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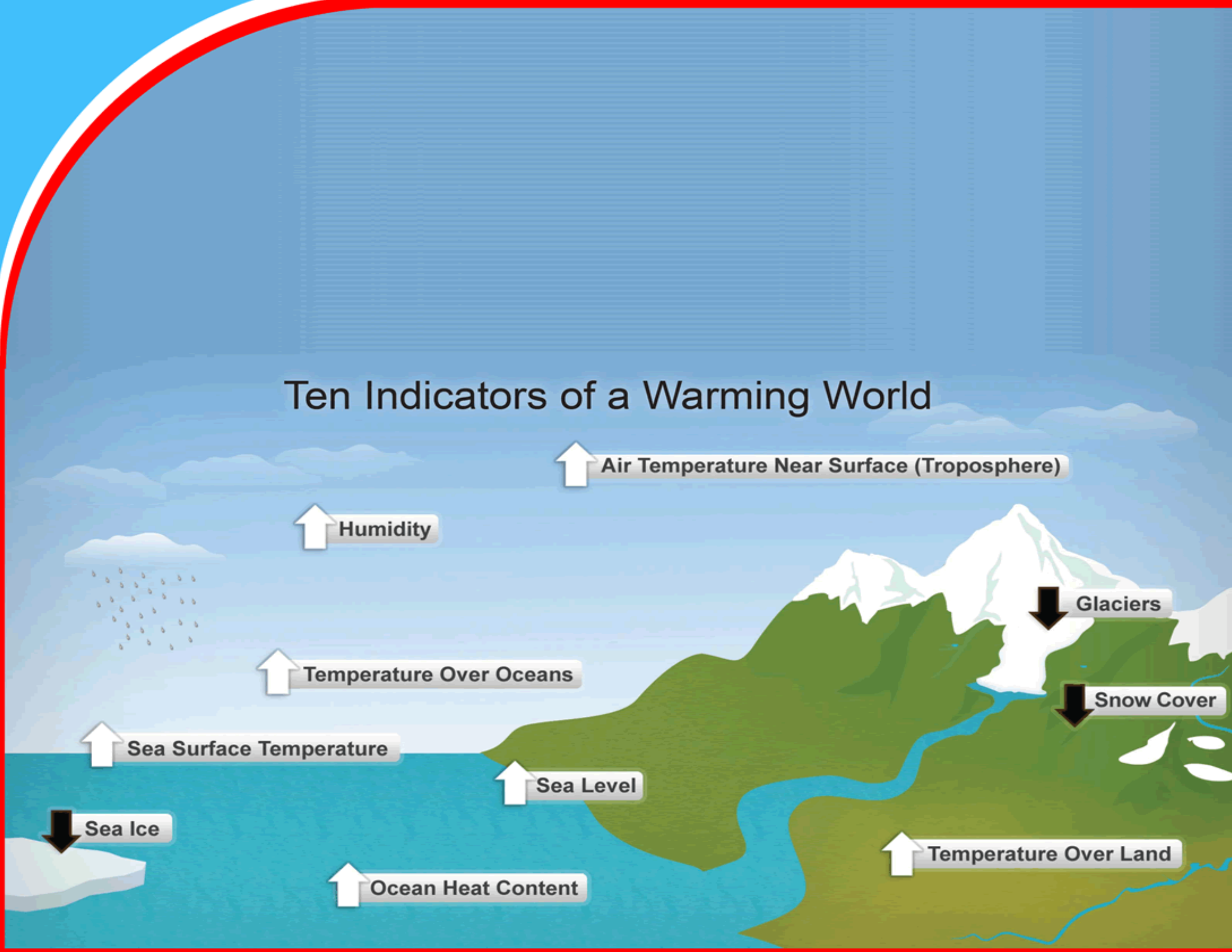

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Abstract

Purpose: The aim of the study was to assess the economic factors influencing the abolition of slavery in the British empire.

