Journal of Agribusiness and Social Sciences (JASS)
ISSN: 3135-9604

https://journals.ageconfrontiers.com/jass

Climate-induced risks to chili production: evidence from Sindh, Pakistan

Fayyaz Hussain Ghanghro [a], Imam Uddin Palal [b, *], Naeeem Qadir [a]
[a] *Department of Statistics, Sindh Agriculture University Tandojam, Pakistan.*
[b] *Department of Agricultural Economics, Sindh Agriculture University Tandojam, Pakistan*

A R T I C L E I N F O

Article History:
Received 19 March 2026
Accepted 02 June 2026
Available online 30 June 2026

Keywords:
Chili Production
Climate Variability
Rainfall Impact
Temperature Trends

A B S T R A C T

This study examines the impact of climate variability on chili production in Sindh, Pakistan, using annual data from 1990 to 2024. Descriptive statistics revealed that average chili production was 104,000 tons, with yields averaging 2.09 kg/hectare. While mean annual temperature remained relatively stable at 27.5°C, rainfall was highly variable, ranging from 26 mm to 951 mm annually. Correlation analysis indicated a moderate positive relationship between yield and production ($r = 0.47$), whereas rainfall was negatively correlated with production ($r = -0.30$). Multiple regression results showed that rainfall had a negative coefficient ($\beta = -0.048$, $p = 0.102$), suggesting that excessive rainfall reduces chili output, though the effect was only marginally significant. Temperature displayed a positive but statistically insignificant association ($\beta = 5.90$, $p = 0.659$). The model explained only 9.6% of the variance in production ($R^2 = 0.096$), highlighting weak predictive power. Diagnostic tests confirmed normality of residuals but suggested potential multi-collinearity. The findings underscore that rainfall variability plays a more critical role than temperature in influencing chili productivity. However, the low explanatory power indicates that other factors such as irrigation, soil fertility, and farm management practices also contribute significantly. The study emphasizes the need for climate-resilient agricultural strategies and recommends incorporating additional agronomic and socio-economic variables in future research to strengthen predictive models.

Introduction

Sindh province experiences semi-arid to arid climatic conditions, where rainfall is irregular and concentrated within short monsoon periods. This often leads to waterlogging, pest outbreaks, and drought stress, which directly affect chili production. (Lohano & Mari, 2020). Previous studies have identified climate variability as a major determinant of agricultural productivity in Pakistan, with chili production being particularly vulnerable due to its sensitivity to rainfall extremes. (Rais et al., 2023)(Sheikh et al., 2019). **Chili: (Capsicum annuum L.)** is an economically important crop in Pakistan as well as globally. In Pakistan, Sindh province is the leading producer of chili, followed by Punjab and Baluchistan, and the crop plays a significant role both as a food item and as a key spice in local cuisine. Despite its importance, chili production in Pakistan has experienced a declining trend over time. While biological factors such as pests and diseases and quality issues such as aflatoxin contamination have contributed to this decline, increasing attention is being given to the role of climatic variability. Fluctuations in rainfall and temperature can create unfavorable growing conditions, leading to reduced productivity and instability in output. In this context, understanding the impact of climatic factors on chili production is essential for developing effective strategies to improve yield, stabilize production, and enhance export potential (Arin, 2019)

Efficiency analyses conducted in Punjab and Sindh further confirm that chili farming faces both climatic and economic constraints, where rainfall variability and farm management practices jointly influence yield outcomes. (Bashir et al., 2022)(Khaskheli et al., 2024). International evidence also reinforces this vulnerability: studies in Indonesia and India show that excessive rainfall and droughts reduce chili productivity and farmer income (Saidah et al., 2020); (Widowati et al., 2023)(Bhutia et al., 2018).

* Corresponding author. *E-mail address:* imamrazaimamraza7@gmail.com (Imam Uddin Palal)

Temperature

The agricultural sector is highly vulnerable to climate variability due to its strong dependence on temperature patterns and water availability. In Pakistan, where a significant proportion of land is under cultivation and most water resources are utilized for agriculture, changes in climate pose serious risks to crop productivity. Recent evidence indicates a noticeable increase in temperature and variability in rainfall across key agro-climatic regions, including Sindh. Rising temperatures and shifting precipitation patterns can alter crop growth cycles, increase irrigation demand, and intensify risks such as drought stress, waterlogging, and soil degradation (Qureshi et al., 2023)

