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Analysis of Precipitation Patterns in the East Coast of Peninsular Malaysia from 1981 to 2019

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Abstract: This study examines the distribution of precipitation across the east coast states of Peninsular Malaysia, specifically focusing on Kelantan, Terengganu, and Pahang, over the period from 1981 to 2019. The analysis aims to understand changes in rainfall patterns due to climate change and weather phenomena, including El Niño and La Niña. Precipitation data are sourced from the APHRODITE dataset, with statistical analysis incorporating indices such as Consecutive Dry Days (CDD) and Consecutive Wet Days (CWD). The research shows a significant increase in total annual rainfall in northern regions, including Kelantan and Terengganu, especially during the La Niña phenomenon. In contrast, southern regions such as Pahang are more susceptible to the impacts of El Niño, leading to drought conditions and reduced rainfall. Visual analysis results, presented through graphs and Geographic Information System (GIS) maps, illustrate temporal and spatial variations in rainfall distribution, revealing a trend of increasing maximum dry days in Pahang and a decrease in dry days in Kelantan. This study provides valuable insights into the risks of floods and droughts, as well as their effects on water resources, agriculture, and the livelihoods of local communities. The findings serve as an important reference for the development of water resource management and disaster mitigation strategies to address the challenges posed by climate change.

Keywords: Precipitation, Consecutive Dry Days, Consecutive Wets Day, Geography Information System

1.0 Introduction

The examination of precipitation distribution along the east coast of Peninsular Malaysia is crucial for understanding the impacts of climate change and various other factors in this region. The east coast, particularly the states of Kelantan, Terengganu, and Pahang, frequently experiences significant rainfall, leading to flooding and landslides. Heavy precipitation has resulted in recurrent floods in these states (Lim & Samah, 2004; MMD, 2009). The geographical and climatic conditions of this region make it especially vulnerable to extreme weather fluctuations. Compared to the west, the east coast of Peninsular Malaysia is more susceptible to climate change (Yusuf & Francisco, 2009).

The region experiences an equatorial climate with two primary seasons: the rainy season and the dry season. The rainy season typically lasts from November to March and is dominated by the northeast monsoon, which brings substantial rainfall. In contrast, the dry season, from May to September, is influenced by the southwest monsoon, resulting in drier conditions. The seasonal transition can significantly alter precipitation patterns, impacting daily life and the local economy. Minor changes in the mean and variance of rainfall due to climate change can lead to significant shifts in the likelihood of extreme events (Su et al., 2006). These changes may also lead to droughts or dry periods in the region, driven by factors such as global warming and human activities, including agriculture and development. The rise in temperature due to global warming is expected to influence evaporation and atmospheric water storage, impacting both the average and variability of rainfall (Wang et al., 2016), which can disrupt human activities. The local community, which depends on agriculture and fisheries, may face severe challenges. Agricultural practices, such as rice and oil palm cultivation, rely heavily on stable precipitation patterns, meaning any alterations in rainfall distribution could significantly affect yields and food security.

Research on precipitation distribution in the eastern coastal states of Peninsular Malaysia is vital for effective water resource planning and management. Precipitation data at broader spatial scales, from regional to global, are essential for assessing climate models (Hulme, 1994a). Climate models forecast precipitation levels and analyze patterns within specific regions. Understanding rainfall patterns allows authorities to improve drainage system planning and implement measures to mitigate flood risks. Precipitation data is also crucial for predicting floods and providing timely alerts to affected communities. Alterations in rainfall distribution can have a substantial impact on agricultural yields and food security in the region. This study aims to examine how climate change and weather phenomena such as El Niño and La Niña have altered rainfall patterns. This research is essential for the efficient management of water resources. At a broader scale, precipitation data are critical for climate model assessments (Hulme, 1994a). Climate models help predict rainfall levels and patterns in specific regions, which aids in improving drainage planning and flood mitigation. Rainfall data also plays a key role in forecasting floods and delivering alerts to vulnerable communities.

This study provides a comprehensive analysis of rainfall patterns along the east coast of Peninsular Malaysia over nearly four decades (1981 to 2019). What makes this study unique is its long-term evaluation of rainfall patterns in a region heavily influenced by monsoon conditions, offering more localized insights compared to previous research. By analyzing changes in rainfall intensity, frequency, and seasonality, this study enhances our understanding of climate variability and potential shifts due to climate change. The findings hold significant value for disaster risk management, particularly in improving flood forecasting and mitigation strategies. Additionally, the research contributes to agricultural and water resource planning by offering valuable insights into long-term rainfall trends. The study also provides empirical evidence that can aid policymakers in developing more effective climate adaptation and resilience strategies for the region

2.0 Study Area

The east coast of Peninsular Malaysia comprises three states: Kelantan (6°08'N, 102°16'E), Terengganu (4°45'N, 103°00'E), and Pahang (3°49'N, 103°21'E). This region experiences a tropical climate, characterized by consistently high temperatures, high humidity levels, and significant rainfall. The year is divided into four distinct seasons, which unfold as follow:

Table 1: Monsoon season tropical climate

Season	Duration Time (month)
Northeast Monsoon	December until March
Transition period	April until May
Southwest monsoon	June until September
Transition period	From October until November

The most significant rainfall typically occurs during the northeast monsoon season (Pour et al., 2014). This season affects Southeast Asia, including Malaysia, Thailand, the Philippines, and Vietnam, and usually spans from November to March. The northeast monsoon is characterized by the development of low-pressure systems in tropical regions. These systems facilitate the movement of moist air from the sea to the land, resulting in dense cloud cover and substantial precipitation. In contrast, June and July, during the southwest monsoon, represent the driest periods. The transition period between the monsoon seasons, which occurs between April and October, also experiences significant rainfall (Suhaila & Jemain, 2007). The eastern coast of Peninsular Malaysia maintains relatively consistent temperatures year-round, with annual fluctuations typically below 2°C, compared to the average temperature of 27°C (Suhaila et al., 2008).