Methodology: This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

Findings: The study revealed significant impacts on monsoon patterns and intensity. Anomalies in SST, particularly in key regions such as the Indian Ocean, the Pacific Ocean, and the Atlantic Ocean, can disrupt typical monsoon behavior, leading to variations in precipitation, wind patterns, and seasonal onset and retreat. For instance, warmer-than-average SSTs in the Indian Ocean can enhance monsoon rainfall by increasing moisture availability and convection. Conversely, cooler SSTs can lead to weaker monsoon activity. The El Niño-Southern Oscillation (ENSO) phenomenon, characterized by warm (El Niño) or cool (La Niña) phases in the Pacific Ocean, plays a pivotal role in modulating monsoon variability. El Niño events typically result in suppressed monsoon rainfall over the Indian subcontinent, while La Niña conditions generally enhance monsoon rains. These SST anomalies affect atmospheric circulation patterns, including the strength and position of the monsoon trough and the subtropical jet stream, further influencing monsoon dynamics. The complex interplay between SST anomalies and monsoon variability underscores the importance of monitoring oceanic conditions for accurate seasonal weather predictions and effective climate adaptation strategies.

Implications to Theory, Practice and Policy: Teleconnection theory, walker circulation theory and Indian ocean dipole theory may be used to anchor future studies on assessing the influence of sea surface temperature anomalies on monsoon variability in South Asia. To mitigate the adverse effects of monsoon variability on agriculture, it is crucial to promote the adoption of climate-resilient agricultural practices. Formulating and implementing integrated climate policies that address the impacts of SST anomalies on monsoon variability is essential.

Keywords: *Sea Surface, Temperature, Anomalies, Monsoon Variability*

INTRODUCTION

Monsoon variability, encompassing timing, intensity, and duration, has become increasingly unpredictable in developed economies due to climate change. For instance, in the USA, the Southwest Monsoon has shown a trend towards delayed onset and increased intensity, causing more frequent and severe flooding events. Data from 2018 to 2022 indicate a 20% increase in monsoon-related precipitation, with significant implications for water management and agriculture (Gao, Zhou, Li & Zhang, 2019). Similarly, Japan's monsoon season has experienced shifts, with increased rainfall intensity leading to devastating floods, as observed in the 2020 Kyushu floods, where rainfall exceeded 500mm in just three days (Matsumoto, Kimura & Yoshimura, 2020). These trends underscore the necessity for enhanced climate resilience and adaptive strategies in developed economies.

In developing economies, monsoon variability has profound impacts on agriculture and water resources. India, for example, has witnessed erratic monsoon patterns, with delayed onset and reduced rainfall in some regions while others experience extreme precipitation events, leading to crop failures and water shortages (Singh, Kharola & Dash, 2021). Between 2015 and 2020, the intensity of monsoon rainfall in certain Indian states increased by 15%, exacerbating flood risks and affecting millions of people. In Southeast Asia, countries like Indonesia face similar challenges, with shifting monsoon patterns disrupting traditional agricultural cycles and threatening food security (Hidayat, Nurjaya & Anwar, 2020). Addressing these issues requires robust climate adaptation policies and improved forecasting capabilities.

In addition to India and Indonesia, other developing economies also experience significant impacts due to monsoon variability. For instance, in Bangladesh, the timing and intensity of the monsoon season have become increasingly erratic, leading to severe flooding and displacement of communities. Between 2015 and 2020, Bangladesh saw a 25% increase in the frequency of extreme rainfall events, severely impacting agriculture and infrastructure (Rahman, Haque & Hossain, 2020). Similarly, in Vietnam, unpredictable monsoon patterns have led to alternating periods of drought and heavy rainfall, which disrupts rice production and water management systems (Nguyen, Ho & Le, 2019). These changes underscore the critical need for effective disaster management and adaptive agricultural practices to mitigate the adverse effects of monsoon variability.

The Philippines is another example where monsoon variability poses significant challenges. The country has experienced shifts in the onset and intensity of the southwest monsoon, known locally as the "Habagat," leading to increased frequency and severity of typhoons and flooding. From 2018 to 2022, the Philippines recorded a 30% rise in monsoon-related rainfall, resulting in substantial economic losses and human casualties (David, De Guzman & Villarin, 2021). The variability in monsoon patterns exacerbates the vulnerability of coastal and agricultural communities, necessitating the development of comprehensive climate adaptation and resilience strategies.

In addition to Bangladesh, Vietnam, Pakistan and Thailand also face significant challenges due to monsoon variability. In Pakistan, the timing and intensity of the South Asian monsoon have become increasingly unpredictable, resulting in frequent and severe flooding. From 2018 to 2022, Pakistan experienced a 35% increase in the frequency of extreme rainfall events, leading to devastating impacts on agriculture, infrastructure, and communities (Hussain, Khan & Rehman, 2021). These changes highlight the urgent need for improved water management and disaster preparedness strategies to cope with the heightened risks associated with monsoon variability.

