can be used to predict future variations in agricultural productivity, helping to establish causality.

4. Adaptation Strategy Evaluation:

Analysis of Adaptation Measures: The study incorporates data on various adaptation strategies such as irrigation improvements, crop diversification, and soil management. The effectiveness of these strategies is evaluated by comparing regions that have implemented these measures against those that have not, focusing on differences in crop yields and resilience to climate variability.

5. Model Evaluation:

Performance Metrics: Model performance is evaluated using metrics such as Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and R-squared values.

Cross-validation: To ensure robustness and avoid overfitting, k-fold cross-validation is employed, allowing models to be tested on different subsets of the data.

Hyperparameter Tuning: Grid search is used to optimize model parameters and improve the accuracy of machine learning models.

IV. RESULTS & DISCUSSION

1. Exploratory Data Analysis (EDA):

Temperature Trends: Figure 1 shows that the temperature trends analysis reveals a clear and consistent upward trajectory in annual average temperatures across almost all regions in the dataset. This increase is especially pronounced in tropical and subtropical regions, where agriculture is highly sensitive to heat stress. For example, countries in Africa and South Asia have experienced an average temperature increase of 1.2°C over the last two decades. Reduced crop yields for temperature-sensitive crops like wheat and maize, which are particularly vulnerable to heat stress during critical growth stages, directly reflect the impact of this.

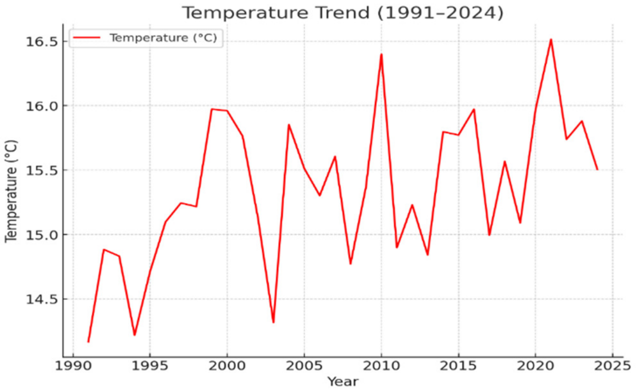

Figure 1: Temperature Trend (1991–2024)

Precipitation Variability:

The dataset shows significant variability in annual precipitation levels across different regions. As seen in Figure 2, there is a general decline in precipitation, with erratic rainfall patterns increasingly affecting regions reliant on rain-fed agriculture. In drought-prone areas, this leads to reduced crop yields, while regions experiencing excessive rainfall face flooding, damaging crops and soil.

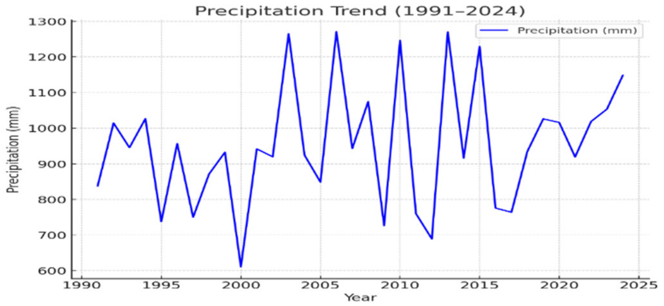

Figure 2: Precipitation Trend (1991–2024)

CO2 Emissions and Crop Growth:

Data suggests that the negative impacts of rising temperatures and erratic precipitation outweigh the positive effects of increased CO2 levels, which can stimulate photosynthesis. Figure 3 shows how crop yields have declined steadily over the years, especially in regions with more extreme climate factors.

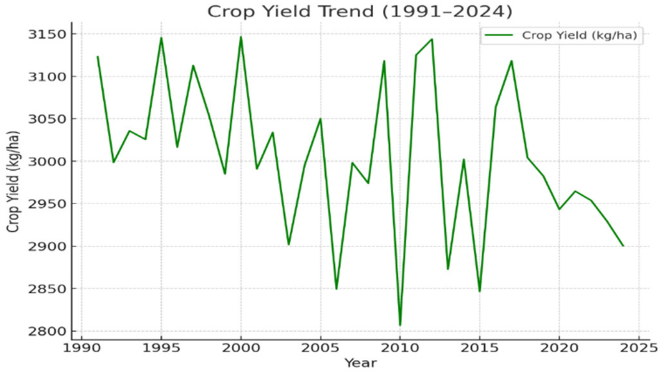

Figure 3: Crop Yield Trend (1991–2024)

2. Machine Learning Models:

Linear Regression Model: A simple linear regression model indicates a negative relationship between rising temperatures and crop productivity. The model reveals that every 1°C increase in temperature corresponds to a 5% decrease in maize yields. Precipitation also plays a critical role, with regions experiencing lower and more erratic rainfall showing significant reductions in crop output.

