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THE IMPLICATIONS OF CLIMATE CHANGE DYNAMICS ON SOUTH ASIAN AGRICULTURE: A TREND-BASED ANALYSIS OF BANGLADESH, INDIA, AND PAKISTAN

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ABSTRACT

South Asia is at a significant risk due to rapid climate change, which is defined as the climate patterns over a period of 30 years as a result of global warming. Irregular rainfall patterns, rising temperatures, and the recurrence of extreme weather events are all important indicators that affect ecosystems, agricultural production, and human populations, making them more vulnerable to climate change. Assessing trends in climate variability is important for developing effective adaptation strategies. This study examines trends in key climate variables such as temperature, rainfall, and carbon dioxide levels. Annual data from 1990 to 2020 were gathered from the Climate Change Knowledge Portal (CCKP) and the World Development Indicators (WDI). The Mann-Kendall (MK) test was used to detect trends in the time-series data, and Sen's slope estimator, a non-parametric approach, was used to quantify the amplitude of these trends. The results affirm that Pakistan and India experience higher temperatures, all three countries experience significant variations in rainfall, and CO_2 emissions are gradually increasing. Despite the advancements in technology, producers continue to encounter hazards as a result of inadequate resources. The study argues for climate-smart agriculture (CSA) that improves productivity, resilience, and environmental sustainability through drought-tolerant crops, water-saving practices, and conservation tillage. Urgent, region-specific CSA strategies are essential to ensure sustainable agriculture in South Asia.

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INTRODUCTION

Climate change threatens the planet through extreme weather events, disrupted food production, water scarcity and increasing irrigation needs, leading to crop losses, economic damage, and increased food insecurity in various regions. Rainfall and temperature variability associated with climate change increasingly threaten agricultural communities and expose smallholder farmers to both environmental and socio-economic difficulties (Hashimoto, 2019). Since the middle of the 20th century, climate conditions have shifted, characterised by rising temperatures and inconsistent rainfall trends, which are increasing slightly at higher altitudes and decreasing at lower altitudes. Overall, temperatures have risen by around 0.72°C, with the effects varying depending on location and time period (Ofgeha and Abshire, 2021). South Asia's significant population, varied ecosystems, and limited ability to adapt make it extremely susceptible to climate change. The region is facing rising temperatures, fluctuating rainfall, and an increase in severe weather events.

Key regions like the Himalayas are warming swiftly, causing glaciers to melt and sea levels to rise (Mbah et al., 2022). These climate changes have made farming less productive, households less resilient, and people more vulnerable. Abusive practices, such as deforestation and input-intensive farming methods, have increased greenhouse gas emissions in response (Abeysekara et al., 2023). Average annual maximum temperatures in South Asia could increase by 1.4 to 1.8 degrees Celsius over the next ten years and by 2.1 to 2.6 degrees Celsius by mid-century. This could lead to a 12% increase in heat stress areas over the next decade and 21% by mid-century. In addition, it is predicted that summer rainfall in the region could increase by 5 to 15%, while winter rainfall is likely to decrease (Bhandari, 2021). Climate change has a significant impact on the agricultural sector of South Asian. The severe impacts of climate change are predicted to reduce food production in various South Asian countries (Abeysekara et al., 2023). Tables 1 and 2 present the latest study findings that are relevant to our research on temperature fluctuations, rainfall variability, and agricultural production in South Asia. As a result, the risk of food shortages and famine is expected to increase throughout the region, driving up food prices (Alvi et al., 2021). Lack of climate change adaptation and lack of resources have put small-scale farmers at serious risk (Srinivasa et al., 2017). Climate change has made it difficult to address poverty and promote environmentally friendly agriculture in the region (Praveen and Sharma, 2019). Several studies show that Climate Smart Agriculture (CSA) is a highly successful strategy for reducing the negative impacts of climate change and improving the resilience of smallholders (Mutengwa et al., 2023). CSA has proven its ability to support national food security and development agendas by continuously growing production and gross sales, improving resilience through adaptation, and mitigating and reducing greenhouse gas emissions (FAO, 2010). The FAO asserts that farmers' lack of understanding of climate-smart agriculture (CSA) methods impedes their implementation on a household scale. While CSA has the potential to advance sustainable agriculture, barriers including common land ownership, climate variability, and uncertain land tenure continue to inhibit farming efficiency and impede the attainment of CSA objectives (FAO, 2013). In the realm of research, agricultural experts are increasingly implementing various climate resilience approaches to address the impacts of climate change. Consequently, understanding long-term climate trends is essential to recognizing the type and scope of agriculture's environmental challenges. Without this fundamental understanding, it is difficult to develop or implement effective CSA strategies that take local climate conditions into account. This study examines trends in South Asia's climate variables, including temperature, rainfall, and CO_2 concentration. The research aims to improve the understanding of the changing climate in the region and the need to adopt climate-smart agricultural (CSA) practices by recognizing patterns and shifts over time. Table 3 provides a brief summary of recent studies on climate change trends relevant to this study.

