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# Shifting in Rainy Season Features in the Mekong Delta under the Background of Global Climate Change

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## ABSTRACT

**Background:** Shifting in the rainy season features (RSFs) have caused impishly cultivation activities around the world, especially under the impacts of enhancing climate change. In the Mekong Delta, rainfall is a crucial factor that determines crop sowing and harvesting dates.

**Methods:** This study investigated the RSFs, including the rainy season onset date (RSOD), cessation date (RSCD) and length (LRS), in the Mekong Delta from 1995 to 2022. The study aimed to understand the spatial and temporal variability of the rainfall features and their implications across the Mekong Delta. The study utilized rainfall data at gauge stations across the Mekong Delta, covering a period of 30 years. The study employed descriptive statistical methods to analyze the RSFs, including RSOD, RSCD and LRS.

**Result:** The results revealed the spatial and temporal variability of RSFs across the study area. The analysis of RSOD, RSCDand LRS revealed consistent patterns. However, the SD and CV values suggested moderate variability in these features, indicating the need for further investigation into the factors influencing these variations. The findings highlight the importance of considering RSFs for effective rain-fed resource management and planning in the Mekong Delta.


**Key words:** Climate change, Mekong delta, Paddies, Rainy season, Water resource.

## INTRODUCTION

The characteristics of the rainy season, including the RSOD, LRS and RSCD, provide invaluable insights for effective agricultural and water resource management (Amekudzi *et al*., 2015; Diaconescu *et al*., 2015). The RSOD and RSCD serve as a critical reference point for understanding seasonal rainfall dynamics and their implications for water availability (Dave, 2018; Hu *et al*., 2019). Accurately determining the RSOD and RSCD is crucial (Misra *et al*., 2023; Muñoz-Sanchez *et al*., 2024).

Numerous methods have been developed to determine the RSOD and RSCD (Hu *et al*., 2019; Joseph *et al*., 2006; Marteau *et al*., 2011). A commonly applied one based on the rainfall-based indices that being widely employed due to their relative simplicity and data availability compared to other approaches (Omay *et al*., 2023; Phung, 2024). For instance, Hu *et al*. (2019) applied the relative rainfall coefficient method to define the RSOD in the Qinghai-Tibet Plateau, lying in southwestern China. Dang *et al*. (2020) used a three-pronged approach to define RSOD in the Mekong Delta coastal. Pham and Phan (2021) based on the similarity between gauge station-based to determine the RSOD for the Central Highlands and Southern Vietnam.

In the context of the Mekong Delta, a region closely reliant on rainfall irrigation agriculture, understanding the dynamics of the rainy season is essential. Farmers in the region rely on the RSOD and RSCD to design critical decisions regarding sowing and harvesting schedules (Lee and Dang, 2019; Phung, 2024). Shifts in the RSOD, LRS and RSCD, potentially exacerbated by climate change, can have profound implications for agricultural productivity and further food security (CGIAR-Research Program on Climate Change, 2016; IPCC, 2018).

Previous studies have highlighted the spatial and temporal variability of rainy season characteristics in Vietnam (Dang, 2023; Nguyen *et al*., 2022; Pham and Phan, 2021). Dang *et al*. (2020) observed an earlier onset and later cessation of the rainy season in the western coastal areas of the Mekong Delta, while Pham and Phan (2022) identified a trend towards an earlier RSOD across the Central Highlands and Southern Vietnam. These shifts in rainy season patterns underscore the need for comprehensive assessments of their potential impacts on agricultural practices and water resource management, providing a comprehensive analysis of rainy season dynamics and their implications for agricultural adaptation solutions within the region renowned as Vietnam's rice bowl.