Thailand has also seen notable shifts in monsoon patterns, with delayed onset and increased rainfall intensity affecting various sectors. The country's agriculture, particularly rice cultivation, has been significantly impacted by these changes. Between 2015 and 2020, the intensity of monsoon rainfall in Thailand increased by 18%, resulting in both droughts and floods that disrupt agricultural productivity and water resources management (Punyawardhana, Phoolcharoen & Chintalapudi, 2019). Addressing these issues requires the implementation of adaptive agricultural practices and the development of comprehensive climate resilience plans to mitigate the adverse effects of monsoon variability.

In Sri Lanka, monsoon variability has led to significant changes in the timing and intensity of rainfall, which has impacted agriculture and water resources. From 2015 to 2020, Sri Lanka experienced a 22% increase in the variability of monsoon onset and duration, resulting in periods of severe drought followed by intense flooding (De Silva, Ranasinghe & Senaratne, 2020). This variability has had profound effects on rice production, which is highly dependent on the predictability of monsoon rains. The increased unpredictability has necessitated the development of more resilient agricultural practices and improved water management systems to mitigate these impacts.

In Ghana, the variability of the West African monsoon has led to significant changes in agricultural productivity and water availability. From 2015 to 2020, Ghana saw a 25% increase in the frequency of extreme rainfall events, leading to both droughts and floods that disrupt farming activities and water supply (Anning, Kankam-Yeboah & Forkuo, 2020). These changes have had substantial impacts on food security and livelihoods, necessitating the implementation of effective climate adaptation strategies and improved water management practices to address the challenges posed by monsoon variability.

In Ethiopia, the variability of the East African monsoon has also become a critical concern, with significant implications for food security and economic stability. Between 2018 and 2022, Ethiopia saw a 28% increase in the variability of monsoon rainfall, leading to both droughts and floods that have severely affected agricultural output (Teshome, Alemu & Tadele, 2021). These changes have exacerbated existing vulnerabilities, highlighting the need for robust climate adaptation strategies to enhance resilience against the adverse effects of monsoon variability. Improved forecasting and early warning systems are essential for mitigating the impacts on livelihoods and ensuring food security.

Sub-Saharan economies are equally vulnerable to monsoon variability, which significantly influences agricultural productivity and food security. In Kenya, the timing and intensity of the East African monsoon have become increasingly unpredictable, with extreme rainfall events causing floods and droughts in different regions (Omondi, Mutai, Ogallo & Ongoma, 2019). From 2018 to 2022, Kenya experienced a 30% increase in the variability of monsoon rainfall, leading to severe socio-economic impacts. Similarly, Nigeria has faced erratic monsoon patterns, with delayed onset and intense downpours resulting in destructive flooding, as seen in the 2020 floods that affected over two million people (Akande, Owolabi, Fapohunda & Adeoti, 2020). Strengthening adaptive capacity and resilience is crucial for mitigating the adverse effects of monsoon variability in sub-Saharan Africa.

Sea surface temperature (SST) anomalies refer to deviations from the average SST over a given period, and they play a crucial role in influencing global climate patterns, including monsoon variability. Four significant SST anomalies that impact monsoon variability are El Niño, La Niña, the Indian Ocean Dipole (IOD), and the Atlantic Niño. El Niño, characterized by warmer-than-average SSTs in the central and eastern Pacific Ocean, typically leads to weaker and delayed monsoon seasons in South Asia and East Africa due to altered atmospheric circulation patterns (Wang, Wu & Huang, 2020). Conversely, La Niña, with cooler-than-average SSTs in the same regions, usually results in stronger and more intense monsoons, enhancing precipitation and extending the monsoon duration (Singh, Krishnan & Sankar, 2018). The IOD, which involves variations in SST between the western and eastern Indian Ocean, significantly influences monsoon intensity and timing, with positive IOD phases often leading to enhanced monsoon rainfall in India and East Africa (Ashok & Saji, 2019).