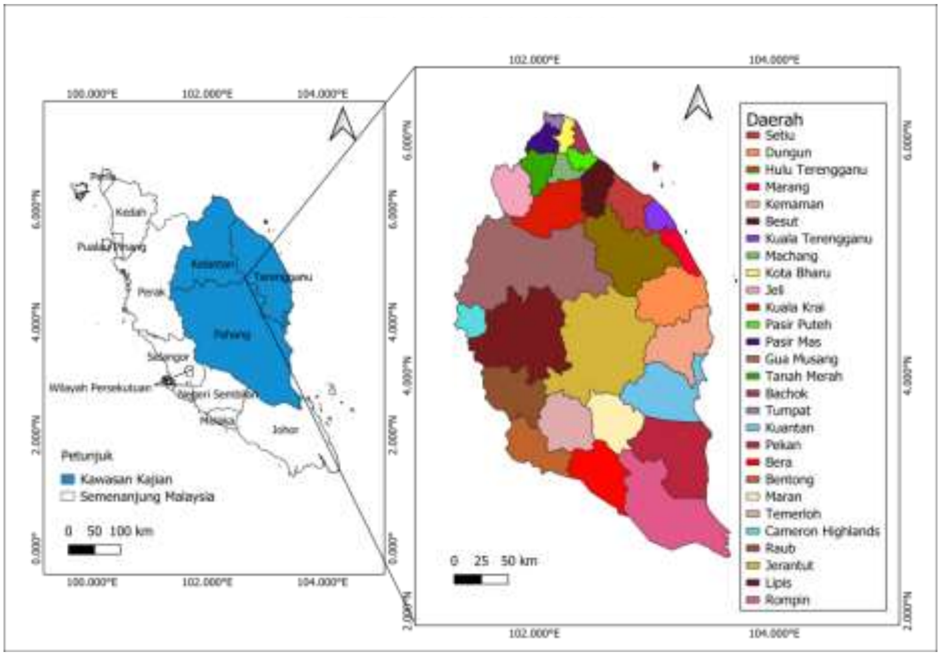

Figure 1: Study area

3.0 Methodology

Figure 2 illustrates a systematic procedure for studying rainfall distribution patterns. The process begins with data gathering and selection using the APHRODITE dataset (1981–2019) and a literature review. Error checking and research area selection are part of the preprocessing and preliminary analysis, with a focus on the east coast of Peninsular Malaysia. The third phase involves calculating distribution indices, such as the annual rainfall distribution, as well as specific metrics like MCDD (Maximum Consecutive Dry Days) and MCWD (Maximum Consecutive Wet Days). The fourth step is data analysis, which includes spatial mapping of rainfall patterns using GIS and temporal trend analysis. The fifth step involves interpreting the findings and discussing trends and influencing factors. The study concludes with key findings and recommendations for future advancements in research methodology and analysis.

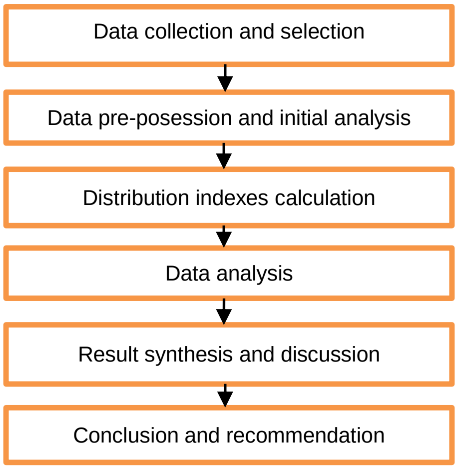

Figure 2: Research Method Chart

3.1 Data Collection

Precipitation data spanning forty years (1981–2019) is available from Aphrodite. The Aphrodite (Asian Precipitation - Highly Resolved Observational Data Integration Towards Evaluation) dataset serves as a crucial resource for climate and hydrological research in Asia, particularly in Malaysia. It provides high-resolution precipitation data derived from weather station observations. This dataset enables researchers to gain insights into precipitation distribution, climate change trends, and the effects of extreme weather events on both the environment and human communities. Aphrodite is the result of a collaborative effort involving Japanese and international researchers. It prominently includes data from regions with a high concentration of meteorological stations, such as East Asia, Southeast Asia, and South Asia. The precipitation data in Aphrodite is typically presented in daily format, facilitating various analyses, including long-term trends, climate variability, and investigations into weather phenomena like El Niño and La Niña. The spatial resolution of this dataset is approximately 0.25° x 0.25° or 0.5° x 0.5°, ensuring high accuracy in spatial analysis. The applications of the Aphrodite dataset extend beyond climate analysis. It offers daily precipitation records over 57 years, establishing it as a valuable resource for evaluating long-term trends in precipitation patterns (Yatagai et al., 2012; Kharol et al., 2013; El Kenawy et al., 2016; Kishore et al., 2016; Soraisam et al., 2018). This approach has been extensively applied in various domains, including water resource management, flood modeling, climate change impact assessments, and disaster mitigation strategy development. In the Southeast Asian region, including Malaysia, this dataset forms the foundation for understanding precipitation distribution patterns and their correlation with flood events, droughts, and other weather phenomena affecting local communities. Therefore, Aphrodite is an essential resource for this study, providing access to accurate and high-resolution data for studying precipitation distribution on the east coast of Peninsular Malaysia. Data from Aphrodite and other platforms can be sourced from their official websites, with registration required. Familiarity with data formats, such as NetCDF or CSV, may also be necessary.

