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Assessing rainfall trends and variability in a climate change

Muhammad Fahmi Muhammad Iskandar[1], Anas Ibrahim[1*], Zul Azmi Mohtar[1], Muhammad Faizal Pakir Mohamed Latiff[1], Nasehir Khan E.M Yahaya[2]

[1]Civil Engineering Studies, Universiti Teknologi MARA Cawangan Pulau Pinang, 13500 Permatang Pauh, Pulau Pinang, Malaysia
[2]National Institute Water Research Malaysia (NAHRIM), 43300 Seri Kembangan, Selangor, Malaysia

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ABSTRACT

Southeast Asia, home to a population of 691.97 million people, faces significant challenges related to rainfall patterns. This study critically reviews 40 articles to explore the intricate rainfall patterns across 11 Southeast Asian countries, examining seasonal variations, impacts, influencing factors, and mitigation strategies. The objective is to develop a comprehensive understanding of rainfall dynamics in the region, particularly its influence on the region's ecosystem and livelihoods. The analysis reveals distinct seasonal periods, with June to September marking the peak rainfall period due to the summer monsoon season, while November to April signifies the onset of dry seasons in several countries. Rainfall impact range plays a crucial role in the economies of nations, particularly in the agricultural sector, where it serves as a vital source of sustenance. However, it also poses risks, including flooding, landslides, and drought. The study emphasizes the significant role of the El Niño Southern Oscillation (ENSO) in influencing rainfall variability across Southeast Asia, with El Niño events often associated with drier conditions and La Niña events with wetter conditions. To mitigate these challenges, Southeast Asian nations have implemented various strategies, including infrastructure development, community-based initiatives, and awareness campaigns. Further research is needed to explore specific factors influencing rainfall in each country, develop more accurate forecasting models, investigate innovative mitigation strategies, and evaluate the effectiveness of existing measures.

1. INTRODUCTION

The rainfall patterns in Southeast Asia play a pivotal role in shaping the region's ecosystem and livelihoods. This sub-tropical area, located east of India and bordered by Korea, Japan, China, Australia, and Papua

[1*] Corresponding author. *E-mail address*: ceanas@uitm.edu.my
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New Guinea, encompasses 11 countries (Fig. 1), including Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, and Vietnam. With a population of 691.97 million (Fig. 2), Southeast Asia accounts for 8.52% of the global population and ranks as the third most populous subregion in Asia. Notably, 52.2% of the population resides in urban areas, reflecting a growing trend of urbanization. The median age in Southeast Asia stands at 30.5 years, showcasing a relatively young population demographic (The World Bank, 2024).

Fig. 1. Southeast Asia map

Source: Vectorstock.com

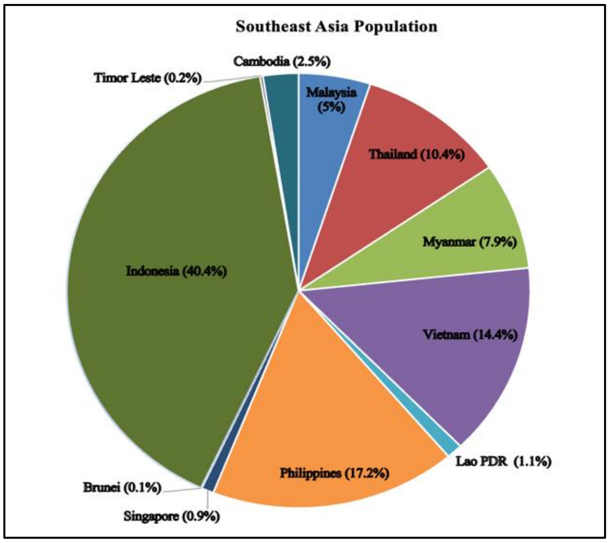

Fig. 2. Southeast Asia Population

Source: The World Bank, 2024

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1.1 Rainfall pattern

In rainfall pattern, 'persistence' signifies a tendency for current rainfall trends to continue, while 'anti-persistence' indicates a reversal in the direction of rainfall from the previous period. The region's rainfall patterns are influenced by the monsoon and El Nino Southern Oscillation (ENSO) extremes, resulting in diverse climatic characteristics. Research by [1] reveals a mix of anti-persistence and persistence features in Southeast Asia's rainfall patterns. While countries like Cambodia, Laos, Myanmar, and Vietnam experience erratic rainfall distribution characterized by anti-persistence, others demonstrate predictable trends based on historical data, indicating long memory. This variability data poses significant challenges for climate monitoring agencies and governments in Southeast Asia, impacting socioeconomic activities and the well-being of the population.