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## MATERIALS AND METHODS

The Mekong Delta is a relatively young delta formed by alluvial deposition from the Mekong River, covering from 8°34′ to 11°10′ N latitude and 104°25′ to 106°48′ E longitude (Fig 1). Characterized by its low-lying topography, with elevations ranging from 0.5 to 4.5 meters above mean sea level (Dinh and Dang, 2021; Lee and Dang, 2019). A dense network of rivers and canals crisscrosses the region, providing a vital source of irrigation for agriculture, which forms the backbone of the Mekong Delta's economy (Dinh and Dang, 2023; Nguyen *et al*., 2022). Situated within a humid tropical monsoon climate zone, the Mekong Delta experiences distinct wet and dry seasons (Lee and Dang, 2019).

The southwest monsoon, from May to October, brings abundant rainfall up to 92% of total of annual rainfall, contributing to shaping the delta's hydrological regime (Lee and Dang, 2019; Nguyen *et al*., 2022). During the dry season, from November to April, the northeast monsoon brings less rainfall, exerting an indirect influence on agricultural irrigation practices, especial coastal cultivation paddies (Fig 2). Understanding the complex interplay of these geographical and climatic factors is crucial for developing sustainable water and agricultural management strategies in the face of climate change (Lee and Dang, 2019; Nguyen *et al*., 2022).

The study utilized daily rainfall data series from 12 gauge stations across the Mekong Delta (Table 1), spanning from 1995 to 2022. Data were obtained from the National Center for Hydrometeorological Forecasting (NCHF). Station selection prioritized both geographical representation and the availability of long-term, homogenous rainfall records to ensure analytical robustness. Rigorous quality control measures were implemented to guarantee data consistency and comparability throughout the time series. The criteria for determining RSOD, RSCD and LRS are referenced from Pham and Phan (2022).