The methodology of this study includes a literature review of previous research on precipitation distribution analysis along the East Coast of Peninsular Malaysia from 1969 to 2019. This review involves gathering sources from relevant journals, articles, technical reports, and research documents. The first step is to identify prior research that investigates precipitation distribution patterns, climate change, and meteorological factors affecting the East Coast of Peninsular Malaysia. Emphasis is placed on studies that utilize long-term data, spatial mapping methods, and statistical analysis to identify precipitation trends and anomalies. Studies published in reputable indexed journals, including Scopus, Web of Science, and Google Scholar, were selected to ensure methodological and data reliability. Additionally, local studies from research institutions and universities were considered. Data from previous research were used to analyze phenomena such as variations in annual precipitation, monsoon seasons, and the impacts of El Niño and La Niña on precipitation distribution. A thorough analysis of prior studies was conducted to identify similarities and differences in findings and to highlight relevant knowledge gaps. Cross-comparisons with additional pertinent sources were performed to ensure the accuracy and relevance of the data. This literature review approach establishes a strong foundation for understanding the background, selecting appropriate methodology, and ensuring the study builds on previous scientific findings.

3.2 Data filtering and Cleaning

The process of data filtering and cleaning is a critical step in ensuring the accuracy and reliability of the study results. We restructured the collected data to present dates alongside daily precipitation values, thereby enhancing the ease of analysis. Data cleaning procedures are implemented to identify and rectify any missing or invalid values. Incomplete or missing data will be addressed through the application of statistical interpolation methods, including linear or spline interpolation, based on the appropriateness of the data pattern. If the missing data is determined to be negligible or minimal in relation to the overall dataset, it may be excluded to prevent any disruption to the analysis. Furthermore, data that is illogical, including precipitation records with negative values or excessively high values that do not align with local weather conditions, will be identified and eliminated. Ensuring data quality control is a crucial step prior to the index calculation, as inaccurate outliers can significantly impact both the index calculation and its trend (You et al. 2008; Shahid et al. 2015). This procedure entails a thorough cross-comparison with alternative weather records, in addition to an analysis grounded in historical trends. For instance, when data indicates that precipitation levels surpass 1000 mm in a day in a region that typically receives under 500 mm, this value is classified as an anomaly and will be subject to investigation or dismissal if found to be invalid. We implement measurement standards to convert all data to a consistent unit, specifically millimetres per day (mm/day). It is essential to maintain consistency when analysing data from various sources. We conduct further filtering, including anomaly detection through statistical methods like standard deviation, to identify atypical data that could potentially impact the study's results. This approach ensures that the data utilized in the analysis is of superior quality, leading to more precise and meaningful outcomes.

3.3 Data Categorization by period

3.3.1 Classification by year

The daily precipitation data spanning from 1981 to 2019 has been segmented into five-year intervals to enable a more structured and comprehensive analysis. This method is used to find long-term patterns in the distribution of precipitation. It considers changes that may happen because of global climate factors like changes in sea surface temperatures, the El Niño-Southern Oscillation (ENSO), and the effects of global warming. This division also aids in identifying notable trends, whether they pertain to increases or decreases in precipitation amounts over a specified timeframe. We analyse precipitation data from 1981–1985 and compare it to the period 1986–1990 to identify any notable differences in precipitation amounts or rainfall patterns. The analysis conducted for each five-year period facilitates the evaluation of atypical events, including significant floods or droughts, which may have influenced the overall precipitation during that timeframe. This approach facilitates a comprehensive analysis of the relationship between changes in precipitation distribution and regional development, human activities, and various environmental factors. An early period, such as 1981–1985, may exhibit more stable precipitation patterns prior to the more pronounced effects of development or global warming. Conversely, the more recent periods of 2011–2015 and 2015–2019 may exhibit more dynamic patterns, including an increase in extreme rainfall events or climate anomalies. This analysis facilitates comparative studies of a specific five-year period against the overall average for the 1981–2019 timeframe, enabling the identification of significant anomaly periods. Dividing the data into five-year intervals allows for the early detection of significant changes in precipitation trends, offering valuable insights for climate change research, weather forecasting, and strategic planning to address the effects of extreme weather. This method also guarantees that subtle patterns that might not be apparent in yearly analyses can be more distinctly recognized.

3.3.2 CDD and CWD Definition

This study defines CDD as the highest number of consecutive days during which daily precipitation is below 1 mm. A day is classified as "dry" when the total rainfall recorded is below 1 mm. Frich et al. (2002) initially established the maximum number of consecutive days with precipitation below 1 mm, referred to as CDD. CDD denotes the highest count of consecutive days experiencing precipitation below a specified threshold, which may differ based on the research conducted (Frich et al. 2002; Nastos and Zerefos 2009; Zolina et al. 2013). CDD is used to identify drought patterns or periods of insufficient rainfall on the east coast of Peninsular Malaysia. Evaluate alterations in dry periods resulting from climate change or weather events like the El Niño phenomenon, as CDD analysis aids in comprehending the risks of water shortages and the effects of drought on agriculture and water resources. For instance, a period is classified as a dry period if it experiences 10 consecutive days with daily precipitation below 1 mm, resulting in a maximum CDD value of 10 days.

CWD is characterized as the highest number of consecutive days during which daily precipitation reaches a minimum of 1 mm. A day is classified as "wet" when the total rainfall recorded reaches a minimum of 1 mm. CDD is utilized to pinpoint durations of uninterrupted rainfall in the East Coast region, which frequently experiences the monsoon season. This analysis aids in comprehending the risk of flooding associated with extended rainfall durations, and the CWD analysis is pertinent for identifying annual variations in rainfall patterns. For instance, a period is classified as a wet period if it experiences 15 consecutive days with daily precipitation of at least 1 mm, resulting in a maximum CWD value of 15 days.