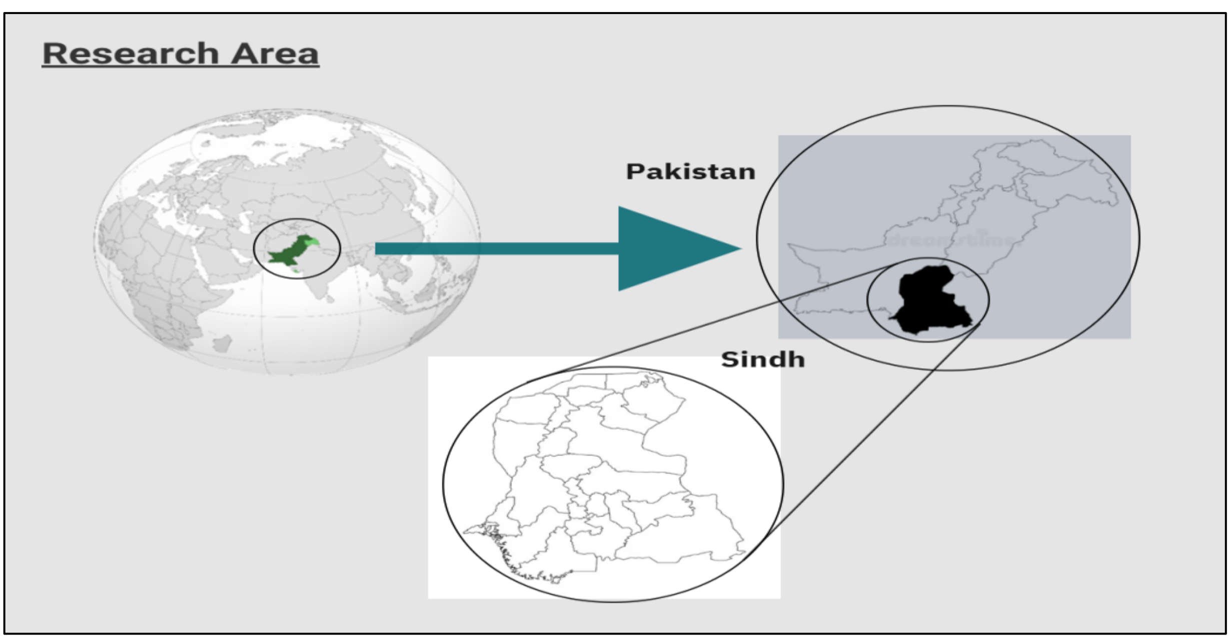
In Sindh, these climatic changes are particularly important for crop production, as fluctuations in rainfall and temperature can directly affect yield stability. Increased rainfall may reduce water scarcity but can also lead to flooding and waterlogging, while higher temperatures may accelerate crop stress and reduce productivity. These evolving climate conditions highlight the need to examine how such variations influence specific crops, particularly climate-sensitive horticultural crops like chili. Understanding these dynamics is essential for developing effective adaptation strategies to ensure sustainable agricultural production and food security. Genetic and agronomic studies highlight that yield-related traits in chili are strongly influenced by climatic stress factors (Arain & Sial, 2022)(Sri (Chili (Capsicum annuum L.) is an economically important crop in Pakistan as well as globally. In Pakistan)nivas et al., 2020) Broader climate–agriculture literature suggests that rainfall variability generally has a stronger impact on horticultural crops compared to temperature fluctuations (Blanc & Reilly, 2017) (Fischer et al., 2005) Against this backdrop, the present study addresses an important research gap by quantitatively analyzing the effects of rainfall and temperature on chili production in Sindh using annual data from 1990 to 2024.

Objectives

i. To analyze the descriptive trends of chili production, yield, temperature, and rainfall in Sindh (1990–2024).
ii. To examine the correlation between chili production and climatic variables.
iii. To estimate the impact of annual mean temperature and rainfall on chili production using multiple regression analysis.

Methodology

Figure 1 *Map highlighting Sindh province in Pakistan, the study area.*



Study Area

The current study was conducted in Sindh province, Pakistan, which is lies between 26°21′N latitude and 68°51′E longitude, and is the third largest province of Pakistan, covering an area of approximately 140914 km², with Population of approximately 55.69 million. Sindh is situated at elevation of 173m from sea level and is characterized by a semi-arid to arid climate. The province is bounded by Balochistan to the west, Punjab to the north, India to the east and Arabian sea to the south as shown in Figure 1.

Data Source and Coverage

This study uses annual time-series data for Sindh province (1990–2024), comprising 35 observations of chili production (000 tons), yield (kg/hectare), mean temperature (°C), and average rainfall (mm/year). Production & Yield: Sourced from the Agricultural Marketing Information Service (AMIS), Government of Pakistan, which provides standardized provincial crop statistics. Temperature & Rainfall: Extracted from the NASA POWER database via the Data Access Viewer, using Sindh's geographic coordinates. Values were aggregated to annual averages to align with production and yield data.

Analytical Approach

The analysis was conducted in three stages: Descriptive Statistics were used to summarize the central tendency and variability of production, yield, temperature, and rainfall (Table 1). Correlation Analysis was applied to examine the linear relationships among the variables (Table 2). Multiple Linear Regression was employed to estimate the effect of annual mean temperature and rainfall on chili production (Tables 2 and 3).
The regression model is specified as:

$$Production_t = \beta_0 + \beta_1(Temperature_t) + \beta_2(Rainfall_t) + \epsilon_t \qquad (1)$$

In Eq.1, Production_t: Chili production in year t, Temperature_t: Annual mean temperature in year t, Rainfall_t: Annual average rainfall in year t, ϵ_t: Error term representing unexplained variation.