An in-depth analysis focusing on the Lao People's Democratic Republic (Lao PDR), Thailand, Vietnam, Cambodia, and Myanmar by [2] using Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) from 1981 to 2021 reveals an increasing trend in rainfall across these countries and major river basins. Vietnam exhibits the highest annual rainfall trend at 5.63 mm/year, while Lao PDR shows the lowest trend at 3.16 mm/year. This research highlights the critical role of rainfall as a key climate change indicator, influencing sectors such as agriculture, urban planning, and disaster management in Southeast Asia.

2. METHODOLOGY

For this review paper, a narrative and systematic review was adopted to analyse 40 research papers. This follows the recommendation of [3] which advocates for a minimum of 30 papers for a robust Literature Review Paper (LRP) while cautioning against exceeding 100 papers. This study focuses on analysing research papers concerning rainfall patterns, effects, influencing factors, and mitigation actions across 11 Southeast Asian countries: Thailand, Lao PDR, Myanmar, Philippines, Singapore, Brunei, Malaysia, Indonesia, Timor Leste, Vietnam, and Cambodia. The analysis aimed to delve into rainfall trends, patterns, seasonal variations, effects on the environment and society, factors influencing these patterns, and diverse mitigation strategies implemented within each country. By conducting a country-specific assessment for each nation, this methodology aims to capture the unique nuances of rainfall dynamics in Southeast Asia, tailoring responses to the distinct characteristics of each country. The study primarily analyses data from 2020 to 2022, aligning with the 2023 IPCC press release. Since, 2018, the IPCC has emphasized the urgent challenges of global warming reaching 1.5 °C, which has led to increased extreme weather events globally, potentially impacting Southeast Asia's rainfall patterns. By illustrating the amount of rainfall in Southeast Asia as an indicator of the impact of rising temperatures, based on the IPCC press release, aims to provide a comprehensive understanding of rainfall dynamics in the region for policymakers, researchers, and stakeholders involved in managing and adapting to changing precipitation patterns, offering valuable insights tailored to the region's unique context.

3. DISCUSSION

3.1 Rainfall pattern and trend

In Southeast Asian countries, the timing of peak and low rainfall periods is crucial to understand the seasonal variations and impacts of precipitation. Research by [1] stated in Fig. 3 reveals a mix of antipersistence and long memory features in Southeast Asia's rainfall patterns.

Fig. 3 provides graphical representations that offer valuable insights into the rainfall patterns of various countries (1901 to 2016), highlighting seasonality, persistence, and erratic rainfall trends. Brunei (BRU) displays a relatively consistent level of rainfall throughout the year with minor fluctuations, indicating a

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stable and predictable rainfall regime. Cambodia (CAB) shows a pronounced seasonality with distinct periods of high and low rainfall, likely influenced by the monsoon season. Indonesia (IND) exhibits a somewhat consistent rainfall pattern with a slight inclination towards higher rainfall during specific periods, possibly linked to its tropical rainforest location. Laos (LAS), on the other hand, portrays an erratic rainfall pattern, oscillating between high and very low rainfall periods, hinting at an unpredictable regime influenced by factors like monsoons and ENSO.

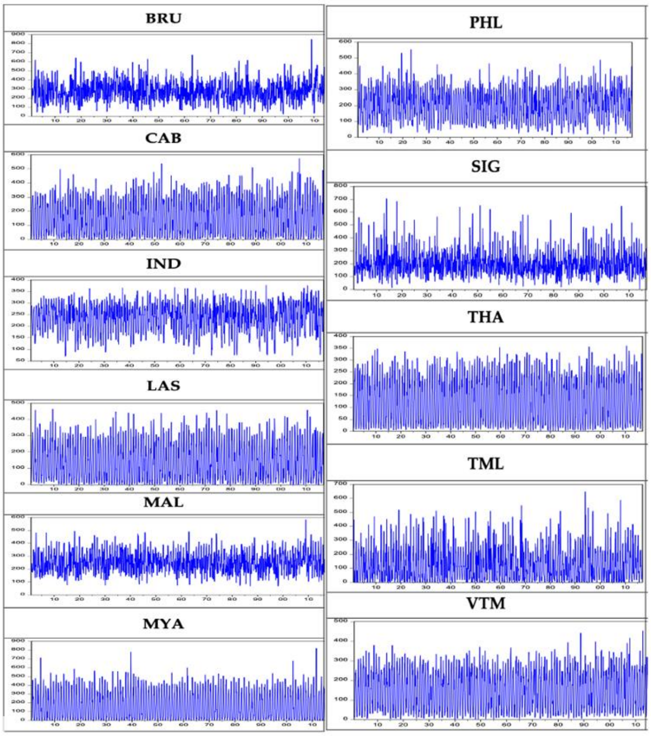

Fig. 3. Time series plot for rainfall data [1]