Table 1. Summary of previous studies on temperature variation (ΔT) and crop yield in South Asia.

Source	Country	Temperature Change (°C)	Wheat	Rice	Maize
[1]Iqbal et al. (2009) [2]Aggarwal and Sivakumar (2011) [3]Hussain, and Bangash (2017)	Pakistan	↑1°C	[1] Shrinking crops 6-8%; [2]Yield decline 5-7%	Shrinking crops 15-20%	[3]Yield decline of 7%
[1]Sinha and Swaminathan (1991) [2] Hundal and Prabhjyot-kaur (1997) [3] Hundal and Prabhjyot-kaur (2007) [4]Rao et al. (2015), [5]Gupta et al. (2017) [6]Saseendran et al. (2000)	India	↑1°C	[1]Yield decline 10% [2]Yield decline 8.1% [3]decline the yield by about 10% [4]Yield decline 7%; [5]Yield declined 5.9%;	[3]Decline the yield about 3% [2]Yield decline 5.4% [6]Decline the yield about 6%	[2]Yield decline 10.4%
[1]Aggarwal and Sinha (1993) [2] Hundal and Prabhjyot-kaur (1997) [3]Aggarwal and Mall (2002) [4] Rani and Maragatham (2013)	India	↑2–3 °C	[1]Decline in all regions [2]Yield decline of 18.7%	[2]Yield decline 7.4% [3]5–7% reduction in yield in eastern and western regions, 8% in northern and 17% in southern India [4]reduction in yield about 13.3%	[2]Yield decline 14.6%
[1] Hundal and Prabhjyot-kaur (1997)	India	↑3 °C	[1]yield decline by 25.7%	[1]Yield decline by 25.1%	[1]yield decline by 21.4%
[1]Karim et al.(1999) [2]Basak et al. (2010)	Bangladesh	↑2–3 °C	[1]Yield decline 60%	[1]Boro rice Yield declined by 4% [2]Yield decrease by 2.6–13.5%	
[1]Malla (2008)	Nepal	↑4 °C	[1]crop yield increased by 5.3% in the hills and by 33.3% in the mountains, it decreased by 1.8% in the Terai.	[1]Crop yield increased by 17.9% in the hills and by 36.1% in the mountains, it decreased by 3.4% in the Terai.	[1]crop yield increased by 9.3% in the hills and by 26.8% in the mountains, it decreased by 26.4% in the Terai.
[1]Ratnasiri et al. (2019)	Sri Lanka	↑1°C		[2]yield increase by 5%	
Ratnasiri et al. (2019)	Sri Lanka	↑2 °C		[1] increase rice yield by 5%	
Ratnasiri et al.(2019)	Sri Lanka	↑4 °C		1 reduced rice yield by 30%	

Table 2. Summary of previous studies on rainfall patterns and crop yield in South Asia.

