**Rainfall Variability in the Central Plain Zone of Uttar Pradesh, India.**

 **ABSTRACT**

**The main objective of the study was** to assess the long-term variability and trends in monsoonal rainfall over the Central Plain Zone of Uttar Pradesh, focusing on its implications for agricultural sustainability. The study specifically examined annual, seasonal, and decadal rainfall patterns in the key districts of Kanpur and Lucknow over a 50-year period (1975–2024).Retrospective climatological data analysis using statistical and trend detection methods were employed Agro-Meteorological Research conducted using historical rainfall data from the India Meteorological Department (IMD) and Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, covering the period from 1975 to 2024. Monthly and annual rainfall data for the districts of Kanpur and Lucknow were collected for a 50-year span (1975–2024). Statistical analyses included calculation of mean rainfall, identification of wettest and driest years, and decadal trend assessments. Linear regression and the Mann-Kendall trend test were employed to detect significant trends and variability in rainfall. Annual, seasonal (June–September), and decadal variability were analyzed to identify fluctuations and long-term patterns. Kanpur recorded a mean annual rainfall of 897.90 mm, with the highest in 1980 (1982.3 mm) and the lowest in 1979 (451.8 mm). Lucknow recorded a mean of 881.21 mm, with 1980 being the wettest year (1721.5 mm) and 1987 the driest (490.7 mm). Significant inter-annual and decadal variability was observed in both districts. Trend analysis revealed a slow but consistent decline in annual rainfall over time, although intermittent recovery phases were noted. These results highlight an increasing unpredictability in monsoonal behavior, potentially affecting the region’s rainfed agriculture.

The Central Plain Zone of Uttar Pradesh is experiencing gradual but significant changes in rainfall patterns. The declining trend and increased variability of monsoonal rainfall pose serious concerns for sustainable agriculture, emphasizing the need for adaptive planning and improved water resource management.

**Keyword:** Rainfall, Variability, Rain-fed, Monsoonal behavior and Central Plain Zone

1. **Introduction**

The Central Plain Zone of Uttar Pradesh is a vital agricultural region, largely dependent on monsoonal rainfall which contributes to about 80% of the annual precipitation (Srivastav et al.,2021). With over 60% of the area under rainfed farming, rainfall variability significantly impacts sowing schedules, crop yields and rural livelihoods. Recent decades have witnessed increasing climate variability, particularly in the form of delayed monsoon onset, erratic rainfall distribution, and more frequent extreme events like floods and droughts. These climatic disruptions have made agricultural planning increasingly uncertain and risky.

Global climate change, driven by rising greenhouse gas emissions, is altering regional hydrological cycles. The temperature increases of 0.4–2.0°C during the *kharif* season and 1.1–4.5°C during *rabi* by 2070 are projected, further intensifying stress on crops. While some models predict a 10% rise in average rainfall, the uneven distribution and intensity of rain pose greater challenges than total volume (Chand and Ray, 2015; Maurya et al.2023). Small and fragmented landholdings make farmers especially vulnerable, as even minor shifts in rainfall during key crop stages can result in substantial yield losses (Baliyan k.,2022). Understanding long-term rainfall patterns and their variability is essential for building climate-resilient agriculture (Srivastav et al.,2021). This study, titled *“Climatic Variability Analysis of Central Plain Zone of Uttar Pradesh”*, aims to assess rainfall trends, seasonal shifts, and anomalies over time. The insights will support adaptive strategies, helping policymakers and farmers to mitigate climate risks and sustain agricultural productivity in this critical region of India.

Change in rainfall patterns due to global warming, particularly after the 1990s and the era of rapid industrialization, has significantly impacted the hydrological cycle. These shifts necessitate a re-evaluation of water demand, hydrological planning, and agricultural practices. Consequently, analyzing long-term trends in rainfall and other climatic parameters across various spatial scales becomes essential for establishing future plans for crop planning and management (Jain & Kumar, 2012).