Malaysia (MAL) experiences relatively consistent rainfall, with slightly higher levels during certain months, suggesting a stable pattern. Myanmar (MYA) showcases a more pronounced seasonality, characterized by distinct periods of high and low rainfall, likely due to the monsoon influence. The Philippines' (PHL) rainfall pattern combines consistent and pronounced seasonal fluctuations, reflecting a regime influenced by stable and variable factors. Singapore (SIG) exhibits a relatively consistent pattern with a slight tendency towards higher rainfall during specific periods, indicating stability. Thailand (THA) displays a pronounced seasonality with distinct high and low rainfall periods, likely driven by monsoon impacts. Timor-Leste (TML) experiences an erratic and unpredictable rainfall pattern, influenced by monsoons and ENSO, while Vietnam (VTM) shows pronounced seasonality, reflecting the monsoon's influence.

Through the review from various articles, Figure 4 presents a comprehensive summary of recent rainfall patterns in Southeast Asian countries, where a rainfall amount of 300mm is considered substantial as indicated by [4]. The categorization of rainfall by BMKG includes four distinct categories: 0 – 100 mm/month classified as low, 100 – 300 mm/month as medium, 300 – 500 mm/month as high, and >500 mm/month as very high. Notably, the analysis reveals diverse peak periods of rainfall which exceed

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300mm, with a particular emphasis on the summer monsoon season from May to August, during which six out of the eleven countries studied exhibit high levels of rainfall, namely Thailand, Lao PDR, Myanmar, Cambodia, Vietnam, and the Philippines.

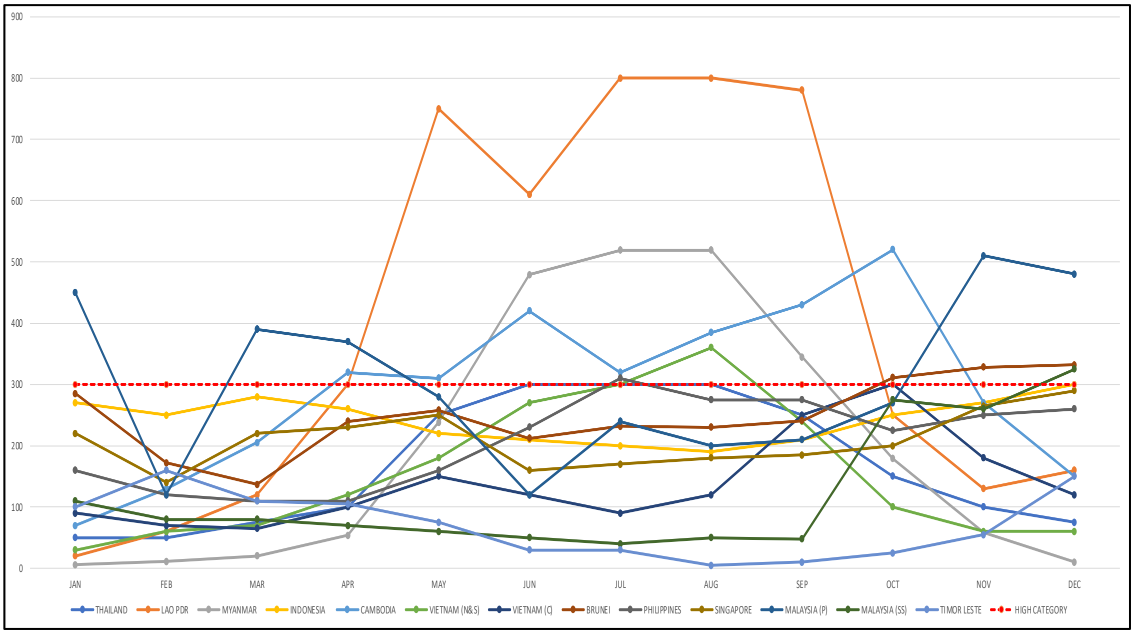

Fig. 4. Rainfall amount in Southeast Asia (a year)

On the other hand, Thailand experiences strong interannual variation in summer rainfall, with peaks occurring during the summer monsoon season from June to September, making the country vulnerable to floods and droughts [5]. Likewise, Laos PDR sees increased rainfall during the rainy season from May to September, coinciding with the southwest monsoon. However, it also experiences a distinct dry season from November to April [6]. Myanmar's southwest monsoon season from May to October witnesses heavy rainfall, largely influenced by the positive correlation between sea surface temperature and rainfall variability [7].