Source	Country	Crop	Impact
[1] Akhtar and Athar (2020) [2]Ali et al. (2021) [3] Abbas et al. (2020) [4]Abbas and Mayo (2021)	Pakistan	[1]Wheat, Rice, Cotton, and Sugarcane wheat, rice, maize, and sugarcane [2] Rice [3]Rice	[1] Detrimental effect on wheat yield, while cotton is greatly influenced negatively, while rice and sugarcane show a considerable favourable correlation. [2] Rainfall has an adverse effect on certain crops, except wheat, which is unaffected. [3] Effects that are both statistically valid and constructive. [4]Rice yield is decreased by excessive rainfall.

[1]Saseendran et al. (2000) [2] Barnwal and Kotani (2013) [3]Guntukula (2019) [4]Zachariah et al. (2020) [5]Bhardwaj et al. (2022)	India	[1]Rice [2]Rice [3]rice, wheat, pulses, rapeseeds and mustard, cotton, sugarcane, and groundnut [4]wheat, cotton, sugarcane, chickpea, and soybean [5]Rice and wheat	[1] A rise in rice yield as a result of more rainfall. [2] Favourable and statistically noteworthy impacts on rice. [3] Increased rainfall harms food crops, with the exception of pulses. [4] More precipitation increases some agricultural yields. [5]Higher rainfall lowers the yield of wheat and rice.
[1]Sarker et al. (2012) [2]Sarker et al. (2014) [3]Chowdhury and Khan (2015) [4]Salan et al. (2022)	Bangladesh	[1]three major rice crops (e.g., Aus, Aman, and Boro) [2]Rice [3]Rice [4]Potato	[1]Increased precipitation has a substantial and statistically validated Effect on Aus and Aman rice. [2] Diminishing rice harvests [3]Favourable and crucial outcome [4]Substantial effects on potato yield
[1]Malla (2008) [2]Maharjan and Joshi (2013) [3] Devkota and Paija (2020)	Nepal	[1]Wheat, Rice [2]Rice, wheat, maize, millet, barley, and potato [3]Rice	[1] positive and statistically significant effect [2]adversely affected the yield of maize and millet, positive impact on potato, wheat, rice, and barley positive and significant relationship exists between rice yields and rainfall
Seo et al. (2005)	Sri Lanka	rice, coconut, rubber, and tea	positive and statistically significant effect

Table 3. Tabular summary of some recent literature (trend of climate change).

Authors	Journal	Model use	Main finding
Mondal et al. (2012)	International Journal of Geology, Earth and Environmental Sciences	Mann-Kendall (MK) Test, Modified Mann-Kendall Test, Sen's Slope Estimator	The research examined 40 years of daily rainfall data (1971–2010) to assess monthly rainfall trends. Statistics showed that rainfall increased in some months and a downward trend in others, yet overall, the variations were statistically significant.
Yadav et al. (2014)	Journal of Agrometeorology	Mann-Kendall (MK) Test, Sen's Slope Estimator	Variable patterns in rainfall and temperature in all months; Some months saw an increase, while others indicated a decrease, resulting in slight changes in seasonal trends in some districts.
Madsen et al. (2014)	Journal of Hydrology	Observational data and climate projections	An overall increase in heavy rainfall is noted and expected.
Jaiswal et al. (2015)	Environmental Processes	Pettitt's test, von Neumann ratio test, Buishand's range test, and standard normal homogeneity (SNH) test. Trend analysis: Linear regression, Mann-Kendall test, Spearman rho test	Significant differences in daylight hours, wind speed, and the lowest possible temperature.
Mcdowell et al. (2016)	Environmental Research Letter	Systematic Review	Increasing patterns in temperature and precipitation fluctuations
Alhaji et al. (2018)	Journal of Scientific Research and Reports	Mann-Kendall Trend Test & Sen's Slope Estimator	The extreme and average temperatures demonstrate a noteworthy upward trend ($p < 0.05$), whereas the minimum temperature displays a positive yet non-significant trend. Results suggest a trend of rising temperatures, probably attributed to climate change, which could result in extreme weather conditions.
Mudelsee (2019)	Earth-science reviews	Systematic Review Approach	Identified a rapid warming trend since 1974 using GISTEMP data.
Alemu and Dioha (2020)	Environmental Systems Research	Mann-Kendall (MK) trend test and Sen's slope estimate	The temperature at Bole station showed a notable upward trend, While Antoto station showed an increasing trend that lacked statistical significance. Increased temperatures may result in severe weather, requiring additional monitoring and response strategies.
Monforte and Ragusa (2022)	Mathematics	Cluster Analysis (Ward's Method) Mann-Kendall Test Sen's Slope Estimator	Temperature patterns indicate significant and statistically significant increases.
Shahbandeh and Elhag (2024)	Environment, Development and Sustainability	Statistical Analysis, Trend Analysis	Carbon dioxide concentrations exhibited a sharp rise, suggesting possible ecological emergencies. The lowest average air temperature in the area rose during the period examined.