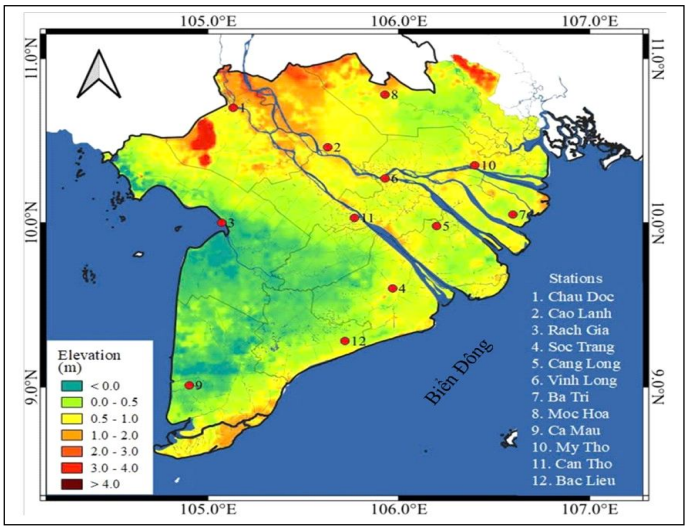



**Fig 1:** Map of the study area with gauge stations marked the red circles.

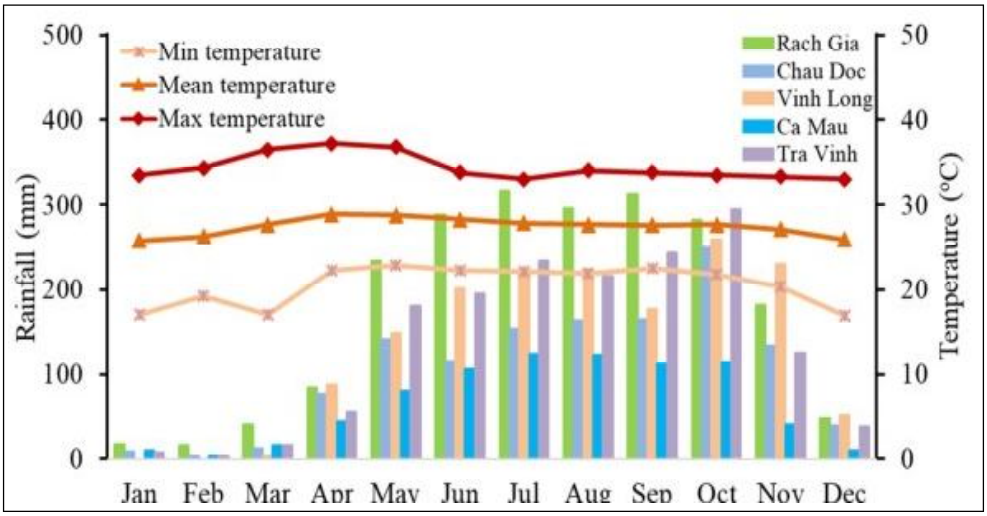



**Fig 2:** Distribution of temperature and mean rainfall at gauge stations across the study area in the period 1995-2022.

## RESULTS AND DISCUSSION

Table 1 presents the base statistical features of rainfall data at gauge stations across the Mekong Delta. The data reveals significant variations in rainfall characteristics across the region. The minimum rainfall values range from 691.5 mm at Chau Doc station to 1905.7 mm at Ca Mau station, indicating a considerable difference in the rainfall distribution across the study area. The maximum rainfall values, however, show a wider range, from 1884.2 mm at My Tho station to 3549.4 mm at Ca Mau station, suggesting substantial differences in the wettest periods (Fig 3).

The mean rainfall values exhibit a moderate variation, ranging from 1344.6 mm at Chau Doc station to 2378.4 mm at Ca Mau station, suggesting a general trend of moderate rainfall across the region. The SD values show a wider range, from 221.8 at Vinh Long station to 350.5 mm at Moc Hoa station, indicating varying levels of rainfall variability. Based on Table 1, the results show that Rach Gia, Soc Trang, Cang Long, Vinh Long, Ca Mau stations have low CV coefficients, varying from 0.13 to 0.15. This implies that the climatic and geographical conditions of the western and southeastern coastal provinces have little fluctuation, resulting in less fluctuations in rainfall features.

Table 2 presents the analysis results of the RSOD at 12 observation stations across the Mekong Delta. The results reveal a consistent pattern of RSOD across the region, with minimal variation in the minimum, meanand maximum onset dates. The early RSOD occurred at Rach Gia on 29 March 1999 while the latest RSOD varies from 3rd June 2002 at Rach Gia station to June 27th, 2020, at Bac Lieu station, suggesting a limited range for the latest RSOD. The mean RSOD exhibits a relatively narrow range, from 08 April at Bac Lieu station to April 14th at Ba Tri station, indicating a general trend of similar RSOD across the study

**Table 1:** Base statitical features of rainfall data at gauge stations across in this study.

| Station | Latitute (N) | Longtitute (E) | Min (mm) | Mean (mm) | Max. (mm) | $K_S$ | $K_C$ | Duration |
|---|---|---|---|---|---|---|---|---|
| Chau Doc | 10°46′ | 105°55′ | 691.5 | 1344.6 | 1920.9 | 314.06 | 0.23 | 1995-2022 |
| Cao Lanh | 10°21′ | 106°23′ | 1084.0 | 1534.1 | 2387.8 | 280.69 | 0.18 | 1995-2022 |
| Rach Gia | 10°03′ | 106°35′ | 1528.6 | 2261.6 | 2895.3 | 344.55 | 0.15 | 1995-2022 |
| Soc Trang | 9°58′ | 106°12′ | 1394.5 | 1900.1 | 2754.2 | 305.28 | 0.16 | 1995-2022 |
| Cang Long | 10°15′ | 105°57′ | 1267.7 | 1646.2 | 2041.4 | 221.25 | 0.13 | 1995-2022 |
| Vinh Long | 10°28′ | 105°37′ | 1017.5 | 1532.0 | 1962.6 | 227.87 | 0.14 | 1995-2022 |
| Ba Tri | 10°41′ | 105°07′ | 1131.1 | 1567.1 | 2238.2 | 265.50 | 0.16 | 1995-2022 |
| Moc Hoa | 10°00′ | 105°04′ | 1046.5 | 1637.2 | 2420.9 | 350.54 | 0.21 | 1995-2022 |
| Ca Mau | 10°01′ | 105°46′ | 1905.7 | 2378.4 | 3549.4 | 335.40 | 0.14 | 1995-2022 |
| My Tho | 09°35′ | 105°58′ | 757.7 | 1525.1 | 1884.2 | 232.75 | 0.15 | 1995-2022 |
| Can Tho | 09°16′ | 105°43′ | 1171.7 | 1648.8 | 2431.0 | 283.18 | 0.17 | 1995-2022 |
| Bac Lieu | 09°10′ | 105°09′ | 1572.9 | 2040.1 | 2821.3 | 314.86 | 0.15 | 1995-2022 |