Table 1: Descriptive Statistics

Variable	Count	Mean	Std. D	Min	25%	50%	75%	Max
Production (000 Tons)	35	104.18	32.24	37.70	82.07	108.58	124.05	172.80
Yield (kg/hectare)	35	2.09	0.51	0.98	1.68	2.12	2.40	3.03
Annual Mean Temperature (°C)	35	27.56	0.42	26.61	27.27	27.56	27.86	28.34
Annual Average Rainfall (mm/year)	35	219.54	191.17	26.55	88.62	167.09	339.87	951.63

Table 1 shows the descriptive statistics of chili production and climate variables in Sindh from 1990 to 2024. Average chili production was 104,000 tons, with yields averaging 2.09 kg/hectare. Production ranged from a minimum of 37.7 thousand tons to a maximum of 172.8 thousand tons, reflecting considerable variability across years. Mean annual temperature remained relatively stable at approximately 27.5°C, whereas rainfall exhibited extreme fluctuations, ranging from 26 mm to 951 mm annually. These results highlight that rainfall variability was far more pronounced compared to temperature changes, making rainfall the more volatile climatic factor influencing chili production in Sindh.

Figure 2 Annual Chili Production in Sindh (1990–2024)

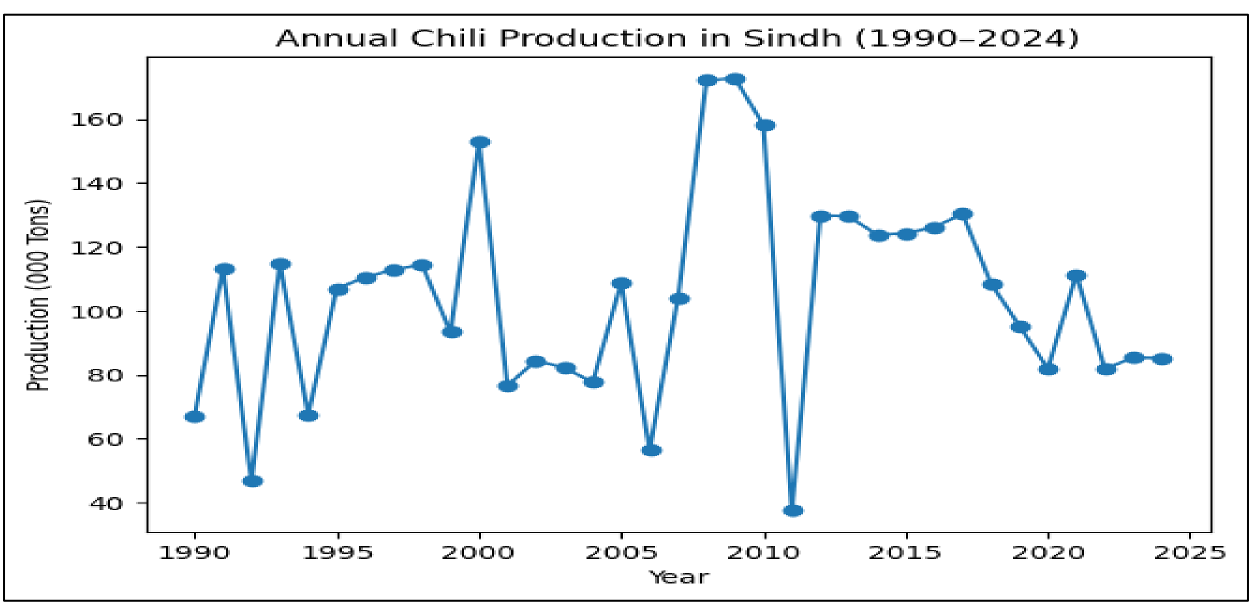


Fig.2 reflects the production fluctuated between 40,000 and 180,000 tons, with peaks around 2000, 2008, and 2012, and declines in 1992, 2006, and 2010. Overall, the figure highlights high variability in chili output, largely driven by climatic factors.

Figure 3 Annual Chili Yield in Sindh (1990–2024)