METHODOLOGY

Description of THE Study Area

The region of South Asia, which spans latitudes 5°38′N to 36°54′N and longitudes 61°05′E to 97°14′E, comprises eight countries: the Maldives, Bhutan, Pakistan, Sri Lanka, Bangladesh, Nepal, India, and Afghanistan. Its total area is 477 million yards. The region is divided into five agro-ecological zones (AEZs): Desert tropics, semi-arid subtropics, semi-arid tropics, sub-humid tropics and humid tropics (Gumma et al., 2022). With its lush agricultural landscape and abundant natural diversity, South Asia is exceptionally vulnerable to climate change due to its population density, widespread poverty, and inadequate adaptive capacity. India, Bangladesh, and Pakistan are among the countries most at risk from climate change, while extreme weather, rising sea levels, and environmental deterioration also pose additional challenges (Griffiths, 2016). Climate trends were examined using annual time series data from Bangladesh, India, and Pakistan from 1990 to 2020. The widely used Climate Change Knowledge Portal (CCKP) was used to collect temperature and rainfall data. Data on CO2 emissions is derived from the World Development Indicators (WDI) database. These multinational statistical compilations were selected for their reliability, accessibility, and broad scope of study. An overview of the data sources and specific variables used in the analysis is given in Table 2.

Table 2. Description of the variables with source of data.

No	Variable	Description	Source
1	TEMP	Average annual temperature (°C)	CCKP
2	RF	Average annual rainfall (millimeters)	CCKP
3	CO2	Annual carbon dioxide emissions (MT)	WDI

WDI means World Development Indicators, and CCKP for the World Bank's Climate Change Knowledge Portal.

Data Analysis Technique

Annual temperature (TEMP), rainfall (RF), and CO2 emissions (CO2) data for Pakistan, India, and Bangladesh were used to analyze trends. A trend is a long-term direction or pattern in a set of data. It describes the evaluation of the dependent variable across time (Babcock et al., 2010). Parametric and nonparametric techniques are commonly used to test for trends in a dataset (Ross and Begeny, 2014; Lefèvre et al., 2014). This study applies the sine slope (SS) estimator and the Mann-Kendall (MK) test. The MK test is a robust statistical tool for analyzing patterns in nonparametric time series data (Mann, 1945; Kendall, 1975). Researchers often use it to analyze meteorological time series data (Djaman et al., 2020; Milentijevic et al., 2020; Begum and Mahanta, 2022; Sanogo et al., 2023). A rank correlation test is run on both data sets to determine the ranking order of the recorded values with respect to their time sequence (Nalley et al., 2013). The main feature of this test is its nonparametric nature, which eliminates the need to transform the data to a normal distribution. Furthermore, when analyzing asymmetric time series data, the evaluation provides a considerable advantage by demonstrating less sensitivity to rapid changes in the data (Tabari et al., 2011). The null hypothesis of the test (H0) states that there is no trend, and the alternative hypothesis (H1) is used to test the null hypothesis and determine whether a trend exists. (Pattnaik and Dimri, 2020). The M-K trend test statistic can be computed using the method specified in equation (1) (Chisanga et al., 2023).