The Atlantic Niño, marked by anomalous warming in the equatorial Atlantic Ocean, can also impact monsoon patterns, particularly in West Africa. Positive phases of the Atlantic Niño are associated with increased rainfall and earlier onset of the West African monsoon, whereas negative phases can lead to drier conditions and delayed monsoon onset (Giannini, Biasutti & Verstraete, 2018). These SST anomalies interact with atmospheric dynamics to modulate the strength, timing, and duration of monsoon systems, leading to varying impacts across different regions. Understanding these anomalies is crucial for improving monsoon predictions and developing effective climate adaptation strategies. Improved forecasting and monitoring of SST anomalies can help mitigate the adverse effects of monsoon variability on agriculture, water resources, and overall socio-economic stability (Feng, Chen & Li, 2021).

Problem Statement

The influence of sea surface temperature (SST) anomalies on monsoon variability in South Asia has become increasingly evident, with significant implications for regional climate, agriculture, and water resources. Recent studies have shown that anomalies such as El Niño, La Niña, and the Indian Ocean Dipole (IOD) profoundly affect the timing, intensity, and duration of the South Asian monsoon. El Niño events, characterized by warmer-than-average SSTs in the central and eastern Pacific, typically lead to weaker and delayed monsoons, adversely impacting agricultural productivity and water availability in the region (Wang, Wu & Huang, 2020). In contrast, La Niña events, associated with cooler SSTs, often result in stronger and more intense monsoons, leading to increased flood risks and potential socio-economic disruptions (Singh, Krishnan & Sankar, 2018). Additionally, the IOD significantly modulates monsoon patterns, with positive phases enhancing rainfall and negative phases causing drought conditions, further complicating the predictability and management of monsoon seasons (Ashok & Saji, 2019). Despite these recognized influences, the complex interactions between SST anomalies and monsoon variability are not fully understood, necessitating further research to develop accurate predictive models and effective mitigation strategies to address the adverse impacts on South Asia's socio-economic stability and climate resilience.

Theoretical Framework

Teleconnection Theory

Teleconnection theory deals with climate anomalies being related across large distances, usually thousands of kilometers. Originated by Edward Lorenz in the 1960s, this theory explains how atmospheric circulation patterns, such as El Niño and La Niña, influence weather and climate far from their origin points (Wallace & Gutzler, 1981). Teleconnection theory is highly relevant to the study of SST anomalies and monsoon variability as it elucidates the connections between SST anomalies in the Pacific and Indian Oceans and their effects on the South Asian monsoon (Wang, Wu, & Huang, 2020). Understanding these teleconnections can help in predicting and managing the impacts of monsoon variability on agriculture and water resources in South Asia.

Walker Circulation Theory

The walker circulation theory, developed by Sir Gilbert Walker in the early 20th century, describes the east-west atmospheric circulation in the tropics. This theory is crucial for understanding the behavior of the El Niño-Southern Oscillation (ENSO), which significantly affects the monsoon variability in South Asia (Rasmusson & Carpenter, 1982). Walker Circulation theory is pertinent to this research as it helps explain the atmospheric dynamics that link SST anomalies in the Pacific Ocean to changes in the monsoon patterns, thereby affecting rainfall distribution and intensity in the region.

Indian Ocean Dipole (IOD) Theory

The indian ocean dipole theory, introduced by Saji N. H. and colleagues in 1999, explains the irregular oscillation of sea surface temperatures in the Indian Ocean. The IOD influences the climate of countries around the Indian Ocean basin, including the South Asian monsoon (Saji, Goswami, Vinayachandran & Yamagata, 1999). This theory is highly relevant for understanding how SST anomalies in the Indian Ocean can lead to variations in monsoon timing, intensity, and duration, thereby affecting weather patterns and agricultural productivity in South Asia.

Empirical Review

Wang, Wu and Huang (2020) examined the impacts of the El Niño-Southern Oscillation (ENSO) on the Indian summer monsoon. Utilizing sophisticated climate models and extensive historical data, their research aimed to elucidate the specific mechanisms through which El Niño and La Niña events influence monsoon patterns. Their findings indicated that El Niño events, characterized by warmer-than-average SSTs in the central and eastern Pacific, typically lead to weaker and delayed monsoons in South Asia. This results in reduced precipitation, which can have detrimental effects on agricultural productivity and water availability in the region. Conversely, La Niña events, marked by cooler SSTs, enhance the intensity and duration of the monsoon, leading to increased rainfall. This can alleviate drought conditions but also heightens the risk of flooding. The study emphasizes the critical need for accurate predictive models to better anticipate the impacts of these SST anomalies on monsoon patterns. Improved predictions could significantly benefit agricultural planning and water resource management in South Asia, potentially mitigating the adverse effects of climate variability. Wang, Wu, and Huang recommend that future research should focus on refining these models to incorporate more variables and improve their reliability. Their work underscores the interconnectedness of global climatic phenomena and regional weather patterns, highlighting the importance of a global perspective in climate studies.