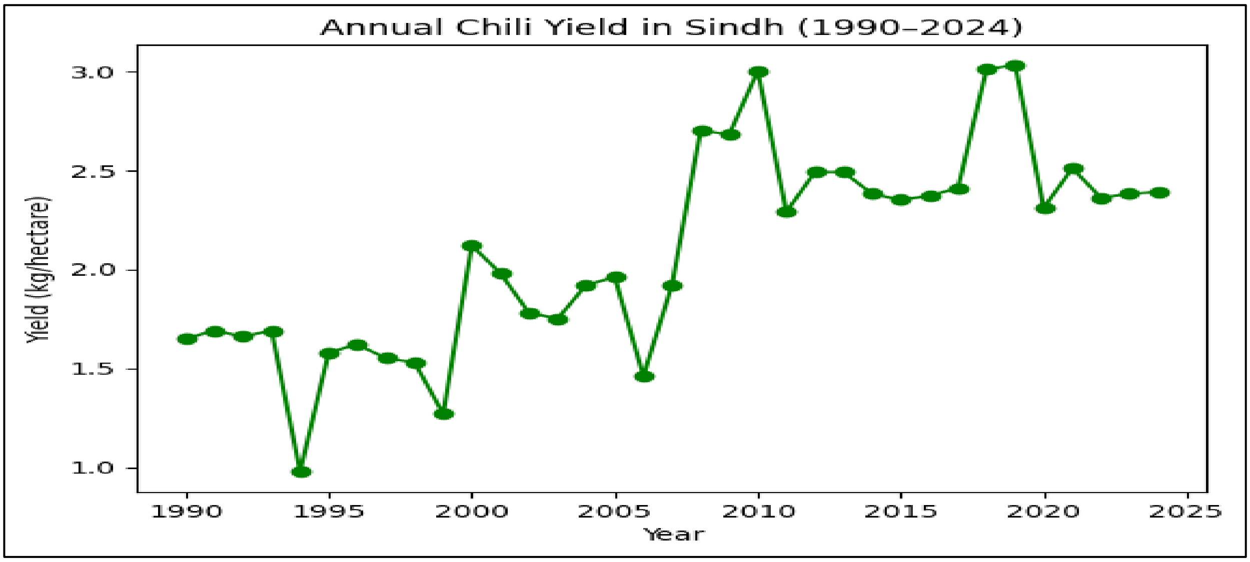


Figure 3 shows the yields fluctuated between ~1.0 and 3.0 kg/hectare, with peaks around 2009 and 2019, and dip near 1994 and 2006. Overall, the figure highlights variability in productivity, reflecting climatic and agronomic influences.

Figure 4 Annual Mean Temperature in Sindh (1990–2024)

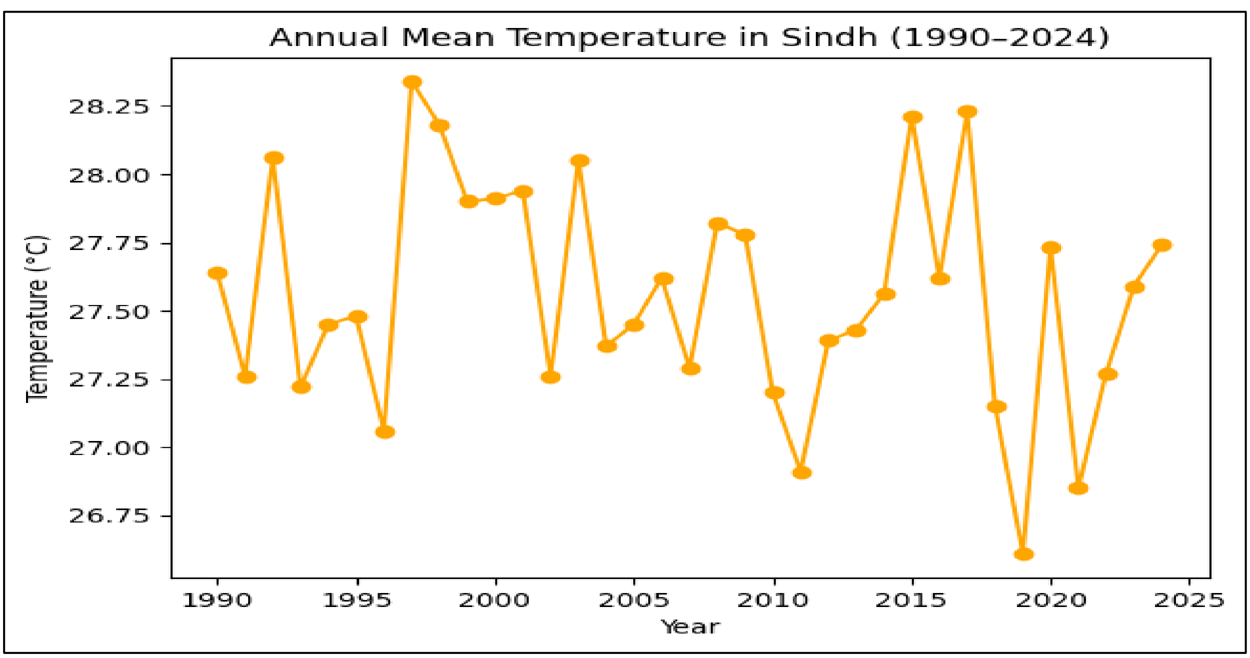
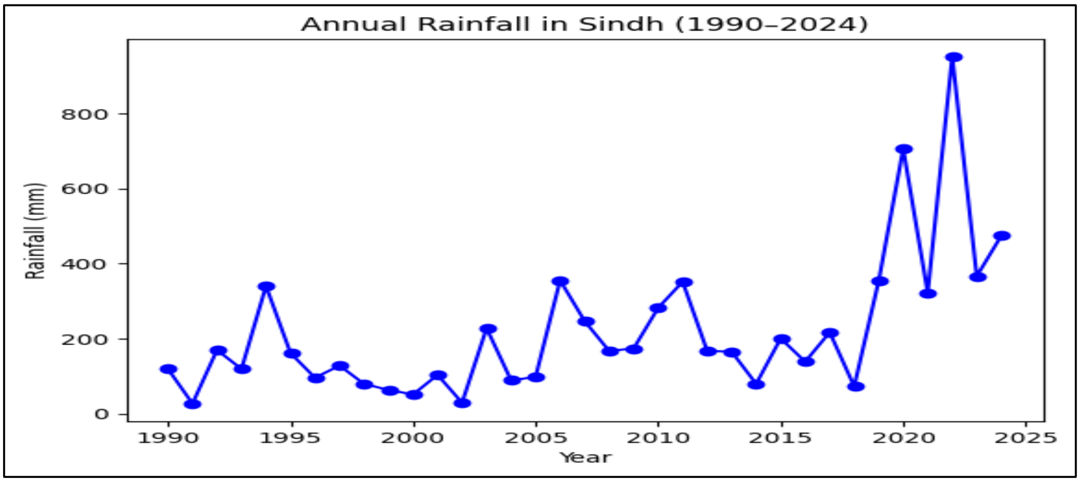