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\ (\mathrm{Xj} - \mathrm{X_i}) \quad (1)$$

Xi and Xj represent sequential data values, while n denotes the data series' range. Eq (2) specifies the sign of the test statistic (Hussein et al., 2021).

$$Sign(\mathrm{Xj} - \mathrm{X_i}) = \begin{cases} 1\ if \mathrm{Xj} - \mathrm{X_i} > 0 \\ 0\ if \mathrm{Xj} - \mathrm{X_i} = 0 \\ -1\ if \mathrm{Xj} - \mathrm{X_i} < 0 \end{cases} \quad (2)$$

The variance of S is calculated as follows:

$$Var(s) = \frac{n(n-1(2n+5)-\sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

Where m denotes the number of tied values and ti denotes the number of ties for the ith value. MK statistic Z is given by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \quad (4)$$

The distribution of Z values seems to be normal. When the Z value exceeds 1.96 in the positive direction, it indicates a potential upward trend. Conversely, a Z value of less than -1.96 indicates a clear downward trend. The null hypothesis (H0) is rejected in the context of a two-sided test if the computed absolute value of Z (|Z|) exceeds the critical value of 1.96 (Zα/2) at a 95% confidence level, indicating that the trend is present in the data set.

Sen's Slope

The MK test is employed to ascertain the existence of a trend. After identifying a trend, the nonparametric Sen's slope estimator (SSE) is used to calculate the magnitude of the trend. This approach is notable for its resilience against outliers, offering a solid estimate of the slope for trend analysis (Sen, 1968).

$$\beta = median\left(\frac{(\mathrm{Xj}-\mathrm{X_i})}{(\mathrm{tj}-\mathrm{t_i})}\right) \quad (5)$$

Here, X_j and X_i represent data values at respective times t_j and t_i. In this study, stat in this study, tests of probability were done on climate variables such as temperature, precipitation, and CO2 data at a significance level of 5%. Statistical tests were performed on climate variables, including temperature, precipitation, and CO2 data, with a significance level of 5%.

RESULTS AND DISCUSSION

In this study, the Mann-Kendall test was used to estimate trends in temperature, rainfall, and CO2 levels across Pakistan, India, and Bangladesh over a 31-year period (1990-2020). We utilized the statistical analysis software XLSTAT.

Temperature Trend Analysis

The Mann-Kendall test results for Pakistan, India, and Bangladesh are presented in Table 3. A significance level (alpha) of 0.05 was employed. According to the results, the null hypothesis is rejected, as the probability coefficients for both Pakistan and India are below a threshold of 0.05. This suggests that there is no trend. Consequently, the alternative hypothesis, indicating a trend in temperature, is readily accepted. This implies a statistically significant positive and upward trend in mean temperature for both Pakistan and India. The result of the study at hand is in line with previous studies (Zarenistanak et al., 2014; Ngulu et al., 2010; Dawood et al., 2018). However, for Bangladesh, the p-value exceeded the critical 0.05 threshold. This suggests that the mean temperature did not exhibit any significant trends during the specified period. The magnitudes of the trends, as determined by Sen's slope test, were 0.035 for Pakistan, 0.17 for India, and 0.007 for Bangladesh. The time series graph, along with the linear trend line, is represented by Figures 1, 2, and 3. Figures 1 and 2 illustrate a noticeable upward trend in the temperature of both Pakistan and India. While Figure 3, will be represents Bangladesh, the trend appears to show a declining pattern.

Table 3. M–K test for temperature.

Countries	M–K Statistics (S)	Kendall's Tau	Var (S)	p-value	Sen's slope
Pakistan	187	0.430	3139.667	0.000	0.035
India	186	0.492	3138.667	0.001	0.017
Bangladesh	45	0.104	3137.667	0.432	0.007

* show statistical significance at the 5% level of significance.