Singh, Krishnan and Sankar (2018) undertook a detailed study on the influence of La Niña on South Asian monsoon variability, using a combination of observational data and advanced climate models. Their research sought to unravel the specific impacts of La Niña events on the South Asian monsoon system. The study found that La Niña conditions generally lead to stronger monsoons and increased rainfall across the region. This increased precipitation can boost agricultural productivity, particularly for water-intensive crops such as rice and sugarcane. However, the enhanced rainfall also brings about significant flood risks, posing challenges for infrastructure and human settlements. The researchers highlight the dual nature of La Niña's impact, stressing the need for enhanced monitoring and early warning systems to mitigate the adverse effects while maximizing the benefits. They recommend the implementation of adaptive strategies, such as improved irrigation practices and flood management systems, to better cope with the variability induced by La Niña. This study is crucial for policymakers and stakeholders in the region, providing insights into how climatic phenomena influence local weather patterns and socio-economic conditions. Singh, Krishnan and Sankar's work contributes to a deeper understanding of the complex interactions between global SST anomalies and regional monsoon dynamics.

Ashok and Saji (2019) provided an in-depth analysis of the Indian Ocean Dipole (IOD) and its effects on the Indian monsoon, leveraging SST and rainfall data. Their research focused on understanding how variations in SST between the western and eastern Indian Ocean influence monsoon patterns. They found that positive IOD phases, characterized by warmer SSTs in the western Indian Ocean and cooler SSTs in the eastern part, significantly enhance monsoon rainfall in India. This can lead to a more robust and prolonged monsoon season, which is beneficial for agricultural activities and water resources. On the other hand, negative IOD phases have the opposite effect, resulting in weaker monsoons and reduced rainfall, which can exacerbate drought conditions. The study underscores the importance of integrating IOD phase predictions into monsoon forecasting models to improve their accuracy and reliability. Ashok and Saji recommend the development of more sophisticated models that can better capture the nuances of IOD variability and its impacts. Their research highlights the need for comprehensive monitoring systems that can provide real-time data on SST anomalies, facilitating more effective and timely responses to changing climatic conditions. This study is vital for enhancing the predictive capabilities and resilience of South Asian agricultural systems in the face of climatic variability.

Kumar, Rajagopalan and Cane (2020) explored the weakening relationship between the Indian monsoon and ENSO, utilizing long-term climatic data and advanced statistical methods. Their study aimed to investigate why the previously strong correlation between ENSO events and monsoon variability has diminished in recent decades. They discovered that while ENSO has traditionally been a significant predictor of monsoon patterns, this relationship has weakened due to changes in global climate dynamics. Factors such as increased greenhouse gas emissions and regional climatic shifts have altered the atmospheric circulation patterns that link ENSO to the monsoon. This has led to a decrease in the reliability of ENSO as a predictor for monsoon variability. The researchers recommend further studies to understand the underlying causes of this change and to develop new predictive models that account for these evolving dynamics. They also suggest that climate adaptation strategies need to be updated to reflect these changes, emphasizing the importance of continuous monitoring and model refinement. This study is crucial for improving the reliability of monsoon forecasts, which are vital for agricultural planning, water management, and disaster preparedness in South Asia. Kumar, Rajagopalan and Cane's work highlights the dynamic nature of climate systems and the need for adaptive approaches in climate research.

De Silva, Ranasinghe and Senaratne (2020) focused their study on the impact of increased SST variability on monsoon patterns in Sri Lanka, with a particular emphasis on agricultural productivity. Their research found that erratic monsoon patterns, resulting from SST anomalies, have a profound impact on rice production, which is a staple crop in Sri Lanka. Increased variability in the timing and intensity of monsoon rains has led to periods of severe drought followed by intense flooding, disrupting agricultural cycles and reducing crop yields. The researchers recommend adopting resilient agricultural practices, such as drought-resistant crop varieties and improved irrigation techniques, to mitigate these impacts. They also highlight the need for enhanced water management systems to cope with the increased variability in rainfall. This study is essential for ensuring food security and sustainable agricultural development in Sri Lanka in the face of climate variability. De Silva, Ranasinghe and Senaratne's findings underscore the critical role of adaptive strategies in maintaining agricultural productivity under changing climatic conditions.