Fig. 4 Temperatures remained relatively stable around 27–28°C, with peaks near 1998, 2002, and 2016, and dips around 1996, 2011, and 2019. Overall, the figure indicates moderate fluctuations compared to rainfall, suggesting temperature is a less volatile climatic factor. While, Fig.5; Rainfall remained relatively low and stable until 2018, followed by sharp increases after 2019, peaking around 2022, and staying higher through 2024. Overall, the figure highlights extreme variability, making rainfall the most volatile climatic factor compared to temperature.

Figure 5 Annual Rainfall in Sindh (1990–2024)



Results

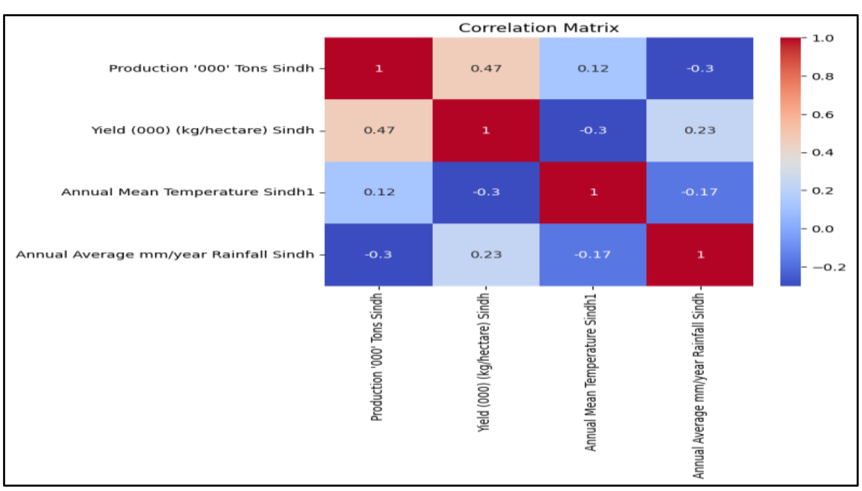
Correlation matrix

Table 2 presents the correlation matrix and the results indicate that production was moderately and positively correlated with yield ($r = 0.466$), indicating that higher yields generally contributed to increased output. Rainfall showed a negative correlation with production ($r = -0.300$), suggesting that excessive rainfall may reduce chili output. Temperature exhibited a weak positive correlation with production ($r = 0.125$), while its relationship with yield was negative ($r = -0.296$). Overall, the results highlight that yield is the strongest positive driver of production, whereas rainfall variability exerts a negative influence, and temperature plays only a minor role.

Table 2: Correlation matrix

Variable	Production	Yield	Temperature	Rainfall
Production (000 Tons)	1.000	0.466	0.125	-0.300
Yield (kg/hectare)	0.466	1.000	-0.296	0.234
Annual Mean Temperature (°C)	0.125	-0.296	1.000	-0.169
Annual Average Rainfall (mm/year)	-0.300	0.234	-0.169	1.000

Figure 6 Correlation Heatmap



Heatmap of correlation matrix shows correlation among chili production, yield, temperature, and rainfall in Sindh. Production is positively linked with yield (~0.47), while rainfall has a negative effect (~-0.30). Temperature shows weak correlations overall.

Figure 7 Correlation Line graph

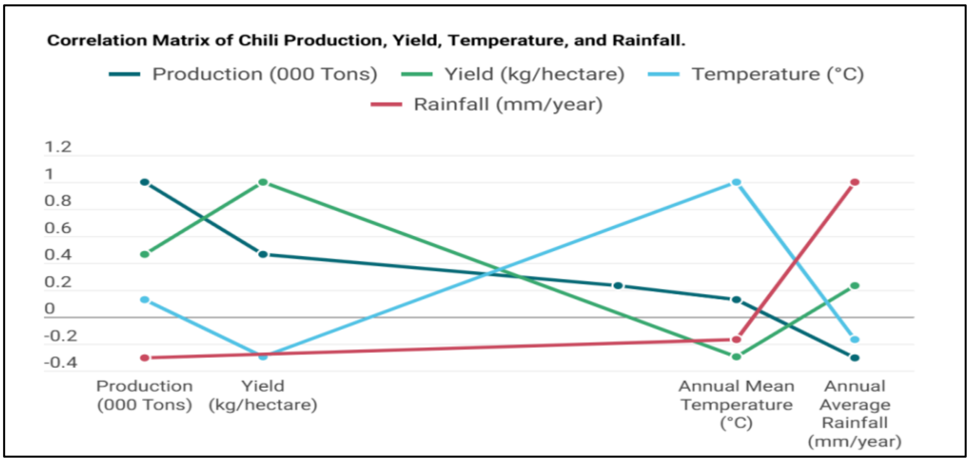


Fig.7 is showing positive association between production and yield (~0.47) and negative correlation between rainfall and production (~–0.30).

