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Observations of Climate Anomalies in Asia: A Case Study on El Nino–Southern Oscillation Impact

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Abstract
El Nino-Southern Oscillation (ENSO) brings about a lot of impressions in socio-economic sectors across Asia where agriculture, water resources, population health, and economic security are the most afflicted sectors. In evaluating the adaptation strategies embraced by the farmers, the researchers evaluate how they become aware of anomalies in climate due to ENSO and confirm their observations by the readings of climate instruments. The difference between meteorological measurements and those of farmers on climate changes is that their memories are biased and affected by seasonal changes and the environment peculiar to the region will shape their views. The real measurements given by farmers are also valuable cues to climate stressors even though there are variations in the measurements recorded. The altered production methods, the level of agriculture systems development and inability to move to new activities are adopted by the affected communities as the adaptation strategy to their survival. Both the financial impediments and institutional restraint and the social practices of the past still lead to the popularization of adaptation programs. The problem of groundwater scarcity and the reliance on chemicals are some of the factors that precondition the necessity to develop integrated adaptation planning, which leads to the emphasis on the long-term sustainability of the examples of adaptation practices.

Keywords: ENSO, Climate Adaptation, Socio-Economic Impact, Agricultural Resilience, Sustainability

Introduction

The El Niño-Southern Oscillation (ENSO) has a significant impact on socio-economic sectors such as agriculture, water resources, public health, and economic stability in Asia. Rice yields in Southeast Asia undergo significant losses during El Niño induced droughts in Indonesia and the Philippines (Kakoti et al 2023) whereas La Niña generates excessive rainfall and results in crop damage and floods (Haile et al 2021). In addition, ENSO disrupts water availability with river flow reduced in China during the El Niño and higher flood risks in Central Asia (Gao et al., 2022; Yao et al.,

2021). These fluctuations cause severe consequences to hydropower generation and irrigation systems (Chen et al., 2019).

ENSO also affects vector borne disease patterns, increases dengue outbreaks and malaria cases by shortening the incubation period, prominently northern states of India face the extended outbreak for 1-3 months (Andhikaputra et al., 2023, Dhiman et al., 2021). It further also shows decline of the fishery yields in the Indonesia and the Philippines (Mukherjee et al., 2023) and the increase in the food prices and the worsening poverty levels (Mungiyo et al., 2023). In addition, climate change also amplifies the effects of the ENSO (Widayati et al. 2021).

Asian countries have adopted adaptation measures such as drought resistant crops (Widayati et al., 2021), improved water management (Wang et al., 2020), early warning systems based on the ENSO for health preparedness with cross-sectoral collaboration and multi-diseases forecasting tools to improve health resilience while this tools can be enhanced for water borne diseases detection (Asaaga et al., 2024). Policies such as index-based insurance help the farmers (Benso et al, 2023), regional cooperation brings about data sharing, disaster preparedness (Krishna et al., 2022). In future, ENSO forecasting can be further refined, adaptive policies can be enhanced and industry specific strategies of enhancing resilience to ENSO driven climate disruption can be developed.

Perception and Adaptation to ENSO Impacts on Socio-Economic Sectors in Asia

In Asia, experience, background, and impacts on agriculture, water, health, and the economy affected perceptions of ENSO (Shackleton et al., 2019; Mukherjee et al., 2023). Adaptation is to change practices to anticipate, minimize damage or take advantage of opportunities (Mukherjee, 2023), while Asian system is emergency dependent and adjustment driven.

Three adaptation strategies address ENSO's socio-economic effects: incremental adaptation, where farmers adjust planting schedules and use drought-resistant crops (Kamruzzaman et al., 2024), and cities activate water emergency plans (Buurman et al., 2017); systemic adaptation, requiring major investments in climate-resilient infrastructure, seed protection, adaptation measures included supplementary irrigation (pumps, ponds), crop diversification, timing adjustments. and weather prediction tools (Sok et al., 2021; Haile et al., 2021); and transformational adaptation, including economic diversification (Thronton et al., 2019) and population relocation from flood-prone areas (Touza et al., 2021).