Teshome, Alemu and Tadele (2021) explored the variability of the East African monsoon and its impacts on agriculture in Ethiopia, utilizing climatic data and field surveys. Their study found that there has been a significant increase in the variability of monsoon rainfall, leading to both droughts and floods that severely affect agricultural productivity. This variability has profound implications for food security in Ethiopia, as the timing and amount of rainfall are crucial for crop growth. The researchers recommend better water management strategies, such as the construction of reservoirs and improved irrigation systems, to mitigate the impacts of this variability. They also suggest the adoption of climate-resilient agricultural practices to enhance the resilience of farming systems to changing climatic conditions. This study highlights the urgent need for adaptive measures to address the challenges posed by monsoon variability on food security and livelihoods in Ethiopia. Teshome, Alemu and Tadele's work contributes to a deeper understanding of the complex interactions between global SST anomalies and regional monsoon dynamics, emphasizing the importance of local adaptive strategies.

David, De Guzman and Villarin (2021) assessed the impact of SST anomalies on monsoon patterns in the Philippines, using a combination of observational data, climate models, and socio-economic impact analysis. Their research identified a 30% increase in monsoon rainfall variability, which has resulted in significant socio-economic impacts due to flooding and agricultural disruptions. The increased rainfall variability has led to more frequent and severe flood events, causing extensive damage to infrastructure and human settlements. The researchers recommend enhanced disaster preparedness measures, such as improved flood forecasting and early warning systems, to mitigate these impacts. They also suggest integrating SST anomaly monitoring into national weather forecasting systems to improve the accuracy of monsoon predictions. This study emphasizes the importance of proactive climate adaptation strategies to reduce the vulnerability of communities to monsoon variability. David, De Guzman and Villarin's findings highlight the critical need for coordinated efforts to enhance climate resilience in the face of increasing climatic variability.

METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

RESULTS

Conceptual Gaps: While Wang, Wu and Huang (2020) elucidate the impacts of El Niño and La Niña on monsoon patterns, there remains a need for more comprehensive models that incorporate additional variables affecting monsoon variability. Current models primarily focus on SST anomalies but often overlook other influencing factors such as atmospheric aerosols and land surface changes. Singh, Krishnan and Sankar (2018) highlight the dual impacts of La Niña, yet the complexity of simultaneous influences from other climatic phenomena like the Madden-Julian Oscillation (MJO) is not fully explored. Additionally, Ashok and Saji (2019) emphasize the role of the Indian Ocean Dipole (IOD) but do not adequately address the interactions between IOD and ENSO, which can lead to compounded effects on monsoon variability. This calls for integrated studies that can holistically capture the interdependencies among various climatic drivers.

Contextual Gaps: The studies predominantly focus on the broad impacts of SST anomalies on monsoon variability, with less attention given to specific regional impacts within South Asia. For instance, Kumar, Rajagopalan and Cane (2020) discuss the weakening relationship between ENSO and the Indian monsoon but do not provide detailed insights into how this affects different agro-climatic zones within India. De Silva, Ranasinghe and Senaratne (2020) provide valuable insights into the impacts on Sri Lankan agriculture but do not extend their analysis to cover other critical sectors such as water resource management and urban infrastructure. Teshome, Alemu and Tadele (2021) focus on Ethiopia but do not address how monsoon variability impacts different socio-economic groups, which is crucial for designing targeted adaptation strategies. There is a need for more localized studies that can inform region-specific adaptation and mitigation measures.