Diagnostic test results

Table 3: Regression Analysis

Variable	Coefficient (β)	Std. Error	t-Statistic	p-Value	95% CI (Lower–Upper)
Constant (Intercept)	-47.876	365.930	-0.131	0.897	-793.252 – 697.500
Annual Mean Temperature (°C)	5.903	13.236	0.446	0.659	-21.058 – 32.864
Annual Average Rainfall (mm/year)	-0.048	0.029	-1.682	0.102	-0.107 – 0.010

Table 3 reports the regression coefficients of the multiple linear regression model. Rainfall had a negative coefficient ($\beta = -0.048, p = 0.102$), indicating that higher rainfall levels tend to reduce chili production, though the effect was only marginally significant. Temperature showed a positive coefficient ($\beta = 5.903, p = 0.659$), but the relationship was statistically insignificant. The intercept was also non-significant. Overall, the results suggest that rainfall variability exerts a modest negative influence on chili output, while temperature has little explanatory power in the model.

Figure 8 Residuals Approximately Normal

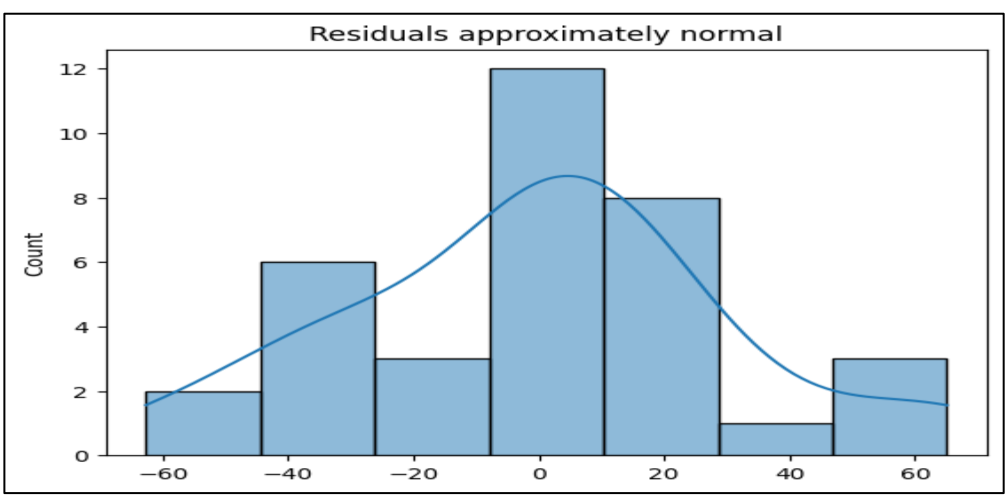
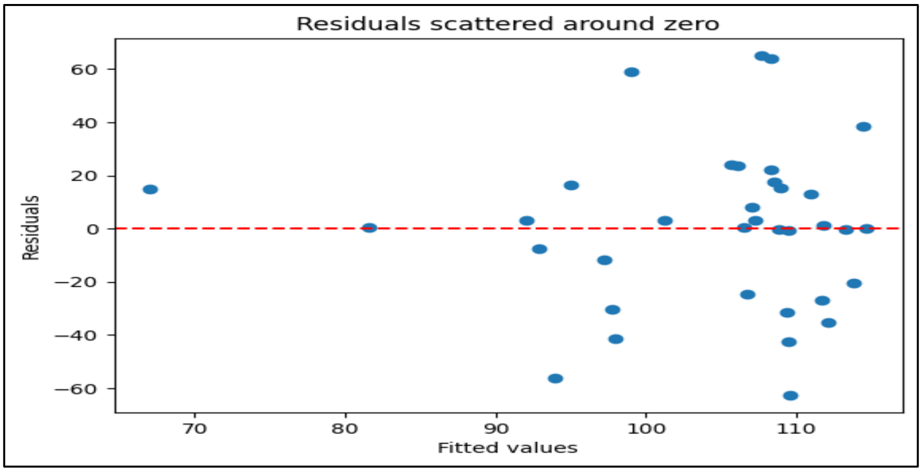


Fig. 8 Shows the distribution of model residuals with a fitted density curve. Residuals are centered near zero and follow an approximately normal pattern, supporting the assumption of normality in the regression model. While, the Fig. 9 Shows residuals plotted against fitted values. Residuals are scattered randomly around the zero line without a clear pattern, indicating no major issues of heteroscedasticity or model misspecification.