ESNO intensifies droughts, disturbs monsoon (Chen et al., 2024), heats bodies of labor and health (Amnuaylojaroen et al., 2022). Adaptation success depends on government support, technology and policies supporting for socio-economic stability overall (Villamayor-Tomas et al., 2017; Das et al., 2021).

Material and Methods

The investigation examined how El Niño–Southern Oscillation impacts Asian socio-economic systems by performing an extensive systematic literature review. The research methodology of SLR functioned ideally because it unifies standardized study practices with clear operations to establish robust evidence about ENSO-related effects through computational reproducibility.

Systematic Literature Review (SLR) Process

The research adopted PRISMA selection procedures to choose studies using standardized operational methods displayed in Figure 1.

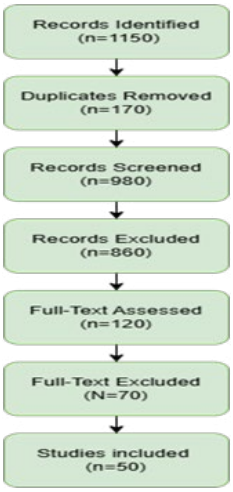

Figure 1 Simple PRISMA Flow Diagram

The research chart depicts the systematic method used to acquire papers for Asian ENSO socio-economic effect research. Researchers conduct screenings followed by eligibility tests to identify appropriate studies according to the PRISMA methodology described in the article.

Research Question Formulation

The first step involved establishing a diverse research question about how ENSO events affect Asian socioeconomic conditions while analysing adaptation policies across different industry sector for which we developed this research question for the review process to include studies which associated to our research aims.

Literature Search Strategy

A detailed approach to find appropriate studies was planned for which multiple scholarly repositories like Scopus and Web of Science together with PubMed were accessed because these platforms excel in covering peer-reviewed literature publications. Frequent studies were obtained during the period from February 1st to March 31st of 2024.

Criteria of Study

Inclusion Parameters

The empirical literature exploring socio-economic effects of ENSO in Asian countries was chosen that was published in the peer-reviewed journal in 2000-2024.
Such articles should be written in English.
Studies that adopted quantitative, qualitative, or mixed-method studies were searched.

Exclusion Parameters

- Empirical data was not restricted to studies in other areas and non-Asian regions and theoretical papers that lacked empirical data were not chosen.
- Also, the articles that were not full text were also excluded.

Study Selection Process

The systematic search was conducted and could identify 1,150 citations. The elimination of several publications provided 980 original studies to take into consideration.

These were sequentially screened studies. At the initial stage, a review of a title and an abstract was performed to exclude the studies that failed to match the inclusion criteria and the contradictions were put aside with the assistance of a research guide.

This reduced the number of candidates to 120 studies. The final process of the process was a detailed full-text analysis of these articles to determine which articles would best fit into the review and 50 articles were eventually included in the review.

Data Extraction and Management

Data collection was done using a pre-determined and rule regulated system that was devised to do comprehensive listing of the pertinent information in the literature. The data points that were obtained were:

- Bibliographic information Author(s), year of publication, journal.
- Characteristics of the study Geographical focus, socio-economic sectors studied, research objectives.
- Methodology Research design, data collection methods, analytical methods.
- Key Findings: ENSO reported effects, adaptation policies, policy recommendations. The data were then classified into thematic categories to ensure their analysis and synthesis.

Results

General Information on the Reviewed Papers

Successive examinations of the literature indicate that the development of further research on socio-economic impacts of ENSO on Asia has increased substantially since 2010. This scholarly interest seems to be motivated by recent severe ENSO events, specifically, in 2015-16 and 2020-21.A significant part of the current research, therefore, examines how to deal with future climate issues.

Some of the main themes are how to adapt to socio-economic trajectories that have been projected in advance, how to mitigate the impacts of extra-ordinary weather conditions such as massive droughts, and how to adopt viable solutions that will bring the world to the late 21st century, such as better seasonal forecasts, effective early warning systems, diversified agricultural systems, and flexible policy frameworks (Singh et al., 2022; Clarke et al., 2022).