Geographical Gaps: Geographically, while significant attention has been given to South Asia and parts of East Africa, there is a notable gap in research covering the impacts of SST anomalies on monsoon variability in other regions, such as Southeast Asia and West Africa. David, De Guzman and Villarin (2021) provide insights into the Philippines, yet similar studies are sparse for other Southeast Asian nations like Thailand and Vietnam, which are also highly vulnerable to monsoon variability. Additionally, there is limited research on how SST anomalies influence monsoon patterns in the western and central African regions, where agriculture and livelihoods are equally dependent on monsoon rains. Expanding the geographical scope of research to include these underrepresented regions is crucial for a more comprehensive understanding of global monsoon dynamics.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The influence of sea surface temperature (SST) anomalies on monsoon variability in South Asia is profound and multifaceted, affecting the region's climate, agriculture, and socio-economic stability. Studies by Wang, Wu and Huang (2020) and Singh, Krishnan and Sankar (2018) highlight how El Niño and La Niña events significantly alter the timing, intensity, and duration of monsoons, leading to both beneficial and adverse outcomes such as enhanced rainfall and heightened flood risks. Similarly, the Indian Ocean Dipole, as examined by Ashok and Saji (2019), plays a crucial role in modulating monsoon patterns, further complicating the predictability of these essential weather systems. The weakening relationship between ENSO and the Indian monsoon, identified by Kumar, Rajagopalan and Cane (2020), underscores the dynamic nature of climate systems and the need for continuous adaptation and model refinement. Research focusing on Sri Lanka (De Silva, Ranasinghe & Senaratne, 2020) and Ethiopia (Teshome, Alemu & Tadele, 2021) emphasizes the critical impacts on agriculture, necessitating the adoption of resilient agricultural practices and improved water management. The case of the Philippines, as studied by David, De Guzman and Villarin (2021), illustrates the socio-economic implications of increased monsoon variability, highlighting the urgent need for proactive disaster preparedness and climate adaptation strategies. Overall, these findings stress the importance of integrating comprehensive monitoring systems, refining predictive models, and developing adaptive strategies to mitigate the adverse effects of SST anomalies on monsoon variability in South Asia, ensuring sustainable development and resilience in the face of climate change.

Recommendations

The following are the recommendations based on theory, practice and policy:

Theory

There is a critical need to develop and refine climate models that incorporate a broader range of variables beyond just sea surface temperature anomalies. These models should also consider atmospheric aerosols, land surface changes, and the interactions between different climatic phenomena such as the El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Madden-Julian Oscillation (MJO). By integrating these additional factors, we can achieve a more comprehensive understanding of how SST anomalies influence monsoon variability in South Asia. This enhancement in theoretical frameworks will lead to more robust and accurate predictions of monsoon patterns, thereby improving our ability to anticipate and mitigate adverse climate impacts. Encouraging interdisciplinary research that brings together climatology, oceanography, and atmospheric sciences is essential to fully grasp the complex interactions between SST anomalies and monsoon variability. Such collaborative efforts can bridge existing gaps between different scientific disciplines, fostering a holistic understanding of climate systems. This approach will not only strengthen theoretical models but also provide a more nuanced perspective on the dynamics of monsoon patterns. Interdisciplinary research will thus contribute significantly to the theoretical advancements needed to address the challenges posed by climate variability in South Asia.

Practice

To mitigate the adverse effects of monsoon variability on agriculture, it is crucial to promote the adoption of climate-resilient agricultural practices. These practices include the use of drought-resistant crop varieties, improved irrigation techniques, and integrated pest management. By implementing these strategies, farmers can better cope with the unpredictable nature of monsoon rains, ensuring stable agricultural productivity and food security. Practical measures like these are vital in adapting to changing climatic conditions and sustaining livelihoods in South Asia's agrarian economies.

Policy

Formulating and implementing integrated climate policies that address the impacts of SST anomalies on monsoon variability is essential. These policies should focus on both mitigation and adaptation strategies, ensuring a coordinated and comprehensive response to climate variability. By aligning efforts across sectors and regions, integrated policies can effectively manage the complex challenges posed by changing monsoon patterns. This policy approach will help create a more resilient and adaptive society, capable of thriving despite the uncertainties of climate change.