Figure 9 Residuals Scattered Around Zero (Residual vs Fitted Plot)



Model Summary and Diagnostics

Table 4 model performance was evaluated using R^2, adjusted R^2, the F-statistic, and associated p-values to assess overall fit and explanatory power. Residual diagnostics included the Durbin–Watson statistic to detect autocorrelation, the Jarque–Bera test for normality, and skewness/kurtosis measures to evaluate distributional properties. Importantly, the condition number (1.99×10^4) was examined to detect potential multi-collinearity. The condition number of this magnitude suggests collinearity risk, possibly due to overlapping effects of climatic variables such as rainfall and temperature. While not invalidating the model, it indicates that predictor variables may share variance, which can weaken the stability and reliability of coefficient estimates. All statistical analysis was conducted using Python's stats-models package, ensuring reproducibility and transparency of results.

Table 4: Model Summary and Diagnostics

Statistic	Value
R-squared	0.096
Adjusted R-squared	0.039
F-statistic	1.690
Prob (F-statistic)	0.201
No. of Observations	35
Df Residuals	32
Df Model	2
Log-Likelihood	-168.96
AIC	343.9
BIC	348.6
Durbin-Watson	1.648
Omnibus Test p-val	0.844
Jarque-Bera (JB) p-val	0.941
Skew	0.143
Kurtosis	2.961
Condition Number	1.99e+04

Discussion

The results of this study highlight that rainfall variability plays a more critical role than temperature in influencing chili productivity in Sindh. Descriptive statistics revealed extreme fluctuations in rainfall (26–951 mm), while temperature remained relatively stable, consistent with earlier findings that rainfall is the dominant climatic driver of chili yield outcomes (Rais et al., 2023; Singh & Kumar, 2025) In particular, the sharp rise in rainfall after 2019, peaking in 2022, coincided with heightened variability in chili production, underscoring rainfall's destabilizing effect. Similar patterns have been reported in Indonesia and India, where rainfall extremes significantly reduced chili output and farmer profitability (Mesang et al., 2025; Saidah et al., 2020). Correlation analysis confirmed a moderate positive relationship between yield and production, while rainfall was negatively correlated with output, aligning with efficiency studies in Punjab and Sindh that identified rainfall shocks as a key constraint on chili farming (Bashir et al., 2022; Channa et al., 2020) Regression results further emphasized rainfall's modest but negative impact, while temperature effects remained statistically insignificant, echoing international evidence that temperature fluctuations exert weaker influence compared to rainfall extremes (Barchenger et al., 2020; Bhutia et al., 2018).

Diagnostic tests confirmed residual normality and no major autocorrelation, supporting model reliability. However, the high conditioning number suggests potential multicollinearity, possibly arising from overlapping climatic influences. This finding resonates with broader climate–agriculture assessments that emphasize the complex interactions between rainfall, temperature, and crop yields (Blanc & Reilly, 2017; Verma et al., 2025) Overall, the weak explanatory power of the regression model ($R^2 = 0.096$) indicates that non-climatic factors such as irrigation, soil fertility, seed quality, and farm management practices also play a significant role in determining chili productivity (Khan et al., 2017; Mangan & Ruthbah, 2018) The low R^2 value (0.096) suggests that climate variables alone are insufficient to explain variations in chili production, highlighting the importance of omitted agronomic and socio-economic factors.

Policy recommendations

The findings underscore the need for climate-resilient agricultural strategies in Sindh. Farmers should adopt improved irrigation systems to mitigate rainfall variability, while policymakers should invest in soil management and pest control programs. Extension services can play a vital role in disseminating knowledge about adaptive practices, such as drought-resistant chili varieties and efficient water use technologies.

Research Implications

Future studies should incorporate additional variables such as irrigation coverage, fertilizer use, and socio-economic factors to strengthen predictive models. (Singh & Kumar, 2025)suggest that integrating genetic improvements with agronomic practices can enhance chili resilience under climate stress. A panel data approach across districts may also provide deeper insights into spatial variability in chili production.

Conclusion

This study assessed the impact of climate variability on chili production in Sindh using annual data from 1990 to 2024. The findings suggest that rainfall variability has a greater influence on production than temperature; however, the statistical evidence remains limited. The low explanatory power of the model indicates that additional factors—such as irrigation, soil fertility, seed quality, and farm management practices—play a significant role in determining chili productivity. The low R^2 value (0.096) further indicates that climate variables alone explain only a small portion of the variation in chili production, highlighting the importance of omitted agronomic and socio-economic factors. Overall, the results highlight the importance of adopting climate-resilient agricultural strategies and improving farm-level practices to sustain chili production under changing environmental conditions.

Key Recommendations

1. **Climate-Resilient Practices:** Farmers should adopt improved irrigation systems, soil management, and pest control measures to mitigate rainfall variability.
2. **Adaptive Varieties:** Development and dissemination of drought-resistant and climate-tolerant chili varieties can enhance resilience.
3. **Policy Support:** Policymakers should invest in extension services to train farmers in adaptive strategies and efficient water use technologies.
4. **Future Research:** Incorporating additional variables such as irrigation coverage, fertilizer use, and socio-economic factors will strengthen predictive models. Panel data across districts can provide deeper insights into spatial variability.

Limitations. The analysis is based on a limited set of climatic variables and annual aggregated data, which may not fully capture short-term variations and localized effects. Additionally, the exclusion of key agronomic and socio-economic variables may have contributed to the model's low explanatory power. Future research should incorporate a broader set of variables and use more disaggregated or panel data to improve the robustness and predictive accuracy of the results.