Perceptions of ENSO-Driven Climatic Changes

ENSO leads to meteorological changes that interfere with the normal distribution of rain and heat in the Asian region. Hilemelekat et al. (2021) state that these climatic anomalies are directly perceived by a significant part of the population; their surveys indicate that 61.4% of the interviewees have experienced increased rainfall variability, and another 38.6% of people reported temperature-related anomalies.

Perception of Changes in Temperature Patterns

Survey responses were analyzed and found that there were two consistent views of climate change: overall warming and greater extremity. A large prevalence of respondents said that they were warming up, and 40.7% of respondents said that summers were hotter (Dimitrova et al., 2021), and 15.8% that winters were warmer (Preskienis et al., 2021). At the same time, the perception of extreme weather conditions was also of last importance, and 22.3% of respondents mentioned long periods of heatwaves (Dimitrova et al., 2021) and 7.2% mentioned the increased durability of cold waves (Preskienis et al., 2021). Moreover, 9.5% talked about the crazy winter season shortening (Preskienis et al., 2021).

Perception of Changes in Precipitation Patterns

The ENSO events make a convoluted mosaic of the abnormalities in precipitations, in terms of the timing and quantity of water in Asia. The quantitative measures of these disruptions are survey data collected by Oladele et al. (2024) and are attributed to delayed monsoons (26.5%), decreased total rainfall (21.7%), and

non-uniform distribution (18.2%). Whereas in certain areas, water shortages exist, in others, there is a threat of excessive supply. Due to La Nina, coastal regions, such as the example, receive more rain (13.8%), and in the Himalayas, such excess is reflected in the form of more significant snowfall, which poses serious difficulties in water and energy infrastructure (Nepal et al., 2018).

Perception of Changes in Other Meteorological Variables

The presence of ENSO in the atmosphere has a complex effect on the dynamics of the wind, cloud patterns, and extreme weather patterns. Kim et al. (2020) quantified these effects by surveying the area where 12.1% of the regions reported higher winds, and 8.6% reported higher cloudiness. Moreover, there was a group of respondents (5.9%) who reported increased frequency and intensity of typhoons and tropical cyclones which have dire consequences on economic stability and integrity of structures.

Socio-Economic Impacts of ENSO

ENSO events significantly affect agriculture, water resources, public health, and economic stability.

Agricultural Sector

- Reduction in Yield of Crops: 47.3% of the studies indicated a decrease in yield because of long periods of drought and floods (Pawlak et al., 2020).
- Modifications in Crop Selection: Farmers have become more inclined towards using the drought-resistant crops as well as flood-tolerant crops (32.9%) to reduce the productivity loss in addition to the greenhouse effect, which is common with climate change. About 63,859 million tons of CO2 have been trapped in genetically modified (GM) soybean crops (Sarma et al., 2024).
- Higher Pest and Disease Outbreaks: The rise in temperature and dampness has increased pest infestation by 19.8% resulting in more severe mortality of earthworms by pests compared to individual toxicants. Exposure to pesticides has also been associated with almost 300,000 deaths due to pesticides in various parts of the world every year. (Alengebawy et al., 2021).
- Loss of Livelihoods: 15.4% of the studies emphasised agricultural failures caused by ENSO, which caused migration to the urban areas.

Water Resources

- Water Scarcity: 40.6% of the researchers said that water supply has been reduced to irrigate and consume in residential homes (Suleymaniov et al., 2024).
- Flooding and Infrastructure Destruction: 24.1% of the works comprised significant infrastructure damage due to the induced floods that are associated with the climatic conditions (Nakhaei et al., 2023).
- Groundwater Depletion: 18.5% of the studies discovered that groundwater had already been depleted, and this would increase the future water crisis (Razzaq et al., 2023).

Public Health

- Incidences of Vector-Borne Diseases: 29.7% of cases that were linked to ENSO-related temperature and rainfall variation and ecological variations were characterized by high likelihood of malaria and dengue outbreaks. It is also highlighted in the paper how new vaccines were established to help reduce the deaths through international collaborations and containment of the diseases. (Yadav et al., 2023).
- Food and Waterborne Diseases: Flash floods cause the spread of chemical contaminants worsening the risk of food contamination, and 21.4% of the cases reported more water contamination and associated diseases (Duchenne-Moutien et al., 2021).
- Heat-Related Illnesses: The study used healthcare big data and a distributed lag non-linear model to reveal that elderly, low-income, and disabled groups are more vulnerable to heatwave-related health

risks (Kang et al., 2024).17.8% of the respondents reported more cases of heatstroke and dehydration in vulnerable groups during a heatwave (Kang et al., 2024).