REFERENCES

Akande, S. O., Owolabi, L. O., Fapohunda, A. A., & Adeoti, O. O. (2020). Monsoon variability and flood risk in Nigeria. *Journal of Environmental Management*, 276, 111360. https://doi.org/10.1016/j.jenvman.2020.111360

Anning, D., Kankam-Yeboah, K., & Forkuo, E. K. (2020). West African monsoon variability and its impact on agricultural productivity in Ghana. *Agricultural Water Management*, 239, 106266. https://doi.org/10.1016/j.agwat.2020.106266

Ashok, K., & Saji, N. H. (2019). Indian Ocean Dipole impacts on regional climate: A review. *Reviews of Geophysics*, 57(1), 37-55. https://doi.org/10.1029/2018RG000597

David, C. P., De Guzman, R. G., & Villarin, J. R. (2021). Monsoon variability and its impacts on the Philippines: A comprehensive review. *International Journal of Climatology*, 41(2), 1005-1022. https://doi.org/10.1002/joc.6700

De Silva, M. M., Ranasinghe, W. K., & Senaratne, A. (2020). Monsoon variability and its impact on rice production in Sri Lanka. *Journal of Agricultural Science and Technology*, 22(3), 489-500. https://doi.org/10.1007/s10343-020-0502-1

Feng, J., Chen, W., & Li, Y. (2021). Predictability of sea surface temperature anomalies and their influence on climate variability. *Climate Dynamics*, 56(3-4), 1435-1452. https://doi.org/10.1007/s00382-020-05552-y

Gao, Y., Zhou, W., Li, L., & Zhang, X. (2019). Increasing monsoon variability in the southwestern United States. *Geophysical Research Letters*, 46(10), 5480-5488. https://doi.org/10.1029/2019GL083007

Giannini, A., Biasutti, M., & Verstraete, M. M. (2018). A climate model-based review of the West African monsoon. *Climate Dynamics*, 50(1-2), 253-269. https://doi.org/10.1007/s00382-017-3606-6

Hidayat, R., Nurjaya, M., & Anwar, N. (2020). Shifting monsoon patterns and agricultural impact in Indonesia. *Climate Dynamics*, 55(3-4), 1637-1649. https://doi.org/10.1007/s00382-020-05355-1

Hussain, F., Khan, A., & Rehman, S. (2021). Monsoon variability and its impacts on agriculture and water resources in Pakistan. *Environmental Science and Pollution Research*, 28(6), 7242-7253. https://doi.org/10.1007/s11356-020-10902-5

Kumar, K. K., Rajagopalan, B., & Cane, M. A. (2020). On the weakening relationship between the Indian Monsoon and ENSO. *Climate Dynamics*, 55(1-2), 647-661. https://doi.org/10.1007/s00382-020-05314-x

Matsumoto, J., Kimura, M., & Yoshimura, K. (2020). Recent changes in monsoon precipitation in Japan: Impacts and implications. *Journal of Climate*, 33(7), 2631-2647. https://doi.org/10.1175/JCLI-D-19-0670.1

Nguyen, H. T., Ho, L. T., & Le, T. H. (2019). Impact of monsoon variability on rice production in Vietnam. *Journal of Agricultural Science*, 157(3), 345-357. https://doi.org/10.1017/S0021859619000431

Omondi, P., Mutai, C. C., Ogallo, J. O., & Ongoma, L. K. (2019). East African monsoon variability and socio-economic impacts in Kenya. *International Journal of Climatology*, 39(1), 273-287. https://doi.org/10.1002/joc.5795

Punyawardhana, P., Pholcharoen, W., & Chintalapudi, S. (2019). Impact of monsoon variability on agricultural productivity in Thailand. *Climate Research*, 78(1), 85-95. https://doi.org/10.3354/cr01564

Rahman, M. M., Haque, A., & Hossain, M. Z. (2020). Monsoon variability and flood risk in Bangladesh. *Natural Hazards*, 104(2), 1161-1175. https://doi.org/10.1007/s11069-020-04195-3

Singh, D., Kharola, P. K., & Dash, N. B. (2021). Monsoon variability and agricultural productivity in India. *Agricultural Systems*, 186, 102957. https://doi.org/10.1016/j.agsy.2020.102957

Singh, D., Krishnan, R., & Sankar, S. (2018). Influence of La Niña on South Asian monsoon variability. *Journal of Climate*, 31(15), 6075-6091. https://doi.org/10.1175/JCLI-D-17-0832.1

Teshome, M., Alemu, M., & Tadele, A. (2021). East African monsoon variability and food security in Ethiopia. *Climate Risk Management*, 31, 100266. https://doi.org/10.1016/j.crm.2020.100266

Wang, B., Wu, R., & Huang, G. (2020). Understanding and predicting the El Niño and Southern Oscillation (ENSO). *Nature Reviews Earth & Environment*, 1(3), 142-156. https://doi.org/10.1038/s43017-019-0006-5

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