In India, In the rainy season, the average temperature is expected to rise by 0.1°C to 0.3°C, and in the dry season, by 0.3°C to 0.7°C, by 2010. In a similar vein, mean rainfall is predicted to rise by up to 10% by 2070 but not to alter much by 2010 (IPCC, 2007; MoEFCC, 2010). At the same time, there is a greater chance of climate extremes such altered monsoon onset timing and more frequent and severe floods and droughts. (Adhya T.K., 2010). While the debate on global warming continues, the majority of scientific research shows that the climate is becoming more unpredictable over time. Agriculture, being highly dependent on weather conditions, is more affected by extreme weather events such as flooding, drought, cold spells, heat waves, cyclones and soil degradation. Unfortunately, these occurrences are growing more frequent and widespread, threatening India's agricultural gains. (Adhya, T. K. 2010).

Climate change is a serious threat to many different ecosystems worldwide. According to the Intergovernmental Panel on Climate Change's sixth assessment report (IPCC, 2018), those that depend on agriculture for a living and those living in arid regions are disproportionately more vulnerable to climate variability. Particularly in India, where 60% of all crops are still rain-fed and a large percentage of landholdings are small and dispersed, the growing frequency of intersession variations in temperature and rainfall as well as other extreme events has a substantial impact on agricultural production and livelihoods (Jain *et al*. 2015: Udmale *et al*. 2014).

1. **Materials and method**

**The present study, titled “Climatic Variability Analysis of Central Plain Zone of Uttar Pradesh,” was carried out with the primary objective of evaluating long-term trends and fluctuations in rainfall patterns over an extensive period of 50 years, spanning from 1975 to 2024.** The investigation was centered on the Central Plain Zone of Uttar Pradesh, a region where agricultural productivity is predominantly dependent on the performance of the monsoon season. As such, any irregularity in rainfall can have significant implications for crop yields, water availability, and overall rural livelihoods.

For this purpose, historical rainfall data were meticulously obtained from two major and reliable sources: the India Meteorological Department (IMD), Pune, and Chandra Shekhar Azad University of Agriculture and Technology (CSAUAT), Kanpur. The compiled dataset was comprehensive, encompassing rainfall records on daily, monthly, seasonal, and annual timescales. This extensive and detailed dataset provided a strong and credible foundation for conducting a thorough analysis of temporal variations and climatic anomalies over the selected timeframe.

In the initial phase of the study, the raw daily rainfall data were systematically aggregated to calculate totals at various temporal resolutions, including weekly, monthly, seasonal (both kharif and rabi seasons), and annual levels. These aggregations allowed for a multi-scale examination of rainfall behavior and facilitated trend identification over both short and long durations.

Basic data processing and preliminary statistical computations were conducted using Microsoft Excel, which served as the primary platform for organizing, analyzing, and visualizing the data. To enhance the reliability and accuracy of the analysis, a cross-verification process was undertaken. This involved comparing rainfall records obtained from different datasets and sources to detect inconsistencies or anomalies, thereby ensuring that the final dataset used for analysis was both authentic and scientifically sound.

Rainfall analysis included the calculation of total and mean rainfall across different time scales. Mean rainfall was computed using the formula $Rˉ =\frac{\sum\_{i=1}^{n}Ri}{n}$​​ where *Ri*​ is annual rainfall and *n* is the number of years. Rainfall events were classified into intensity categories—light, moderate, heavy, and extremely heavy—based on daily thresholds.

Trend analysis was conducted using both linear regression and the non-parametric Mann-Kendall test. Linear regression determined the direction and rate of change in rainfall using the equation Y=mX+C. The Mann-Kendall test assessed the statistical significance of trends without assuming data normality, utilizing the standardized Z-statistic for interpretation.