Ks- Standard deviation; Kc- Coefficient of variation.

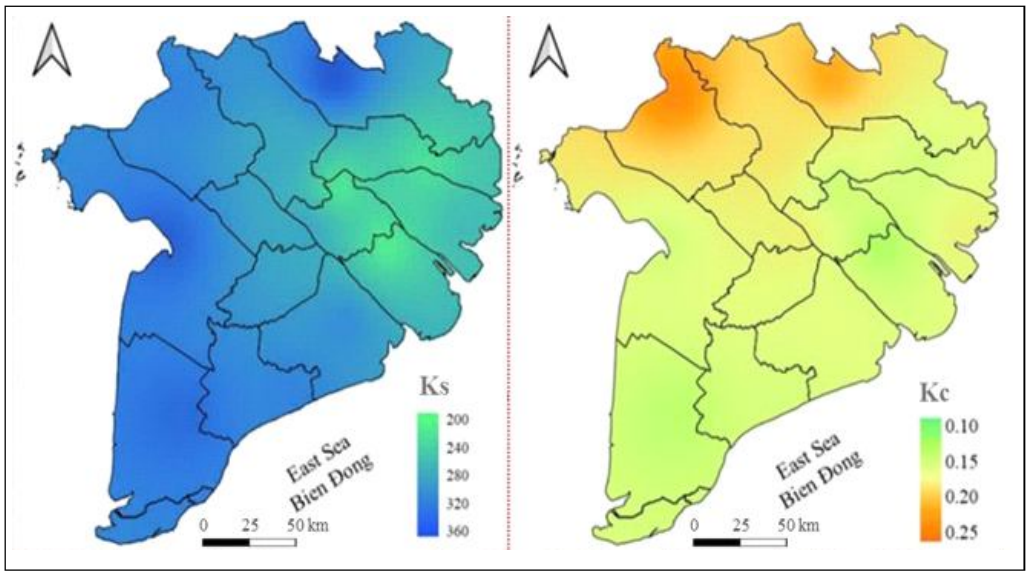



**Fig 3:** Spatial distribution of the standard deviation ($K_S$) and coefficient of variation ($K_C$) of annual rainfall at observation stations across the study area throughout 1995-2022.

area. The SD values, however, show a moderate range, from 13.52 days at Cang Long station to 23.56 days at Cao Lanh station, suggesting varying levels of variability in the RSOD. The CV, which measures the relative variability of the RSOD, also displays a range from 0.09 at Ca Mau station to 0.17 at Cao Lanh station, highlighting the diverse patterns of rainy season onset across the region.

The analyzed results from Table 2 reveal a relatively consistent pattern of RSCD across the study area. The early RSCD ranges from October 20$^{th}$ at Soc Trang station to November 7$^{th}$ at Ca Mau station, indicating a narrow window for the earliest end of the rainy season. Similarly, the maximum cessation date varies from December 12$^{th}$ at Rach Gia station to December 30$^{th}$ at Chau Doc and Ca Mau stations, suggesting a limited range for the latest RSCD. The mean RSCD exhibits a relatively narrow range, from November 9$^{th}$ at Ba Tri station to December 4$^{th}$ at Chau Doc station, indicating a general trend of similar RSCD timing across the study area (Fig 4).