References

Arin, S. (2019). Scenario of chilli production and hindrances faced by the growers of Sindh province of Pakistan. Modern Concepts and Developments in Agronomy, 4(3), 436-442.

Arain, S. M., & Sial, M. A. (2022). Association analysis of fruit yield and other related attributes in four chilli (Capsicum annum L.) genotypes grown in Sindh Province, Pakistan. Pak. J. Bot, 54(3), 817–822.

Barchenger, D. W., Thandar, K., Myint, T. G., Hung, T. N., Hung, N. Q., Lin, S., Wang, Y., & Lin, T. (2020). Yield and yield component performance of chile pepper in Myanmar and Vietnam. HortTechnology, 30(3), 463–467.

Bashir, M. K., Ali, A., Farrukh, M. U., Alam, M., & Javed, A. (2022). Efficiency analysis of chilies production in district Sheikhupura, Punjab Pakistan. Custos E@ Gronegócio, 18(3), 15–33.

Bhutia, K., Khanna, V., Meetei, T., & Bhutia, N. (2018). Effects of climate change on growth and development of chilli. Agrotechnology, 7(2), 1–4.

Blanc, E., & Reilly, J. (2017). Approaches to assessing climate change impacts on agriculture: an overview of the debate. Review of Environmental Economics and Policy, 11(2), 247–257.

Channa, M. H., Sial, M., Dahri, G. N., Jamro, A. S., Solangi, T., Nasir, A., & Aamir, A. (2020). Measuring profitability of chilli pepper production in Sindh, Pakistan. Journal of Economics and Sustainable Development, 11(8), 81–89.

Fischer, G., Shah, M., N. Tubiello, F., & Van Velhuizen, H. (2005). Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. Philosophical Transactions of the Royal Society B: Biological Sciences, 360(1463), 2067–2083.

Khan, M. T. I., Qamar Ali, Q. A., Muhammad Ashfaq, M. A., & Muhammad Waseem, M. W. (2017). Economic analysis of open field chilli (Capsicum annuum L.) production in Punjab, Pakistan.

Khaskheli, A. S., Lashari, S. H., Subhpoto, M. H., Khoso, I. A., Khoso, M. A., Arain, A. H., Hayat, M. N., & Bhatti, N. A. (2024). Economic Evaluation of Red Chilli Farming in District Mirpurkhas, Sindh, Pakistan. Global Research Journal of Natural Science and Technology, 2(1).

Lohano, H. Das, & Mari, F. M. (2020). Climate Change and Implications for Agriculture Sector in Sindh Province of Pakistan. Mehran University Research Journal of Engineering and Technology, 39(3), 668–677.

Mangan, T., & Ruthbah, U. (2018). Preliminary report on the growers' and marketing channel surveys (chilli) in Sindh. Policy and Institutional Reforms to Improve Horticultural Markets in Pakistan: ACIAR Project 2014, 43.
Mesang, M., Arvianti, E. Y., & Santoso, B. (2025). Assessing the impact of climate change on the productivity, income, and yield of chili and shallot farming in East Java, Indonesia. Journal of Agricultural Socio-Economics (JASE), 6(2), 49–59.
Qureshi, H. U., Shah, S. M. H., & Teo, F. Y. (2023). Trend assessment of changing climate patterns over the major agro-climatic zones of Sindh and Punjab. Frontiers in Water, 5, 1194540.
Rais, M. U. N., Solangi, A. W., & Wagan, H. (2023). Climate change affects chilli production, profitability, and costs: implications for sustainable agriculture. Journal of Agriculture and Food, 4(2), 102–113.
Saidah, Z., Harianto, Hartoyo, S., & Asmarantaka, R. W. (2020). Change on production and income of red chili farmers. IOP Conference Series: Earth and Environmental Science, 466(1), 12003.
Sheikh, M. J., Narejo, A. A., Khushk, G. M., & Magsi, H. (2019). Influence of climate shifting on agricultural and daily life activities in lower sindh province of Pakistan. Advances in Agriculture and Animal Sciences, 35(2), 113–118.
Singh, J., & Kumar, S. (2025). CLIMATE CHANGE IMPACTS AND MITIGATION ON CHILLI PRODUCTION: ADAPTIVE AGRONOMIC AND GENETIC STRATEGIES. Plant Archives (09725210), 25(2).
Srinivas, J., Reddy, K. R., Saidaiah, P., Anitha, K., Pandravada, S. R., & Balram, M. (2020). Correlation and path analysis study in chilli (Capsicum annuum L.) genotypes. International Research Journal of Pure and Applied Chemistry, 21(21), 1–11.
Verma, K. K., Song, X., Kumari, A., Jagadesh, M., Singh, S. K., Bhatt, R., Singh, M., Seth, C. S., & Li, Y. (2025). Climate change adaptation: challenges for agricultural sustainability. Plant, Cell & Environment, 48(4), 2522–2533.
Widowati, I., Dhamira, A., Anggrasari, H., & Seleky, R. N. (2023). Climatic factors and its effect on chili production: one step forward combating climate change. BIO Web of Conferences, 69, 4001.