Indonesia's rainfall pattern features distinct wet and dry seasons, with the wet season typically from December to February during the southern hemisphere summer monsoon [8]. Cambodia experiences a wet season from May to October, with significant trends in extreme rainfall events and fluctuations in precipitation intensity between the wettest and driest months [9]. In Vietnam, the rainy season varies regionally, with the northern and southern parts experiencing tropical westerly winds from mid-May to September, while central Vietnam encounters a dry season due to the Foehn effect from the Truong Son Mountain range [10].

Brunei Darussalam is experiencing an increasing trend in annual rainfall, with peak precipitation occurring from late October to early January during the northeast monsoon and from May to July in the southwest monsoon season [11]. The Philippines anticipates a rise in extreme rainfall events by 2100, with the wet season from June to September being the peak period for heavy precipitation in different regions of the country [12]. Singapore reports an increase in rainfall frequency and intensity, with its wet season during the northeast monsoon from the end of October to early March and the southwest monsoon from June to September [13-14].

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Timor-Leste experiences a decreasing trend in annual rainfall, with its rainy season from December to May showing reduced precipitation over the years [15]. In Peninsular Malaysia, the period between November to February marks the northeast monsoon with high rainfall, while the southwest monsoon from May to August exhibits lower precipitation levels, emphasizing the seasonal variations in rainfall across the country [16]. These distinct patterns in peak and low rainfall periods reflect the diverse climate dynamics and seasonal fluctuations observed in Southeast Asia, influencing the vulnerability and resilience of these nations to changing precipitation patterns. According to [17], East Malaysia receives an average annual rainfall of 2,550 mm per year due to the presence of yearly monsoon seasons. The southwest monsoon season starts in April and lasts until October, while the northeast monsoon season starts in October and lasts until February. Additionally, Sabah experiences an annual rainfall ranging from 1,920 to 3,190 mm, while Sarawak sees rainfall levels ranging from 3,300 mm near the coast to 4,600 mm further inland.

Across Southeast Asian countries, Table 1 explains the dynamics of rainfall patterns, revealing distinct seasonal variations impacting the region's vulnerability and resilience to precipitation fluctuations. The analysis indicates that June to September is a crucial period for most nations, marked by the peak of heavy rainfall during the summer monsoon season. In contrast, November to April stands out as a time of reduced precipitation levels, reflecting the onset of dry seasons in several countries. Notably, this seasonal contrast underscores the importance of understanding peak and low rainfall periods in shaping the region's climate dynamics and responses to changing precipitation patterns. Such insights are essential for improving preparedness, mitigating risks, and fostering sustainable adaptation strategies in the face of evolving climatic conditions in Southeast Asia.

Table 1. Southeast Asia's Country Rainfall Season

Country	**Rainfall Season**	**Author**
Thailand	Summer Rainfall Season: June, July, and August	[5]
Lao PDR	Rainy Season: May to September	[6]
Myanmar	Southwest Monsoon Season: June to September (JJAS)	[9]
Indonesia	Wet Season: December to February Dry Season: May to September	[10]
Cambodia	Rainfall Season: May to October	[9]
Vietnam	North and South Vietnam Rainy Season: Mid-May to September Central Vietnam Rainy Season: September to October	[10]
Brunei Darussalam	Rainfall Season: Late October to early January (Northeast Monsoon) Rainfall Season: May to July (Southwest Monsoon)	[18]
Philippines	Rainfall Season: June to September	[12]
Singapore	Northeast Monsoon: End of October to early March Southwest Monsoon: June to September	[13-14]
Timor Leste	Rainfall Season: December to May	[15]
Peninsular Malaysia	Northeast Monsoon (NEM): November to Feb Southwest Monsoon (SWM): May to Aug	[19]
East Malaysia	Southwest Monsoon Season: April to October Northeast Monsoon Season: October to February	[17]

3.2 Rainfall impact

In analysing the impact of rainfall, it is essential to consider both its positive and negative aspects. On the positive side, rainfall plays a crucial role in the economies of nations, particularly in the agricultural sector, serving as a vital source of sustenance [20]. However, the focus primarily shifts towards addressing the negative repercussions to implement adequate mitigation measures. These adverse consequences include heightened risks of flooding due to increased rainwater, periods of drought resulting from low

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rainfall levels, potential losses of infrastructure, threats to livelihoods, and economic downturns. Addressing these negative impacts becomes imperative to enhance policy formulation and strengthen community preparedness initiatives.