The SD values, however, show a moderate range, from 11.6 days at Vinh Long station to 17.5 days at Bac Lieu station, suggesting varying levels of variability in the RSCD. The CV of the RSCD also displays a range from 0.03 at Rach Gia and Vinh Long station to 0.05 at Cang Long and My Tho station, highlighting the diverse patterns of RSCD entire the study area.

Table 3 presents the analysis results of the LRS at 12 observation stations across the Mekong Delta. The analysis reveals a relatively consistent pattern of LRS across the area. The minimum length ranges from 128 days at Can Tho station to 171 days at Ca Mau station, indicating a narrow window for the shortest rainy season duration. Similarly, the maximum length varies from 225 days at Moc Hoa station to 259 days at Chau Doc and My Tho station, suggesting a limited range for the longest LRS. The mean length exhibits a relatively narrow range, from 128 days at Can Tho station to 171 days at Ca Mau station, indicating a general trend of similar LRS across the area. The SD values show a moderate range, from 17.9 days at Moc Hoa station to 29.9 days at Chau Doc station, suggesting varying levels of variability in the LRS while the CV displays a range from 0.08 at Cao Lanh

**Table 2:** Analysis results of the rainy season onset data (RSOD) and cessation date (RSCD) at observation stations in the period 1995-2022.

| Station | RSOD | | | | | RSCD | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Mean | Max | $K_S$ | $K_C$ | Min | Mean | Max | $K_S$ | $K_C$ |
| Chau Doc | Mar-29 | May-12 | Jun-25 | 23.5 | 0.17 | Oct-27 | Dec-04 | Dec-30 | 15.5 | 0.04 |
| Cao Lanh | Apr-02 | May-08 | Jun-11 | 13.8 | 0.10 | Oct-27 | Nov-27 | Dec-15 | 14.2 | 0.04 |
| Rach Gia | Mar-28 | May-12 | Jun-02 | 13.8 | 0.10 | Oct-25 | Nov-23 | Dec-12 | 12.2 | 0.03 |
| Soc Trang | Apr-03 | May-06 | Jun-02 | 13.5 | 0.10 | Oct-20 | Nov-22 | Dec-23 | 14.2 | 0.04 |
| Cang Long | Apr-03 | May-12 | Jun-24 | 17.1 | 0.12 | Oct-05 | Nov-19 | Dec-20 | 16.6 | 0.05 |
| Vinh Long | Apr-02 | May-17 | Jun-20 | 18.3 | 0.13 | Nov-01 | Nov-25 | Dec-20 | 11.6 | 0.03 |
| Ba Tri | Apr-14 | May-13 | Jun-21 | 14.1 | 0.10 | Oct-16 | Nov-09 | Dec-15 | 14.2 | 0.04 |
| Moc Hoa | Apr-23 | May-16 | Jun-12 | 13.5 | 0.09 | Oct-26 | Nov-25 | Dec-21 | 14.3 | 0.04 |
| Ca Mau | Apr-02 | May-09 | Jun-11 | 14.7 | 0.11 | Nov-07 | Nov-30 | Dec-30 | 12.9 | 0.03 |
| My Tho | Apr-03 | May-12 | Jun-10 | 17.4 | 0.13 | Oct-24 | Nov-21 | Dec-20 | 16.2 | 0.05 |
| Can Tho | Mar-30 | May-05 | Jun-27 | 16.9 | 0.13 | Nov-01 | Nov-26 | Dec-26 | 14.2 | 0.04 |
| Bac Lieu | Apr-08 | May-06 | Jun-09 | 14.3 | 0.11 | Oct-12 | Nov-20 | Dec-22 | 17.5 | 0.05 |

Ks- Standard deviation; Kc- Coefficient of variation.