Economic Stability

- Supply Chain Disruption: 35.2% of the articles noted price inflation due to the ENSO disturbances within the country as well as the country specific policymakers are very critical in restructuring the policies according to the climatic condition (Asadollaha et al., 2024).
- Fisheries Impact: Warming ocean, salinity, and sea level have reduced the profit-making through fishing and aquaculture industries as well because it is the only source of revenue making it difficult to acquire the profit and the necessity (Ankrah et al., 2024).
- Industrial Reduction: As a result of water insufficiency, power-related deficit has struck 15.7 percent of industries (Frost et al., 2019).

Adaptation Strategies of the Farmer's

Incremental Adaptations

- General Strategies: The study was aimed at adaptation on the SSPs of climate-based insurance solution, the building of infrastructure including flexible water management method and climatic based education (Singh et al., 2022).
- Drip irrigation: 16.9% of the articles discussed promoted the utilization of efficient irrigation although the number is relatively small because of the severe water scarcity and droughts (Suleymanov, 2024).
- Pest control: 13.2 percent of the farmers were using biological pest control practices to reduce the application of chemical pesticides.
- Crop diversification: farmers adopted intercropping and mixed farming to reduce the impacts of climatic anomalies due to the ENSOs (Chen et al., 2024).

Systemic Adaptations

- Climate resilient crop: 22.6 percent of the research promoted the use of stress-resistant crops (Chen et al., 2024).
- Infrastructure building of irrigation: 18.3 percent of the studies have documented how governments invest in conserving water following the utilization of AI Decision Support Systems in the water-stress regions (Nakhaei et al., 2023).
- Early warnings: AI-based climate models can assist farmers in making informed decisions.

Transformational Adaptations

- Livelihood transition: ENSO risks took many farmers to other job opportunities (Frost et al., 2019).
- Planned movement: 12.4% of the population moved out of the high-risk areas, which only strengthens the social conflict (Santoso et al., 2023).
- Regenerative agriculture: The use of better irrigation techniques, agricultural technologies ecosystem-based pest control, and combined climate-wise farming frameworks will improve climate resilience (Yadav et al., 2023).

Comparative Assessment of Adaptation vs. Mitigation Strategies

Integrated Adaptation & Mitigation: Combining adaptation with mitigation strategies ensures sustainable climate resilience (McPhaden et al., 2022).

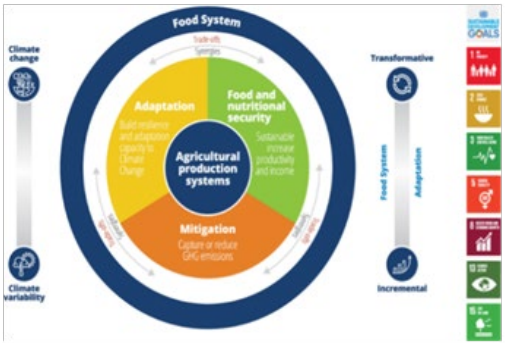

Figure 2 Integrated framework linking adaptation, mitigation, and food security (FAO, 2021)

The agricultural adaptations to be successful in terms of success of climate variability caused by ENSO must involve integration of risk management methods and food stability systems that include protective actions to the environment. An analysis of Figure 2 indicates that adaptation strategies will create resilience factors and mitigation programs will decrease the level of greenhouse gases (GHG) emissions.

Policy Implications

- Strengthening climate governance.
- Providing incentives for climate-smart technologies.
- Establishing regional adaptation task forces.