3.4 Statistical Analysis

3.4.1 CDD and CWD Annual Calculation

This research employs a statistical analysis methodology to investigate the trends in precipitation distribution across the East Coast states of Peninsular Malaysia from 1981 to 2019. This analysis involves the calculation of two significant indices: Consecutive Dry Days (CDD) and Consecutive Wet Days (CWD) for each year. The computation of CDD entails determining the highest number of successive days devoid of rain (precipitation < 1 mm), whereas the computation of CWD focuses on identifying the highest number of consecutive days with rain (precipitation ≥ 1 mm). The precipitation data is acquired in NetCDF format and analysed using Python software, along with climate analysis libraries such as Xarray and NumPy. Statistical analysis is utilized to discern long-term trends in both indices, highlighting notable changes in both temporal and spatial contexts. Descriptive statistics and trend tests, including the Mann-Kendall test, are employed to evaluate significant changes in the data. This analysis provides a comprehensive understanding of the distribution patterns of dry and wet days in the region, which is crucial for effective water resource management and climate risk mitigation. We perform trend analysis using primary statistical methods to identify long-term patterns of change in the CDD and CWD data.

The Mann-Kendall Test is employed to identify significant trends within a data series. This test is great because it doesn't make any assumptions about how the data is distributed. This means it can be used with climatological datasets that often don't follow a normal distribution or have outliers. Confidence levels of 90%, 95%, and 99% serve as benchmarks for determining the significance of both positive and negative trends. The Mann-Kendall test has demonstrated its utility in identifying trends that are likely to be statistically significant across different probability levels (Shahid 2010a). This method yields analysis results that are more robust, accurate, and devoid of bias. The findings offer significant insights into climate change, especially regarding the patterns of dry and wet days, which could influence the agricultural sector, water resources, and public health in the region under study. This information can assist policymakers, urban planners, and disaster management agencies in enhancing strategic planning and the execution of climate change adaptation and mitigation measures with greater efficacy. Geographic Spatial Analysis (GIS) is utilized to illustrate the distribution of CDD and CWD within the study area and to facilitate comparisons across states.

3.5 Data Visualization

Data visualization is essential for effectively communicating the results of the analysis. This research employs a range of visualization techniques to depict trends and variations in the Consecutive Dry Days (CDD) and Consecutive Wet Days (CWD) indices along the East Coast of Peninsular Malaysia from 1969 to 2019. The data is represented through GIS graphs and mapping techniques. The outcomes of the yearly analysis are represented through line graphs. This graph illustrates the trend of changes in CDD and CWD over the course of the study period. This line graph presents annual values for each parameter, effectively illustrating the direction and magnitude of change. Furthermore, a moving average has been incorporated into the graph to enhance the clarity of the long-term trend and mitigate the impact of significant annual fluctuations. This graph facilitates the identification of distinct periods exhibiting notable increases or decreases in CDD or CWD. Thematic maps are created to demonstrate the spatial distribution of maximum values of CDD and CWD within the study area. This analysis employs Geographic Information System (GIS) software, including QGIS and ArcGIS, to generate high-resolution maps. This map illustrates the regions exhibiting the highest values for both parameters by coloured symbols or gradients, thereby enhancing the ability to identify areas susceptible to extreme dry or wet days. Legends, directional signs, and geographic coordinates supplement this map to ensure a clear and precise presentation of information. The integration of line graphs with GIS mapping offers a comprehensive view of the temporal and spatial trends of CDD and CWD indices. This resource serves as an effective visual aid for policymakers, researchers, and stakeholders to comprehend the implications of climate change in the East Coast region. A discussion is held to connect the study results with climate factors, including variations in monsoon patterns and the El Niño and La Niña phenomena. This study looks at the results in more detail by comparing them to earlier research to find out how consistent the changes in the distribution of rainfall along the East Coast of Peninsular Malaysia are and what they mean.

4.0 Results

4.1 Annual Precipitation

Figure 3 illustrates the distribution of annual precipitation (PRCPTOT) across the East Coast states of Peninsular Malaysia for the years 1981 to 2019. The highest recorded precipitation value occurred in 2016, exceeding 2000 mm, which signifies a notable peak in the annual precipitation distribution pattern. Conversely, the minimum precipitation value was documented in 2015, measuring approximately 1300 mm. This denotes the year that experienced the lowest precipitation rate throughout this study period. The most notable change trend took place between 1995 and 1996, characterized by a substantial rise in precipitation that indicated a sudden shift in the annual pattern. On the other hand, the early 1980s saw the least change, with the precipitation value remaining nearly constant and showing no significant fluctuations. The analysis of precipitation patterns over the decades revealed significant variations. During the 1980s, the alterations were relatively modest, characterized by minor fluctuations in annual precipitation levels. In the 1990s, changes in precipitation became more evident, with significant variations in amounts occurring between specific years, particularly noted in the middle of the decade. We observed a notable increase in precipitation amounts during the 2000s. This indicates a more defined trend towards an increase in the overall distribution of annual precipitation. During the 2010s, the observed pattern exhibited increased erraticism, with certain years documenting extreme precipitation values at either end of the scale. A comprehensive analysis indicates that the observed patterns and distributions in annual precipitation exhibit characteristics of uncertainty, which may be linked to shifts in regional climate. The significant decline in 2015 followed by a substantial rise in 2016 demonstrates considerable fluctuations that greatly affect the annual average. The observed consistency of increased precipitation values in specific decades indicates the presence of wetter periods, whereas abrupt decreases or years characterized by low values suggest the potential for drought conditions or significant deficiencies in rainfall. This analysis indicates that, despite the variable patterns observed, total precipitation exhibits a tendency to rise in specific decades, with a distinct trend becoming increasingly evident as the study period nears 2020.