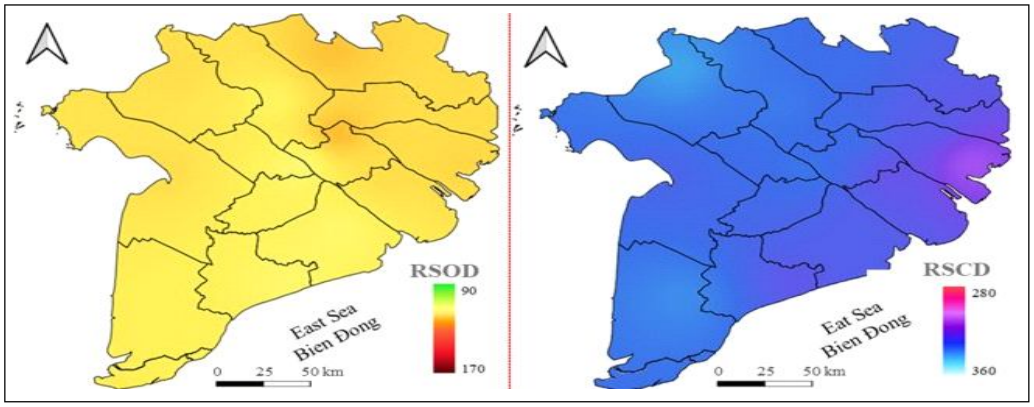



**Fig 4:** Spatial distribution of the rainy season onset date (RSOD) and the rainy season cessation date (RSCD) across the study area throughout 1995-2022.

**Table 3:** Features of the length of rainy season at observation stations across the study area.

| Station | Max | Min | Mean | $K_S$ | $K_C$ |
|---|---|---|---|---|---|
| Chau Doc | 259 | 137 | 207 | 29.9 | 0.14 |
| Cao Lanh | 240 | 168 | 203 | 17.97 | 0.08 |
| Rach Gia | 253 | 164 | 195 | 18.6 | 0.09 |
| Soc Trang | 236 | 160 | 200 | 18.6 | 0.09 |
| Cang Long | 259 | 130 | 191 | 26.1 | 0.13 |
| Vinh Long | 237 | 155 | 193 | 21.7 | 0.11 |
| Ba Tri | 229 | 149 | 180 | 19.0 | 0.10 |
| Moc Hoa | 225 | 149 | 194 | 17.9 | 0.09 |
| Ca Mau | 256 | 171 | 205 | 20.2 | 0.09 |
| My Tho | 259 | 152 | 193 | 22.8 | 0.11 |
| Can Tho | 254 | 128 | 205 | 21.3 | 0.10 |
| Bac Lieu | 250 | 156 | 199 | 22.1 | 0.11 |

Ks- Standard deviation; Kc- Coefficient of variation.

station to 0.14 at Chau Doc station, highlighting the diverse patterns in the Mekong Delta.

Overall, the analysis of the rainy season features reveals a consistent pattern of RSOD, RSCD and LRS across the Mekong Delta. However, the SD and CV suggest moderate variability in the RSOD, RSCD and LRS, indicating the need for further investigation into the factors influencing these variations for effective water resource management and planning.

## Conclusion

The study investigated the spatial and temperal variability of the rainy season features and their implications for rice cultivation paddies in the Mekong Delta from 1995 to 2022, focusing on the rainy season onset date, cessation dateand length of rainy season. The analysis revealed consistent patterns in the rainy season features across the Mekong Delta.

The rainy season characteristics significantly influence rain-fed resource management in the Mekong Delta under the background of climate variability. Understanding these environmental interactions is vital for developing sustainable agricultural practices and water management strategies in the region

Further research is needed to explore the specific drivers of the rainy season features variability and their implications for agricultural adaptation solutions in the Mekong Delta.

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### Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

### Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

### Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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