Rainfall patterns in Southeast Asia are highly variable and influenced by factors like the monsoon and ENSO events. This variability can lead to significant negative impacts, including an increased risk of flooding (Thailand, Lao PDR, Myanmar, Indonesia, Cambodia, Vietnam, Brunei, Philippines, Singapore, Timor-Leste, Malaysia), landslides (Indonesia, Cambodia, Philippines, Singapore, Timor-Leste, Malaysia), and drought (Thailand, Lao PDR, Myanmar, Indonesia, Cambodia, Vietnam, Brunei, Philippines, Timor-Leste, Malaysia). Accurate analysis of rainfall data is crucial for implementing early mitigation measures, such as improved forecasting models (Thailand, Vietnam), water resource management (Lao PDR, Indonesia, Cambodia, Timor-Leste, Malaysia), flood control infrastructure (Myanmar, Indonesia, Cambodia, Vietnam, Brunei, Philippines, Singapore, Timor-Leste, Malaysia), and community-based disaster preparedness (Myanmar, Indonesia, Cambodia, Vietnam, Brunei, Philippines, Malaysia, Timor-Leste). Table 2 presents case studies highlighting the impacts of rainfall events in various Southeast Asian countries.

Table 2. Case study of effect of rainfall event in Southeast Asia's country

Country	Case study	Author
Philippines	Super typhoon Haiyan (known as Yolanda in local) hit Samar and Leyte, killing at least 6,300 people. Super typhoon Goni in 2020 surpassed Haiyan in strength.	[12]
Timor Leste	Rainfall-induced slope failures were observed in roadways constructed around 2012 due to severe weather conditions.	[21]
Malaysia	Landslide incidents occur in 2017, 2018 at Pulau Pinang and 2020 at Perak due to rainfall.	[22]
	Flash floods have been reported in 2017, 2018, and 2019. This situation causes many problems for residents as property damage occurs every time a flood occurs (Pulau Pinang)	[23]
Thailand	Severe 2011 floods due to record-breaking rainfall, and devastating droughts occur every 6 years in northeastern Thailand.	[5]
Singapore	Eleven landslides in 2006/2007 due to above-average monthly rainfall, affecting stability of low-conductivity slopes.	[24]
Vietnam	Heavy rainfall in Hanoi in 2008 caused by interaction between cold surges and tropical disturbances.	[10]
Brunei	Over 115 flooding cases and 105 landslides were reported in 2014.	[18]
Indonesia	In 2021, Batu City experienced a total of 78 landslides, with the majority taking place in Songgokerto Village, accounting for 15 incidents.	[11]

3.2 Factor of anti-persistence rainfall

Monsoon

Fig. 5 displays the directional movement of winds during the northeast (winter monsoon) and southwest (summer monsoon) episodes in Southeast Asia. During the northeast monsoon, prevailing winds originate from the northeast, travelling towards the southwest direction, while in the southwest monsoon, winds move from the southwest towards the northeast direction. These seasonal wind patterns play a pivotal role in shaping the region's climate and precipitation dynamics. On the other hand, Fig. 6 illustrates the intermonsoon periods, showcasing the transition from winter to summer and summer to winter exchange periods. These transitional phases mark shifts in wind circulation and atmospheric conditions as the region transitions between monsoon seasons. Understanding these wind patterns and transitional phases is essential for comprehending the intricate mechanisms driving monsoons and climate variations in Southeast Asia.

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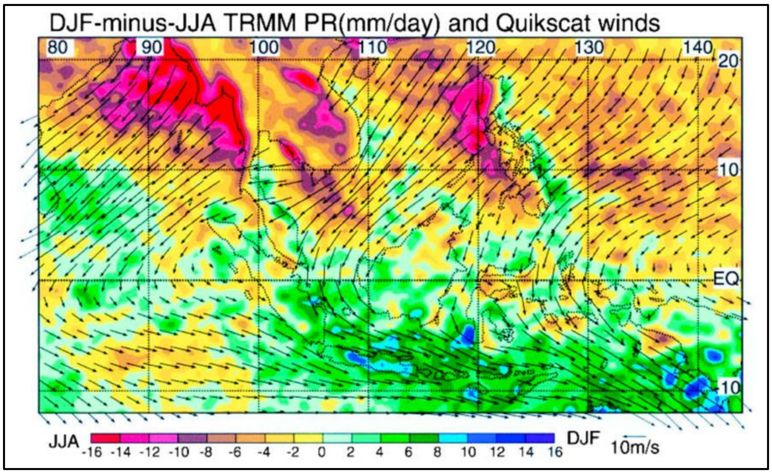

Fig.5. Northeast Monsoon (DJF); Southwest Monsoon (JJA) [25]