1. **Result and Discussion**
	1. **Annual Rainfall Variability in Kanpur District**

**The analysis of annual rainfall variability in the Kanpur district over a 50-year period (1975–2024) (refer to Table 1 and Graph 1) revealed significant inter-annual and decadal fluctuations, with a calculated mean annual rainfall of 897.90 mm.** The highest annual rainfall was recorded in 1980 (1982.3 mm), while the lowest occurred in 1979 (451.8 mm), indicating pronounced variability even within short time spans.

Decadal analysis further highlighted notable shifts in rainfall patterns. The first decade (1975–1984) recorded the highest mean annual rainfall of 1026.79 mm. This was followed by a substantial decline in the second decade (1985–1994), with the mean dropping to 783.51 mm—reflecting a marked increase in rainfall irregularity. A partial recovery was observed during the third decade (1995–2004), where the mean rose to 925.26 mm, supported by significantly wet years such as 1997 and 1998.

However, this recovery was not sustained. The fourth decade (2005–2014) witnessed a further decrease in average rainfall to 835.48 mm, underscoring climatic instability. This period included years of both high rainfall (2013 with 1234.1 mm) and deficient rainfall (2006 with 551.3 mm). The fifth and most recent decade (2015–2024) showed a modest rebound, with a mean of 918.57 mm, although variability persisted illustrated by below-average years like 2015 (623.3 mm).

Overall, the long-term trend suggests a gradual decline in mean annual rainfall accompanied by an increased frequency of extreme rainfall events, both excess and deficit. This growing variability has direct implications for agricultural planning, water resource management, and crop productivity in the Central Plain Zone particularly in rain-fed farming systems where rainfall reliability is critical.

* 1. **Annual Rainfall Variability in Luck now District**

**The analysis of annual rainfall variability in Luck now district over the 50-year period from 1975 to 2024 (refer to Table 1 and Graph 2) revealed significant inter-annual and decadal fluctuations, with a mean annual rainfall of 881.21 mm.** The highest annual rainfall was observed in 1980 (1721.5 mm), whereas the lowest was recorded in 1987 (490.7 mm), underscoring the pronounced variability in precipitation over time. Decadal trends displayed alternating phases of increase and decline, reflecting growing unpredictability in monsoonal patterns. The first decade (1975–1984) registered the highest mean decadal rainfall (1033.98 mm), marked by multiple high-rainfall years such as 1980, 1975, and 1982. However, notable dry years like 1979 and 1976 also occurred within this period, illustrating ongoing fluctuations. A sharp decline was observed in the second decade (1985–1994), with the mean dropping to 721.01 mm. Several critically dry years—1987, 1993, and 1989—contributed to this significant reduction. The third decade (1995–2004) remained below the long-term average, with a mean of 794.91 mm. Although years like 1997 and 1998 experienced higher rainfall, they were interspersed with dry spells in 1995, 2000, and 2002.

A partial recovery was noted in the fourth decade (2005–2014), where the mean rose to 889.32 mm. This improvement was supported by wetter years such as 2008, 2011, and 2012; however, drought-prone years like 2006 and 2007 reflected continued climatic instability. The most recent decade (2015–2024) exhibited further improvement, with a mean annual rainfall of 966.85 mm—second only to the first decade. Above-average rainfall in years such as 2018, 2019, and 2023 contributed to this rise, although deficits remained in years like 2015 and 2017.In summary, the long-term rainfall pattern in Luck now district is characterized by high variability, with alternating periods of drought and excessive rainfall. These fluctuations pose significant challenges to sustainable agriculture, irrigation planning, and water resource management. The findings emphasize the urgent need for adaptive and climate-resilient strategies, particularly in rain-fed agricultural systems within the Central Plain Zone.

1. **Conclusion**

The 50-year climatic analysis of rainfall variability in the Central Plain Zone of Uttar Pradesh focusing on Kanpur and Lucknow districts reveals a concerning trend of increasing irregularity in monsoonal patterns. While certain decades showed signs of partial recovery, the overarching trajectory indicates a gradual decline in average annual rainfall accompanied by a rising frequency of extreme events, including both prolonged droughts and episodes of intense precipitation.