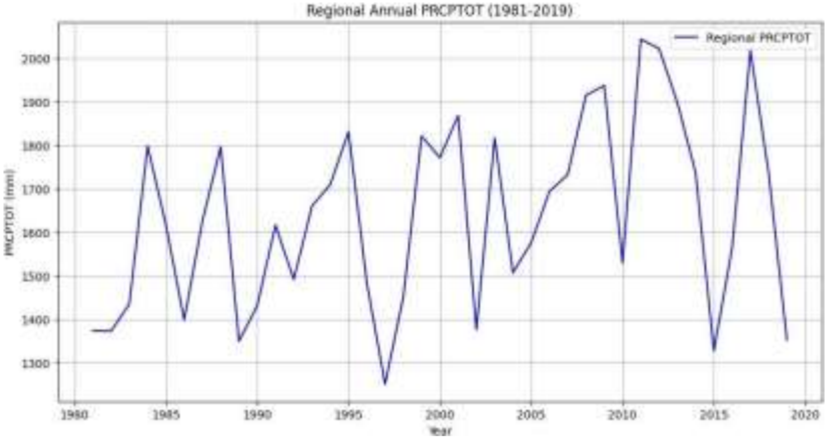

Figure 3: Precipitation Distribution on the East Coast of Peninsular, Malaysia

Figure 4 indicates the notable trend in annual precipitation change (PRCPTOT) for the period from 1981 to 2019. The blue gradient on the map illustrates the variation in precipitation rates measured in mm/year, with darker shades of blue signifying a more substantial increase in total annual precipitation. Locations marked with black dots indicate areas that exhibit a significant change trend at the $p < 0.05$ level, signifying a high level of statistical confidence in the observed changes within those regions. The northern East Coast region, particularly the state of Kelantan and the majority of Terengganu, demonstrates a notable upward trend in precipitation levels. In Kelantan, districts including Kota Bharu, Pasir Mas, and Tumpat demonstrate a notable upward trend, with many areas represented in dark blue and marked by black dots. This suggests that these districts are likely to experience increased rainfall during this period. In the interior regions of Kelantan, including Gua Musang, an increase in precipitation is observable, albeit at a less pronounced rate, as indicated by the map featuring a lighter blue hue and the absence of black dots. Furthermore, an examination of Terengganu reveals that coastal districts, including Kuala Terengganu, Marang, and Dungun, exhibit a trend like that of Kelantan, as evidenced by the dark blue coloration and the presence of black dots that signify a notable rise in precipitation. The inland regions of Terengganu, including Hulu Terengganu, exhibit an increase, though it is less pronounced. This indicates a more measured rate of change in contrast to coastal regions. Conversely, the state of Pahang, particularly in the southern regions including Kuantan, Pekan, and Rompin, exhibits an increase in precipitation, albeit at a lower rate compared to the northern areas of the East Coast. The increase is indicated by the more vibrant blue hue and the absence of black dots. This indicates that this area exhibits lower statistical significance. The districts in the central and western regions of Pahang, including Temerloh and Jerantut, exhibit no significant change. This map illustrates that the change in annual precipitation distribution is notably more pronounced in the northern regions of the East Coast, particularly with a marked increase in areas adjacent to the coast and the northern border of Peninsular Malaysia. This analysis suggests that weather changes may be more pronounced in regions that are more susceptible to the effects of the South China Sea and the northeast monsoon system.

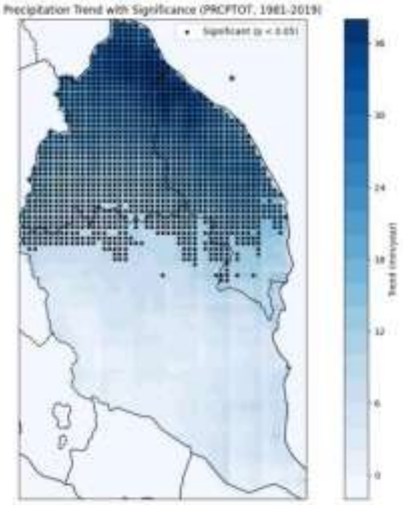

Figure 4: Precipitation Distribution on the East Coast of Peninsular, Malaysia

4.2 Distribution of Maximum Consecutive Dry Days (MCDD)

Figure 5 illustrates the trend of Maximum Consecutive Dry Days (MCDD) in the eastern coastal states of Peninsular Malaysia spanning from 1981 to 2019. MCDD denotes the count of consecutive days experiencing minimal rainfall (≤1 mm), offering valuable insight into the prevailing dry weather pattern in this region. The MCDD graph illustrates a distinct annual trend. The peak value was noted in 2005, with a maximum dry period surpassing 22 days, whereas the lowest value was observed in 1983, featuring a dry period of under 8 days. The most substantial change took place from 2004 to 2005, marked by a noteworthy increase of 10 days, whereas the least variation was observed during the 2010s, characterized by more stable annual dynamics. This figure presents the annual analysis of Maximum Consecutive Dry Days (MCDD) for the period from 1981 to 2019, indicating the maximum number of consecutive dry days recorded in each year. The MCDD value exhibited notable fluctuations during this period, lacking a distinct trend of either increase or decrease. The year 1982 experienced a notable initial spike, with values surpassing 20 days, followed by a marked decline in 1984 to below 10 days, indicating a significant shift in the dry period during that timeframe. The MCDD values from the 1980s and early 1990s exhibited a fluctuating pattern, averaging approximately 12–16 days while lacking the extreme spikes observed in the early 1980s. In the subsequent years, the MCDD values remained relatively stable, until 1999, which recorded one of the lowest values during the study period, approximately 8 to 9 days. Subsequently, the graph indicates a steady rise, culminating in its peak in 2005, where values surpassed 22 days, marking this year as the one with the longest maximum dry period throughout the study duration. In the subsequent decades, the graph illustrates a more equitable distribution pattern. Following the significant peak in 2005, MCDD values experienced a decline to more moderate levels during the mid to late 2000s, yet they continued to exhibit notable fluctuations ranging from 10 to 15 days. From 2010 to 2019, the data exhibited a stable trend, with MCDD consistently ranging between 13 and 15 days and demonstrating minimal fluctuations. Nonetheless, this period continued to exhibit characteristics of fluctuations that indicate regional climate variability.