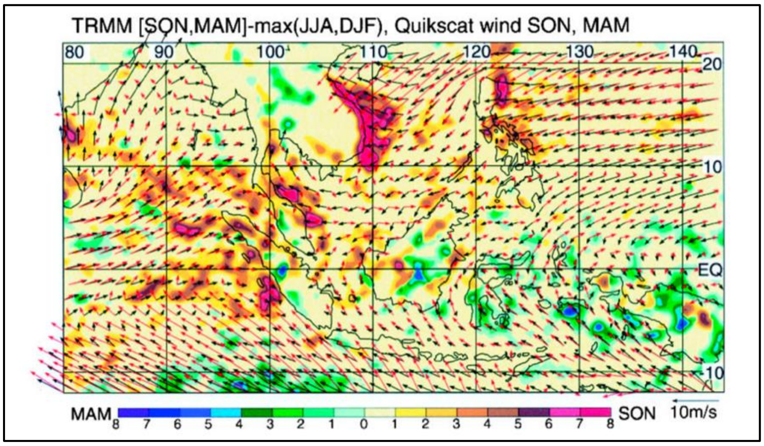

Fig. 6. Intermonsoon (MAM); Intermonsoon (SON) [25]

The monsoon winds in Southeast Asia play a crucial role in the region's water supply, agriculture, and overall climate. These winds shift direction twice a year, creating distinct wet and dry seasons in different parts of the region. For example, in Thailand, the southwest monsoon brings heavy rainfall from June to October, while the northeast monsoon brings drier conditions from November to February. This seasonal wind shift is crucial for agriculture, providing essential moisture for rice cultivation and other crops. However, the monsoon can also bring extreme weather events, such as floods and droughts, which can have devastating impacts on communities and economies.

Researchers have identified several factors that influence the monsoon patterns and rainfall in Southeast Asia, leading to variations in the strength and timing of the monsoon. One crucial factor is the interaction between the complex terrain and the annual reversal of the surface monsoonal winds [25]. The monsoon winds are influenced by the difference in air pressure between the land and the ocean, and the topography of Southeast Asia, with its mountains and valleys, can significantly alter the wind patterns.

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Global warming is another factor that is impacting the monsoon patterns and rainfall in Southeast Asia [26]. The increase in global temperatures has been linked to an increase in precipitation anomalies, particularly after the 1970s. The westward shift of the Indian summer monsoon and the Western Pacific Subtropical High (WPSH) also influence rainfall patterns and the onset of monsoons in the region. Additionally, the El Niño Southern Oscillation (ENSO), a climate pattern that involves the periodic warming and cooling of the central Pacific Ocean, can influence the variability of monsoon rainfall in Southeast Asia.

El Niño Southern Oscillation (ENSO)

Rainfall patterns in Southeast Asia are complex and influenced by a variety of factors, including the monsoon system, the Intertropical Convergence Zone (ITCZ), and the El Niño Southern Oscillation (ENSO). ENSO plays a significant role in influencing rainfall variability across the region. El Niño events are often associated with drier conditions, while La Niña events are associated with wetter conditions. Understanding this relationship is crucial for predicting and managing the impacts of ENSO events on agriculture and other sectors in the region. Climate change is also expected to significantly affect rainfall patterns in Southeast Asia, with many studies predicting an increase in the frequency and intensity of extreme rainfall events. Nino Index or regions are specific areas in the tropical Pacific Ocean where SST anomalies are measured. These regions are used to monitor ENSO events and predict their impacts. Niño 1+2, located in the eastern equatorial Pacific Ocean, from 0° to 10°S and 90°W to 80°W. Niño 3, in the central equatorial Pacific Ocean, from 5°N to 5°S and 150°W to 90°W. Niño 4, in the eastern equatorial Pacific Ocean, from 5°N to 5°S and 160°E to 150°W and Niño 3.4, located in the central equatorial Pacific Ocean, from 5°N to 5°S and 170°W to 120°W as shown in Fig. 7.