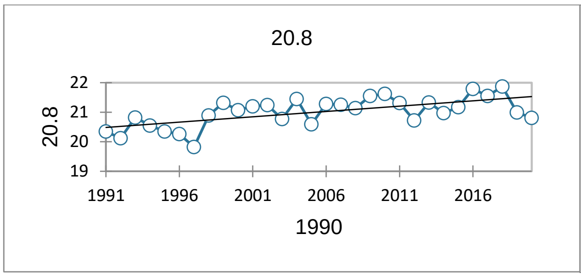

Figure 1. Temperature trend (Pakistan).

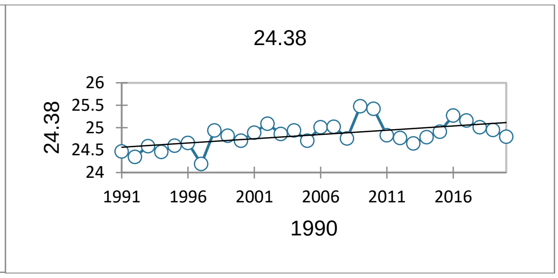

Figure 2. Temperature trend (India).

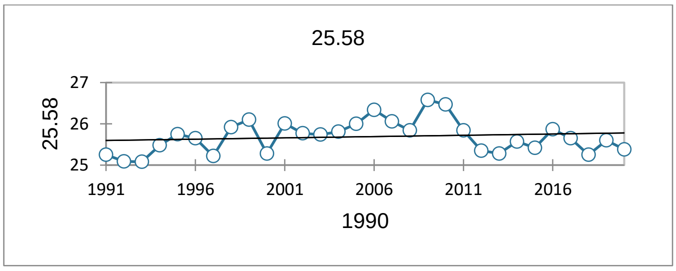

Figure 3. Temperature trend (Bangladesh).

Rainfall Trend Analysis

The Mann-Kendall test results for Pakistan, India, and Bangladesh are presented in Table 4. A significance level (alpha) of 0.05 was employed. The findings indicate that the p-values for these countries were greater than the critical threshold of 0.05. Therefore, the null hypothesis, suggesting no trend, was easily accepted, and the alternative hypothesis, indicating a trend in rainfall, was readily rejected. This implies a statistically insignificant positive trend in rainfall for both Pakistan and India and a statistically insignificant negative trend in mean rainfall for Bangladesh. The findings of this study were built on a previous study that identified an upward trend in annual rainfall, although statistically insignificant (Sa'adi et al., 2019; Nyikadzino et al., 2020; Gadedjisso-Tossou et al., 2021). The magnitudes of the trends, as determined by Sen's slope test, were 1.001 for Pakistan, 3.803 for India, and -9.794 for Bangladesh. The time series graph, along with a linear trend line, is represented by Figures 4, 5, and 6. Figures 4, 5, and 6 illustrate a noticeable downward trend in the rainfall of Pakistan, India, and Bangladesh.

Table 4. M–K test for rainfall.

Countries	M–K Statistics (S)	Kendall's Tau	Var (S)	p-value	Sen's slope
Pakistan	33	0.076	3141.667	0.568	1.001
India	103	0.237	3141.667	0.069	3.803
Bangladesh	-71	-0.167	3137.667	0.121	-9.794

* show statistical significance at the 5% level of significance.

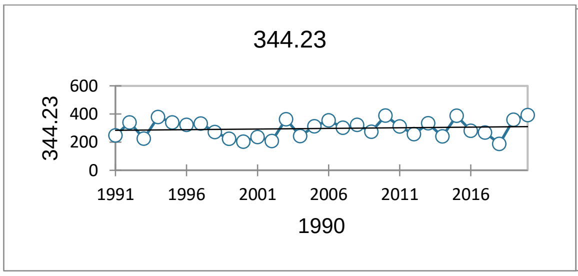

Figure 4. Rainfall trend (Pakistan).