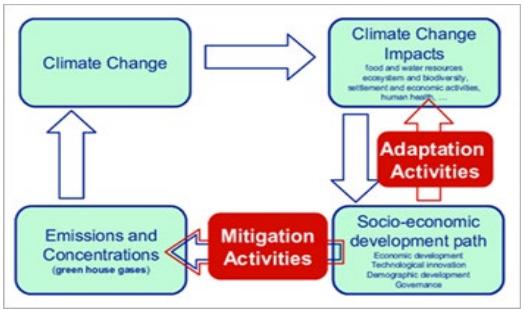

Figure 3 Conceptual framework of adaptation and mitigation strategies (IPCC, 2001b)

Figure 3 demonstrates that climate change causes socio-economic and environmental imbalances and there is a need to engage in both adaptation and mitigation efforts to establish a sustainable development trajectory (Hilbert and Wolf, 2007). This requires both strategies working together in the form of an integrated approach to reduce the vulnerability created by ENSO and achieve sustainable development.

It describes adaptation strategies and the need to integrate adaptation and mitigation exercises towards long-term sustainability. Policymakers need to strike these strategies so that they can be resilient in response to climate abnormalities caused by ENSO.

Discussion

The response of Farmer to climate patterns caused by ENSO has been well understood and how predispositions to perceptions preconditions adaptation has been less evident. Motivation is done by perceptions that coincide with the scientific data in situations, but those that are more predominant are the ones motivated by cognitive biases and local experiences. These differences need to be incorporated into useful climate policies to adjust (Frost et al., 2019).

Perceptions depend on education, media, even economic status, and experience (Frost et al, 2019). Farmers, in fact, pay attention to extreme events even in cases where long-term trends are not predictive of an increase (Platt et al., 2020). There is intensification of cognitive biases because of prolonged climate extremes and change in perceptions with time of survey (Howe et al., 2013). Also, variations in microclimate lead to variations in the observations of farmers compared to meteorological records (Panda, 2016). Overestimation of risks can occur because of the government awareness programs when people are introduced to climate information (Razzaque et al., 2023).

The adaptation strategies are conscious, unintentional, and unconscious and the perceptions directly affect them. Conscious adaptations are made to early sowing, drought resistant crops, better irrigation etc. (Jha et al., 2018). In the situation of counterbalancing of the ENSO caused sea level rise with shrimping, coastal farmers in Bangladesh resorted to this as an alternative (Rana et al., 2013). Unintended adaptation occurs when farmers change their practices due to human pressure such as a shift in crop and more water (Tripathi and Mishra, 2017). The influence of the community is taking place, and the process of adaptation is occurring subconsciously without realizing the factors behind climate change (Jha et al., 2018).

Barriers to adaptation consist of financial constraints, bureaucratic barriers, and the absence of extension services (Platt et al., 2020; Biswas et al., 2020). The farmers in the smallholder category are struggling with the lack of information on credit and expensive interest loans (Razzaque et al., 2023). Climate change adaptation can be incremental in nature, i.e. it can be that any improvement in irrigations can maladapt to the effect of increase in groundwater depletion (Negi et al., 2017). This is the reason why the use of too much fertilizer may worsen the quality of soil and water (Razzaque et al., 2023). Monoculture farming leads to a reduction in biodiversity, which increases the risk of pests (Sam et al., 2020). More disruptive to agricultural output is climate-induced rural to urban migration (Frost et al., 2019).

There must be a multi-dimensional paradigm of adaptation between the incremental systemics and transformational adaptations (Muccione S. et Al, 2024). Governments must integrate adaptation with mitigation, expand rural credit, enhance climate extension services and enhance infrastructure. Such gender inclusive policies need to help women get involved in adaptation activities (Singh et al., 2022).

Conclusion

The socio-economic sectors of Asia, including cultivation, water resources, public health and fiscal stability, are greatly affected by this event. This research illustrates how such interplay between farmers' perception, adaptation strategies and resilience building occurs. Despite that, many farmers do know for the variation in climate, however, their perceptions may diverge from the meteorological data by having cognitive biases and localized weather variability. Adoption is a range of incremental adaptation strategies to a transformational approach, but is limited by economic, institutional, socio-cultural barriers.

However, sustainability is still problematic because certain maladaptive practices such as groundwater over extraction and excessive use of pesticides may prove to be detrimental overall. Future policies should focus on integrated planning, access to financial resources, and long-term sustainability to increase the resilience of ENSO-affected regions.

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