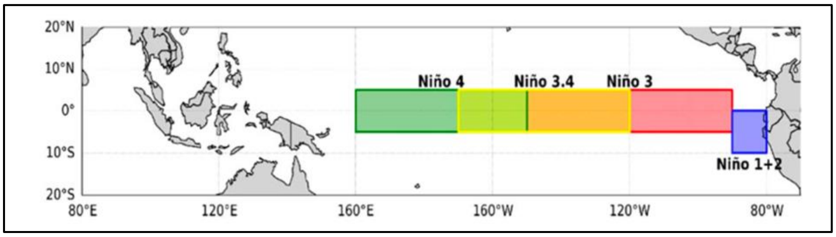

Fig. 7. Nino Index [27]

The El Niño Southern Oscillation (ENSO) is a significant climate pattern that exerts a considerable influence on Southeast Asian weather patterns, as evidenced by numerous studies within the document. It is characterized by fluctuations in sea surface temperatures in the central and eastern Pacific Ocean, oscillating between three phases: El Niño, La Niña, and a neutral phase [28] (Fig. 8). El Niño events, marked by warmer-than-average sea surface temperatures in the central and eastern Pacific, often lead to drier conditions in Southeast Asia, while La Niña events, characterized by cooler-than-average sea surface temperatures, tend to bring wetter conditions [28]. It highlights the specific impacts of ENSO on various Southeast Asian countries, such as the Philippines, Cambodia, Indonesia, and Malaysia, noting that these impacts vary depending on the specific phase of ENSO and the geographic location within Southeast Asia. For example, El Niño events are associated with drier conditions in the Philippines, while La Niña events bring wetter conditions [29]. Similarly, El Niño events typically provide warmer and drier temperatures in Southeast Asia than average, while La Niña episodes usually bring lower temperatures [9]. These climate variations have profound implications for agriculture, fisheries, and other sectors in Southeast Asia, highlighting the importance of understanding ENSO's influence on regional weather patterns.

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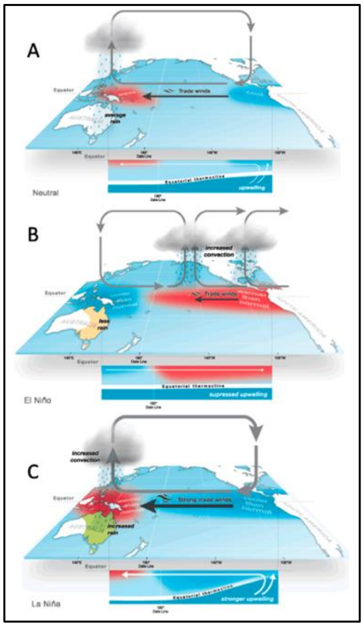

Fig. 8. ENSO phase (a) Neutral; (b) El-Nino; (c) La-Nina [28]

El Niño-Southern Oscillation (ENSO) significantly impacts tropical cyclone activity in the Philippines by changing the conditions that cyclones need to form and grow. When the Pacific Ocean is warmer than usual (El Niño), it weakens the winds that typically bring cyclones, leading to fewer cyclones. However, these cyclones might be stronger. Conversely, when the Pacific Ocean is cooler than usual (La Niña), the winds that bring cyclones become stronger, resulting in more cyclones, but they might be weaker. This means there's a trade-off: more cyclones but less intense, or fewer cyclones but more intense [30].

Diverse climatic phenomena play a crucial role in shaping precipitation patters across Southeast Asia. Various atmospheric and oceanic interactions contribute to regional rainfall trends, with distinct influences observed in different countries. Thailand exhibits a notable correlation between observed rainfall anomalies and the Niño3.4 index, with the IAP model replicating this correlation while underestimating the observed negative correlation [5]. Lao PDR's rainfall trends are significantly impacted by Greenhouse Gas Emissions (GHGs) and climate change (CLiM), with projections indicating an increase in rainfall under different emission scenarios, emphasizing the influence of GHG levels on precipitation variations [6]. Factors such as sea surface temperature (SST) and ocean-atmosphere interactions are found to strongly influence the average trend of June to September (JJAS) rainfall in Myanmar, highlighting the impact of these interactions on precipitation variability [7]. Indonesia's rainfall patterns are notably shaped by the Indian Ocean Dipole (IOD), with regions like southern Sumatra and southern Java Islands exhibiting positive correlations with the negative IOD, while northwestern Sumatra displays positive correlations with the positive IOD, elucidating the significant role of IOD in modulating rainfall distributions [31], [8]. Cambodia's rainfall variability is influenced by the southwest monsoon, with the El Niño Southern Oscillation contributing to interannual fluctuations in monsoon patterns, underscoring the importance of these climate drivers in shaping seasonal precipitation trends [9]. These factors collectively illustrate the complex interplay of climatic elements in dictating rainfall dynamics across Southeast Asia, highlighting the multifaceted nature of regional precipitation trends and the diverse influences that govern seasonal variations in rainfall patterns.

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Indian Ocean Dipole (IOD)

Other climate patterns, such as the Indian Ocean Dipole (IOD) and the Madden-Julian Oscillation (MJO), also impact rainfall in Southeast Asia [32]. These factors, along with the influence of tropical cyclones, create a complex and dynamic system that shapes the monsoon patterns and rainfall in Southeast Asia.