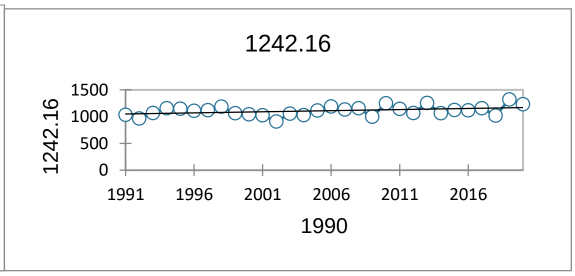

Figure 5. Rainfall trend (India).

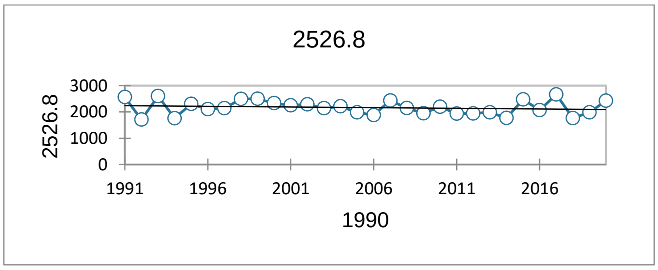

Figure 6. Rainfall trend (Bangladesh).

Table 5. M–K test for CO2.

Countries	M–K Statistics (S)	Kendall's Tau	Var (S)	p-value	Sen's slope
Pakistan	315	0.724	3141.667	<0.000	0.010
India	401	0.922	3141.667	<0.000	0.041
Bangladesh	405	0.931	3141.667	<0.000	0.015

* show statistical significance at the 5% level of significance.

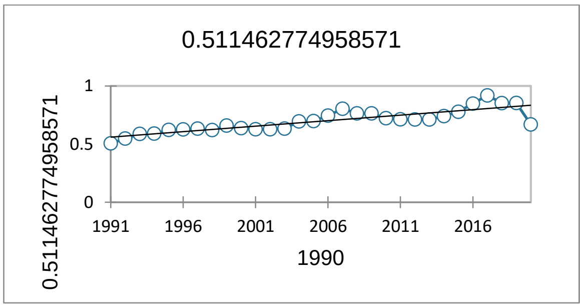

Figure 7. CO2 emission trend (Pakistan).

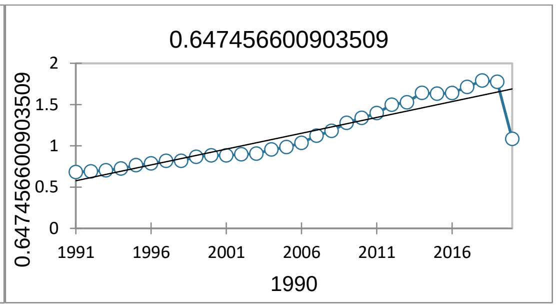

Figure 8. CO2 emission trend (India).

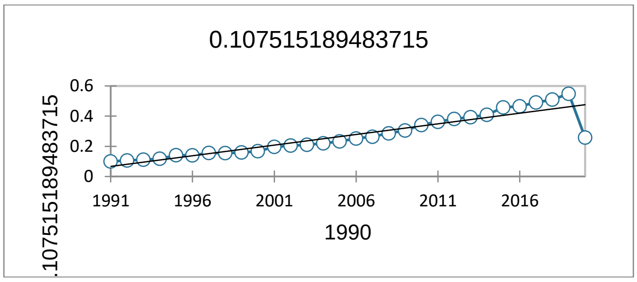

Figure 9. CO2 emission trend (Bangladesh).