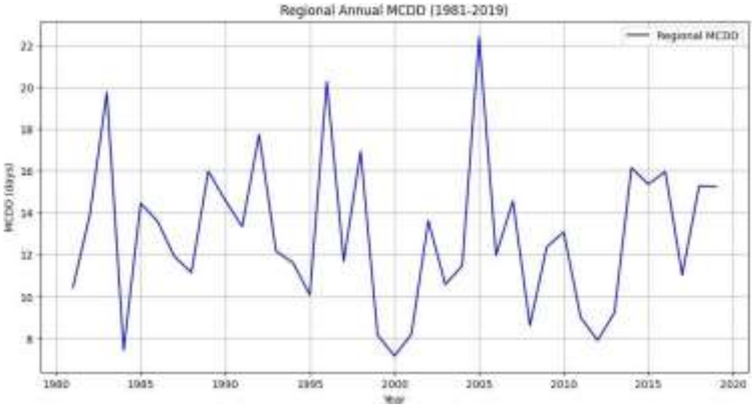

Figure 5: Maximum Number of Dry Days on the East Coast of Peninsular, Malaysia

Figure 6 illustrates the trend of changes in Maximum Consecutive Dry Days (MCDD) on the East Coast of Peninsular Malaysia, encompassing the states of Kelantan, Terengganu, and Pahang, for the period from 1981 to 2019. The map's colours illustrate the direction and magnitude of annual changes in MCDD, with blue signifying a reduction in the number of consecutive dry days and red denoting an increase in the number of consecutive dry days. The colour depth signifies the extent of the change, with darker hues representing a more substantial transformation. Black dots represent regions that exhibit a statistically significant trend ($p < 0.05$), whereas areas lacking black dots indicate an insignificant trend. In Kelantan, the northern regions including Jeli, Pasir Mas, Kota Bharu, and Tanah Merah exhibit a range of light to dark blue hues, indicating a declining trend in MCDD. The reduction observed is notable in various areas, particularly in Jeli and Tanah Merah, where the change rate reaches as much as -0.27 days annually. This suggests that these regions are witnessing a reduction in the frequency of consecutive dry days, potentially because of heightened rainfall or a more consistent rainfall distribution. Nevertheless, regions in the southern part of Kelantan, including Gua Musang, exhibit a more consistent trend with no significant fluctuations. In Terengganu, the northern districts, including Besut and Hulu Terengganu, exhibit a declining trend in MCDD, with certain areas demonstrating statistical significance. The predominant blue hue observed in these districts indicates a decrease in consecutive dry periods. Nonetheless, the central and southern regions of Terengganu, including Marang, Dungun, and Kemaman, exhibit a varied pattern. The Dungun District exhibits a modest increase in MCDD, indicated by a light red colour, whereas Kemaman demonstrates a more pronounced upward trend with areas that are statistically significant. Most districts in Pahang, particularly in the central and southern regions, exhibit a notable upward trend in MCDD. Districts including Jerantut, Temerloh, Raub, and Lipis exhibit a range of light to dark red hues, indicating a rise in the number of consecutive dry days by up to +0.27 days annually. Certain regions, including Bera, demonstrate a notable trend, indicating a steady upward trajectory. In the northern region of Pahang, including Cameron Highlands, this trend is less pronounced, exhibiting smaller and statistically insignificant changes. This map illustrates the distinct patterns present in each state. The prominent red regions illustrate that the rise in the number of dry days is particularly significant in certain areas, notably in the central and southern sections of the east coast. In contrast, the blue colour indicates that certain regions of the north and interior are experiencing a reduction in the number of dry days, suggesting a potential rise in the frequency of rainfall in specific areas.

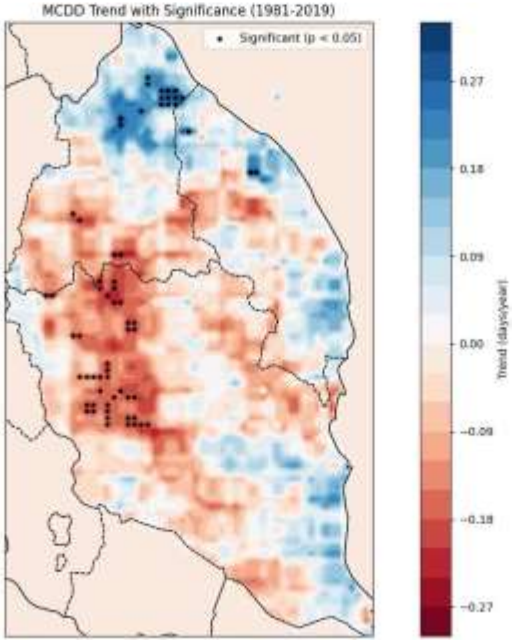

Figure 6: Maximum Number of Dry Days on the East Coast of Peninsular, Malaysia.

4.3 Distribution of Maximum Consecutive Wet Days (MCDD)

Figure 7 illustrates the annual pattern of Maximum Consecutive Wet Days (MCWD), representing the maximum number of consecutive wet days for the East Coast of Peninsular Malaysia, which includes the states of Kelantan, Terengganu, and Pahang, throughout the study period from 1981 to 2019. The vertical axis denotes the quantity of MCWD days, whereas the horizontal axis reflects the corresponding study year. The blue line illustrates the yearly fluctuations of MCWD, highlighting notable shifts in distribution throughout the specified period. MCWD denotes the maximum number of consecutive days within a year that experience significant rainfall (≥1 mm), offering valuable insights into the intensity and duration of prolonged rainfall events in the region. This graph illustrates a dynamic annual pattern, with the peak MCWD value recorded in 2016, reaching approximately 14 days. These years may suggest prolonged and significant rainfall durations. On the other hand, we noted the minimum MCWD value in 1990, which coincided with a continuous rainfall duration of approximately 6 days. Recent years indicate the briefest duration of rainfall in terms of the number of consecutive rainy days annually. The MCWD value throughout the study period exhibited notable fluctuations, lacking a distinct trend of either an upward or downward trajectory. The 1980s exhibited a notable fluctuation, with an average MCWD value ranging from approximately 8 to 13 days. The initial significant increase was noted in 1984 when the MCWD value rose sharply to approximately 14 days, subsequently followed by a notable decline to under 8 days in 1990. During the 2000s, the graph illustrates a more gradual yet still dynamic transformation. Following 1999, there was a steady rise leading to the subsequent peak in 2003, where the MCWD value reached approximately 13 days. Subsequently, the MCWD value experienced a decline, stabilizing at a more moderate level in the late 2000s and averaging approximately 8 to 10 days. The 2010s exhibited a more consistent pattern while still preserving its fluctuating traits. The MCWD throughout this period consistently ranged from 8 to 13 days, reaching its highest peak in 2016. This year has been characterized by one of the notable extended rainy periods observed during the study timeframe, likely attributable to regional climate anomalies. Towards the conclusion of the decade, the graph indicates stability with MCWD values ranging from 10 to 12 days, demonstrating a more balanced rainfall pattern. The MCWD graph indicates significant variability in consecutive rainy periods on the East Coast of Peninsular Malaysia. This variation illustrates the interplay of global climate phenomena, including El Niño and La Niña, alongside local influences such as monsoon patterns and the region's topography. This data is crucial for comprehending the rainfall dynamics in the region, particularly in relation to the complexities of climate change.