The Madden-Julian Oscillation (MJO) and the Indian Ocean Dipole (IOD) are significant climate patterns that contribute to the variability of rainfall in Southeast Asia [32]. The MJO, an eastward-propagating wave of atmospheric disturbances, can enhance rainfall in the region when it is in a strong phase, but suppress it when it is weak, leading to short-term fluctuations in precipitation [32]. The IOD, characterized by differences in sea surface temperatures between the western and eastern Indian Ocean, influences rainfall distribution over a longer period, with positive IOD events leading to increased rainfall in eastern Indonesia and decreased rainfall in western Indonesia. These two climate patterns, along with other factors like topography and global warming, create a complex and dynamic system that shapes the monsoon patterns and rainfall in Southeast Asia [32].

4. MITIGATION

Southeast Asia nations are actively engaging in infrastructure development and management to mitigate the adverse effects of increasingly erratic rainfall patterns. A key strategy involves the construction and maintenance of flood control systems, with countries like Thailand [5], Lao PDR [16], Myanmar [7], Indonesia [31], Cambodia [9], Vietnam [10], Brunei [18], the Philippines [12], Singapore [24], Timor-Leste [15], and Malaysia [33] investing in dams, levees, and drainage systems to manage extreme rainfall events. Additionally, Brunei [18] and Malaysia [33] are prioritizing the improvement and maintenance of their drainage systems, particularly in urban areas, to handle excess rainwater and prevent flooding. Singapore [24] has implemented slope stability management strategies to mitigate landslide risks, which intensify during periods of heavy rainfall.

Beyond infrastructure, Southeast Asia nations are adopting community-based initiatives and awareness campaigns to bolster resilience against rainfall-related hazards. Myanmar [7], Indonesia [31], Cambodia [9], Vietnam [10], Brunei [18], the Philippines [12], Timor-Leste [15], and Malaysia [33] are actively promoting community-based disaster preparedness programs, educating residents about flood risks and empowering them to take appropriate action. Brunei [18] is raising awareness among residents about flood risks and educating them on preparedness measures, such as evacuation procedures and emergency supplies. Indonesia [34] is taking a leadership role in capacity building, providing training and knowledge-sharing programs to other ASEAN countries in areas like climate change adaptation and mitigation strategies. These efforts highlight the important role of a comprehensive approach, combining infrastructure development, community engagement, and policy changes to effectively address the challenges posed by changing rainfall patterns and climate change.

5. CONCLUSION

As a conclusion, this comprehensive study explores the complex nature of rainfall in Southeast Asia, encompassing its patterns, trends, impacts, contributing factors, and mitigation strategies. The analysis focuses on eleven countries within the region, employing a critical review method by country to understand the unique characteristics and challenges faced by each nation on rainfall. The study reveals distinct seasonal periods, with June to September marking the peak rainfall period due to the summer monsoon season (Lao PDR), while November to April signifies the onset of dry seasons in several countries (Thailand, Myanmar, Vietnam North and South, and Timor Leste).

https://doi.org/10.24191/esteem.v21iMarch.4892.g3087

This study enhances the significant role of the El Niño Southern Oscillation (ENSO) in influencing rainfall variability across Southeast Asia. El Niño events are often associated with drier conditions, while La Niña events are associated with wetter conditions. This study emphasizes the importance of understanding ENSO's influence on regional weather patterns and its implications for various sectors, particularly agriculture and fisheries. Furthermore, explores mitigation strategies implemented by Southeast Asian nations, including infrastructure development, community-based initiatives, and awareness campaigns. These efforts aim to enhance resilience against rainfall-related hazards and highlight the need for a comprehensive approach to address the challenges posed by changing rainfall patterns and climate change. This research serves as an important awareness for Southeast Asia nations to prioritize preparedness measures and invest in comprehensive mitigation strategies to address the complex and evolving rainfall dynamics within the region. Further research is essential to delve deeper into the factors influencing rainfall in each country, develop more accurate forecasting models, investigate innovative mitigation strategies, and evaluate the effectiveness of existing measures.

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7. CONFLICT OF INTEREST

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

8. AUTHOR’S CONTRIBUTION

Anas Ibrahim and **Muhamad Faizal Pakir Mohamed Latiff**: Conceptualization, supervision, formal analysis, investigation, and review; **Muhammad Fahmi Muhammad Iskandar**: Conceptualisation, methodology, and paper writing; **Mohd Zul Azmi Mokhtar**: Conceptualisation, supervision, writing-review and editing, and validation. **Nasehir Khan E. M. Yahaya.** Writing- review and editing, and validation.

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