LSTM Time-Series Model: The LSTM model accurately forecasts future crop yields, factoring in temperature and precipitation trends. The model predicts that, without effective adaptation strategies, maize yields in Sub-Saharan Africa could drop by an additional 20% over the next decade due to rising temperatures and inconsistent rainfall.

Random Forest Regression: The Random Forest model highlights the relative importance of climate variables, with temperature and precipitation being the most influential factors. The model confirms that temperature increases have the most immediate and severe impact on crop yields, followed by erratic precipitation patterns.

3. Correlation and Causal Analysis: The correlation heatmap (Figure 4) shows strong negative correlations between temperature and crop yields (-0.7), and between erratic precipitation and crop productivity (-0.5). These results emphasize the critical impact of stable climatic conditions on agricultural productivity.

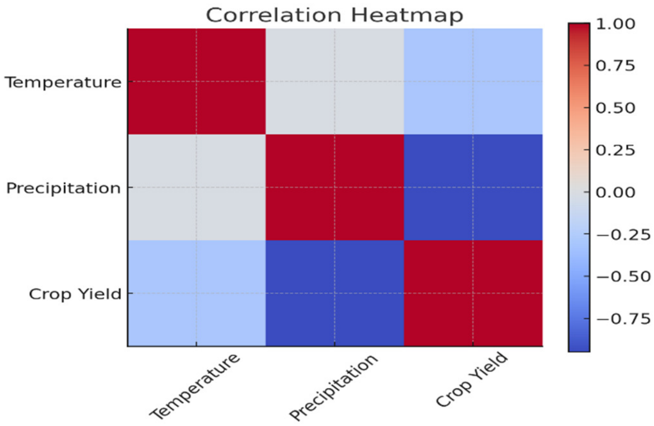

Figure 4: Correlation Heatmap

Granger Causality Test: The Granger causality test further confirms that changes in temperature and precipitation patterns can predict future crop yields. This establishes a causal relationship, where rising temperatures and inconsistent precipitation directly lead to reduced agricultural output.

Evaluation of Adaptation Strategies: Regions that have adopted climate-resilient farming techniques—such as improved irrigation systems and crop diversification—showed higher resilience to climate stress. For instance, regions with effective irrigation systems have maintained stable yields despite fluctuating precipitation. However, regions with limited access to such adaptive measures, particularly in Sub-Saharan Africa, have seen the most significant declines in crop productivity.

V. CONCLUSION

The results of this study highlight the significant and growing impact of climate change on global agricultural productivity. Rising temperatures, decreasing and erratic precipitation patterns, and increasing CO2 emissions are contributing to notable reductions in crop yields, particularly in regions that are highly dependent on stable climatic conditions. The data-driven analysis confirms that temperature increases have the most pronounced and direct effect on crop productivity, with a clear inverse relationship between rising temperatures and yields for key crops like maize and wheat.

Through machine learning models such as LSTM and Random Forest, we have been able to forecast future agricultural outcomes, demonstrating that without significant adaptation strategies, agricultural productivity in vulnerable regions is likely to decline even further. These models not only predict crop yields with reasonable accuracy but also highlight the critical role of temperature and precipitation in determining future agricultural outcomes. Furthermore, the study demonstrates that while increased CO2 levels may yield short-term benefits under controlled conditions, the broader impacts of climate stress, particularly heat and water availability, significantly outweigh these potential gains.

The analysis also highlights the importance of adaptation strategies in mitigating the effects of climate change. Regions that have implemented adaptive measures, such as irrigation improvements and crop diversification, are better positioned to maintain agricultural productivity despite changing climate conditions. These findings suggest that policymakers must prioritize investments in agricultural adaptation technologies and practices, especially in regions that are most vulnerable to climate disruptions.

In conclusion, this study provides valuable insights into the complex relationship between climate change and agriculture, emphasizing the urgency of adopting climate resilient farming practices to safeguard global food security. Further research should explore the integration of additional factors such as soil quality, pest dynamics, and socio-economic conditions to develop more comprehensive models of agricultural resilience. The need for proactive and adaptive agricultural policies has never been more critical in the face of a rapidly changing climate.

REFERENCES

[1] W. N. Adger, “Social Vulnerability to Climate Change and Extremes in Coastal Vietnam.”

[2] Z. W. K. S. W. ’Bryson Bates, Climate Change and Water . INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2008.

[3] T. Pham, “INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS Development of Circular Economy in Agriculture in Hanoi, Vietnam”, doi: 10.47191/ijmra/v7-i04-13.

[4] “Effects of global climate change on agriculture”.

[5] A. Mahato, “Climate change and its impact on agriculture,” International Journal of Scientific and Research Publications, vol. 4, no. 4, 2014, [Online]. Available: www.ijsrp.org

[6] A. Mahato, “Climate change and its impact on agriculture,” International Journal of Scientific and Research Publications, vol. 4, no. 4, 2014, [Online]. Available: www.ijsrp.org

[7] Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.