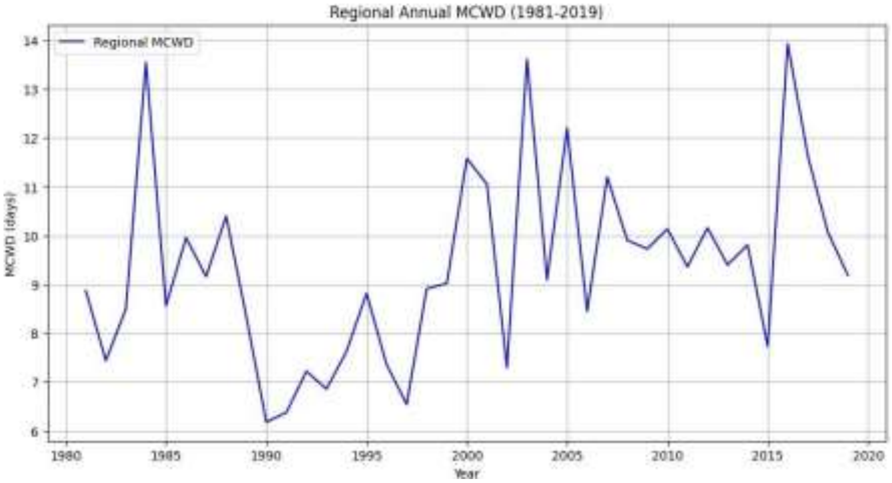

Figure 7: Maximum Number of Wet Days on the East Coast of Peninsular, Malaysia

Figure 8 presents an analysis of the trend changes in the maximum consecutive wet days (MCWD) on the east coast of Peninsular Malaysia, encompassing the states of Kelantan, Terengganu, and Pahang from 1981 to 2019. The map uses a colour scheme to represent the magnitude of trend changes, measured in "days per year." Blue signifies an increase in the number of consecutive wet days, indicating a positive trend, whereas red denotes a decrease in consecutive wet days, reflecting a negative trend. The presence of black dots on the map signifies regions exhibiting statistically significant changes, characterized by a p- value of less than 0.05. Kelantan exhibits notable differences in the MCWD trend pattern. In the central and western regions of the state, including districts like Kota Bharu, Pasir Mas, and Bachok, red is the dominant colour. This suggests a declining trend in the frequency of consecutive wet days in this region, which may affect water resources and agricultural practices, particularly in rice cultivation. Conversely, the eastern and northern regions of Kelantan, including Jeli, Tanah Merah, and the Gua Musang area, exhibit blue alongside the presence of black dots. This demonstrates a notable rise in the frequency of consecutive wet days in the specified regions. This trend indicates a sustained rise in rainfall within the region. Furthermore, in Terengganu, a notable distinction exists in the patterns observed across the northern, central, and southern regions. The northern regions, including Besut and Setiu, predominantly exhibit red, indicating a reduction in the number of consecutive wet days. This may elevate the long-term risk of drought in this region. Central and inland regions, including Hulu Terengganu, exhibit a blue hue, indicating a rise in the frequency of wet days. The southern regions of Terengganu, including Dungun and Kemaman, exhibit a varied pattern, with certain areas experiencing a modest increase, while others reflect a decline. The state of Pahang exhibits a more intricate pattern. The western and central regions of Pahang, including districts like Temerloh, Maran, and Bentong, seem to exhibit areas marked in blue with numerous black dots present. This suggests a notable rise in the frequency of consecutive wet days in this region, potentially benefiting water resources and agricultural practices. In the eastern regions of Pahang, including Kuantan and Pekan, along with coastal areas, there is a notable prevalence of red, indicating a reduction in the number of consecutive wet days. The east coast of Peninsular Malaysia exhibits varied trends in MCWD change, with inland regions generally experiencing an increase in consecutive wet days, whereas coastal areas demonstrate a decline. This modification illustrates the unpredictability's in weather patterns resulting from global climate change, alongside local influences such as alterations in land use and urban development.