CO2 Trend Analysis

Table 5 displays the results of the Mann-Kendall test for Pakistan, India, and Bangladesh. A significance level (alpha) of 0.05 was employed. The findings indicate that the p-values for Pakistan, India, and Bangladesh were below the critical value of 0.05. Therefore, the null hypothesis, suggesting no trend, is easily rejected, and the alternative hypothesis, indicating a trend in CO2, is readily accepted. This implies a statistically significant positive trend in CO2 for Pakistan, Bangladesh, and India. This study's results align with previous findings that identified a statistically significant increasing trend in CO_2 emissions (Mahmoud and Gan, 2018; Tunde et al., 2022; Polisetty and Chesneau, 2024). The magnitudes of the trends, as determined by Sen's slope test, were 0.010 for Pakistan, 0.041 for India, and 0.015 for Bangladesh. The time series graph, along with a linear trend line, is represented by Figures 7, 8, and 9.

CONCLUSIONS AND RECOMMENDATIONS

In this study, the trends in key climatic factors such as temperature, rainfall, and CO_2 emissions for Pakistan, India, and Bangladesh from 1990 to 2020 were analyzed using the Mann-Kendall trend test and the Sen Slope method. The results show a continued increase in CO_2 emissions, erratic rainfall patterns in all three countries, and a dramatic spike in temperatures in India and Pakistan. Some of the new challenges posed by climate change include heat stress, shifting planting seasons, and water scarcity, all of which increase the risk of crop diseases and parasite infestations. Adopting specific adaptation and mitigation methods to boost resilience across several sectors is so critical. This study emphasizes the importance of developing climate-smart agriculture (CSA) in light of each country's unique agro-ecological characteristics. Agroforestry, conservation farming, climate-resilient crop varieties, integrated nutrition, sustainable livestock farming, and community irrigation systems are all effective solutions. By using these strategies, South Asia can preserve agricultural systems, protect rural livelihoods, and improve its ability to withstand the consequences of climate change.

South Asia is especially prone to climate change due to its geographical location, high population, and dependency on climate-sensitive sectors such as agriculture (Naab et al., 2019). Research shows that significant changes have occurred in the climate patterns of Bangladesh, India, and Pakistan between 1990 and 2020. These include rising average temperatures, unpredictable and irregular rainfall patterns, and a continued increase in CO2 emissions. Shifts have increased the occurrence and severity of extreme weather events, such as heat waves, heavy precipitation, and protracted droughts. The region has been affected by numerous climate-related incidents. For example, the 2022 heatwave in India and Pakistan resulted in the hottest March in roughly a century, which significantly reduced yields and had an impact on wheat agriculture (IMD, 2022). Heavy monsoon rains in Pakistan have caused severe floods, destroying homes, infrastructure, and crops while inundating millions of hectares of land (Qamer et al., 2023 Bangladesh experienced severe flooding in 1987, 1988, 1998, and 2004 that caused significant damage. Over 60% of the country was submerged by the floods, which also flooded an area of about 100,000 km^2 for about three months (Haque et al., 2022). Climate extremes not only disrupt agricultural cycles but also increase the prevalence of pests and plant diseases, reduce soil fertility, and rapidly modify growing seasons (Abeysekara et al., 2023). The study highlights the urgent need to adopt sustainable, community-specific, and effective approaches to address these complex issues. Climate Smart Agriculture (CSA), including sustainable livestock management practices, holistic water and nutrient management, conservation agriculture, drought and heat-tolerant cropping systems, and small-scale irrigation, shows promise for increasing resilience to climate change and increasing productivity (Chapagain et al., 2023). Additionally, it is important to improve early alert systems, expand agricultural insurance options, and promote educational programs for farmers to reduce exposure and strengthen adaptive capacities. Furthermore, international cooperation is crucial. South Asian countries face relatively high levels of climate risk and agricultural challenges. To ensure sustainable durability, concerted efforts are needed to share information, combine resources, and develop group mitigation plans. The results of the study have significant ramifications for decision-makers, development organizations, and farmers. Enhancing food security and rural prosperity is vital, but so is promoting long-term growth by promoting adaptive agricultural methods in South Asia that are socially acceptable, commercially viable, and ecologically conscious.

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