Such variability has profound implications for rain-fed agriculture, irrigation planning, and overall water resource management. These fluctuations threaten regional food security and disrupt rural livelihoods, making agricultural systems increasingly vulnerable to climatic uncertainties.

The observed trends underscore the urgent need for adaptive strategies, including the promotion of climate-resilient cropping systems, enhanced weather forecasting capabilities, and the implementation of sustainable water management practices. This study offers valuable insights into long-term regional climatic dynamics and can serve as a foundational resource for policymakers, researchers, and farming communities working toward mitigating climate risks and achieving sustainable agricultural development in the Central Plain Zone.

Add practical recommendations based on your findings? Any Policy recommendations?

**Table 1. Annual Rainfall variability in Kanpur and Lucknow districts**

|  |  |  |
| --- | --- | --- |
| **Year (1975-2024)** | **Annual Rainfall (mm) in Kanpur District** | **Annual Rainfall (mm) in Lucknow District** |
| 1975 | 937.80 | 1243.50 |
| 1976 | 811.30 | 664.70 |
| 1977 | 1045.00 | 828.90 |
| 1978 | 1035.00 | 1197.90 |
| 1979 | 451.80 | 540.70 |
| 1980 | 1982.30 | 1721.50 |
| 1981 | 1054.90 | 947.40 |
| 1982 | 1204.50 | 1205.80 |
| 1983 | 996.00 | 1157.90 |
| 1984 | 749.30 | 831.50 |
| 1985 | 1250.30 | 1216.70 |
| 1986 | 939.80 | 725.30 |
| 1987 | 437.40 | 490.70 |
| 1988 | 752.70 | 829.70 |
| 1989 | 666.30 | 548.10 |
| 1990 | 870.70 | 792.70 |
| 1991 | 629.80 | 810.10 |
| 1992 | 754.50 | 694.20 |
| 1993 | 661.80 | 532.70 |
| 1994 | 871.80 | 569.90 |
| 1995 | 756.90 | 657.90 |
| 1996 | 1053.20 | 943.20 |
| 1997 | 1116.30 | 1006.50 |
| 1998 | 1347.60 | 1127.50 |
| 1999 | 865.40 | 698.10 |
| 2000 | 755.00 | 604.10 |
| 2001 | 641.30 | 780.50 |
| 2002 | 845.40 | 546.00 |
| 2003 | 1105.90 | 746.90 |
| 2004 | 765.60 | 838.40 |
| 2005 | 702.90 | 703.66 |
| 2006 | 551.30 | 551.50 |
| 2007 | 590.90 | 590.33 |
| 2008 | 1175.30 | 1419.50 |
| 2009 | 809.00 | 1129.60 |
| 2010 | 998.10 | 695.29 |
| 2011 | 904.50 | 1134.80 |
| 2012 | 725.40 | 1092.40 |
| 2013 | 1234.10 | 931.97 |
| 2014 | 663.30 | 644.20 |
| 2015 | 623.30 | 669.40 |
| 2016 | 690.90 | 878.80 |
| 2017 | 669.90 | 749.10 |
| 2018 | 981.10 | 1262.70 |
| 2019 | 963.90 | 1184.90 |
| 2020 | 1228.70 | 934.00 |
| 2021 | 1025.60 | 961.40 |
| 2022 | 1083.40 | 1086.80 |
| 2023 | 934.80 | 1117.60 |
| 2024 | 984.1 | 823.80 |

**Fig. 1 Graphical representation of Annual Rainfall in Kanpur district 50 years (1975 - 2024)**

**Fig. 2 Graphical representation of Annual Rainfall in Lucknow district 50 years (1975-2024)**

**Disclaimer**
The authors affirm that no artificial intelligence tools (such as ChatGPT, GitHub Copilot, or similar platforms) were utilized in the writing, analysis, or preparation of this manuscript. All the content, including analytical scripts and interpretations, is entirely original, manually developed, and grounded in scientific methodology.

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