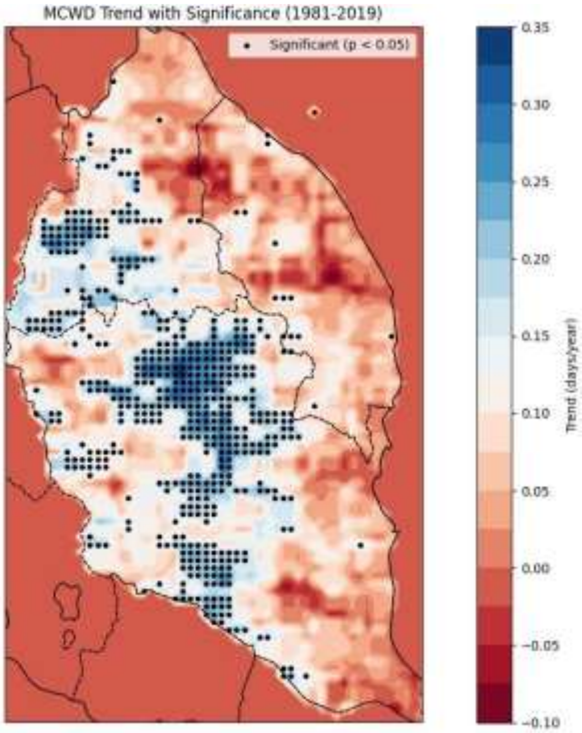

Figure 8: Maximum Number of Wet Days on the East Coast of Peninsular, Malaysia

5.0 Discussion

The findings of the study offer a comprehensive overview of the alterations in annual precipitation distribution on the East Coast of Peninsular Malaysia from 1981 to 2019. In this case, the graph showing the changes in the annual distribution of precipitation shows patterns and trends over time, while the map shows features of space, such as areas that see big changes or small changes over the same time period. The connection between this graph and the map offers a more thorough understanding of regional climate patterns. The highest precipitation values recorded in 2016, as illustrated in the graph, correspond with notable regions on the map, particularly in the northern section of the East Coast, including Kelantan and Terengganu. The Malaysian Meteorological Department (2016) reported that the year 2016 was linked to the La Niña phenomenon, which typically results in heightened rainfall in tropical areas, including Malaysia. This transition is underpinned by a notable trend in the northern region, as evidenced by the dark blue hue and the presence of black dots on the map. Conversely, the low precipitation values in 2015 depicted in the graph indicate regions on the map that exhibit less pronounced rates of change, particularly in the southern section of the East Coast, including Pahang. The Malaysian Meteorological Department (2015) reported that the year 2015 was linked to a significant El Niño phenomenon, which typically results in drought conditions and decreased rainfall across the Southeast Asian region. This will impact economic activities, including agriculture, business, and others. This aligns with the perspective of Piratheeparajah, N. (2022), who noted in his research that farmers across different regions, including Kelantan, Malaysia, encounter comparable challenges related to climate change, such as droughts and unforeseen floods that frequently jeopardize the sustainability of agriculture and water resources. The map indicates that the southern regions, including Kuantan, Rompin, and Pekan, experienced a negligible increase, represented by a faded blue colour and a lack of black dots, illustrating the impacts of El Niño, which reached its peak during that year.

The MCDD trend map from 1981 to 2019 indicates that the peak MCDD value in 2005 signifies a notable rise in dry days, particularly in the interior regions of southwestern Kelantan and central Terengganu. This period is thought to be affected by the significant El Niño phenomenon that took place in 2004–2005, resulting in a reduction of rainfall in Malaysia (Tangang et al., 2007). During the mid-1980s, particularly in 1985, the northeastern coastal region observed a rise in rainfall, resulting in diminished MCDD values. The northeast monsoon of 1985 was notably active, as indicated by regional climatological data. This condition resulted in increased rainfall frequency in northern regions, including Kelantan and Terengganu (Tangang et al., 2007). The monsoon wind flow transports elevated humidity from the South China Sea, resulting in frequent rainfall and a decrease in the number of maximum dry days (MCDD). The Malaysian Meteorological Department (2023) indicates that the Northeast Monsoon is associated with significant rainfall, particularly affecting the states along the east coast of Peninsular Malaysia, western Sarawak, and eastern Sabah. For MCWD, notable years like 1983, 2005, and 2017 illustrate the La Niña phenomenon, which contributes to increased heavy rainfall and extended wet periods. In contrast, years with lower performance, such as 1992 and 2016, may be associated with the El Niño phenomenon, which leads to a weakened monsoon season and diminished rainfall (Suhaila & Jemain, 2012). Regions including Kelantan, Terengganu, and Pahang experienced elevated MCWD during significant flood years, notably in 2005, 2014, and 2017, attributed to successive heavy rainfall (Suhaila & Jemain, 2012). Coastal regions like Kuala Terengganu and Kota Bharu exhibit distinct MCWD patterns, which are characterized by shorter consecutive rainfall durations in comparison to inland areas (Yusop et al., 2007). The socio-economic conditions of the residents will be impacted, as they rely on weather conditions. Roslan et al. (2023) indicate that informal sector workers and farmers are the most impacted groups, as their income is contingent upon weather conditions. For instance, significant rainfall and flooding hinder the sales of small traders, while agricultural yields diminish during periods of drought.

6.0 Conclusion

In summary, the examination of rainfall distribution along the east coast states of Peninsular Malaysia from 1981 to 2019 reveals notable alterations attributed to climate change and weather events such as El Niño and La Niña. Regions like Kelantan and Terengganu experienced notable rises in annual rainfall, particularly during La Niña years, whereas southern areas such as Pahang faced greater susceptibility to drought conditions because of El Niño. The examination of Consecutive Dry Days (CDD) and Consecutive Wet Days (CWD) offers a comprehensive understanding of the rise in weather extremes, highlighting the extension of both dry and wet intervals. This data illustrates the direct effects of climate change on rainfall patterns in the region, which carries significant implications for water resources, agriculture, and the sustainability of local ecosystems. Potential impacts of climate change in Malaysia include rising sea levels, declining crop yields, increased disease in forest species, biodiversity loss, coastal erosion, more severe flooding, coral reef bleaching, increased disease incidence, coastal tidal flooding, reduced water availability, and more frequent droughts (Abdul Rahman et al., 2013). This study underscores the critical importance of comprehending the evolving precipitation patterns on the east coast of Peninsular Malaysia to effectively address the challenges posed by climate change. The insights derived from this analysis can support policymakers in formulating effective strategies for water resource management and disaster mitigation, including floods and droughts. Furthermore, it is crucial for researchers, authorities, and local communities to collaborate to create sustainable and adaptive solutions to climate change. By adopting a proactive strategy, we can mitigate negative effects on livelihoods and the economy, thereby promoting enhanced sustainability for future generations.

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