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El Niño and India's Climate-Economy Nexus: Risk Assessment, Adaptation Strategies and Policy Implications

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Abstract

El Niño, a recurring phase of the El Niño Southern Oscillation (ENSO) is one of the most important factors of interannual climate variability affecting the Indian monsoon and, hence, the economic performance of the country. India's agriculture, water resources and rural lives are highly dependent on monsoon rains. Climatic abnormalities linked to El Niño pose major threats to economic stability and sustainable development. This paper investigates the climate-economy relationship in India, measures the climate risk associated with El Niño episodes, finds sectoral and regional vulnerabilities, and considers adaptation measures and policy actions undertaken. The paper analyses the regional and temporal characteristics of El Niño effects across India using secondary data on rainfall variability, agricultural productivity, economic indicators, drought incidence, and climate adaptation efforts. The data indicate that El Nino years are expected to see below normal rainfall, decreased agricultural production, water scarcity, rises in food prices and strain on rural economies. However, the extent of these effects varies considerably between locations, depending on exposure, sensitivity and adaptive capacity. The report also emphasises the importance of climate risk management methods such as early warning systems, crop insurance, expanding irrigation, climate resilient agricultural practices and institutional support mechanisms in reducing economic losses and building resilience. The article contends that the rising difficulties of climatic variability cannot be addressed without improving integrated climate risk governance, supporting adaptive resource management and weaving climate resilience into economic planning. The work adds to the understanding of climate driven economic vulnerabilities in India and offers policy relevant insights to enhance long term resilience in the face of increasing climate unpredictability.

Keywords: El Niño, ENSO, Climate-Economy Nexus, Climate Risk Assessment, Economic Vulnerability, Monsoon Variability, Agricultural Productivity, Drought Risk.

Introduction

Climate variability has become one of the most serious concerns for sustainable development in the twenty-first century. The El Niño Southern Oscillation (ENSO) is a primary cause of interannual climate variability and one of the several climatic phenomena which influence the worldwide weather patterns. El Niño is the warm phase of the ENSO and is characterised by anomalous rising of sea surface temperatures (SSTs) in the central and eastern equatorial Pacific Ocean that results in large changes in atmospheric circulation and precipitation patterns in various parts of the world.

El Nino episodes have traditionally been linked to less monsoon activity, rainfall deficits, droughts and substantial socio-economic disruptions for India, where the southwest monsoon accounts for about 75-80% of the annual rainfall. Even when structural revolutions continue on and industrialisation speeds up, India's economy remains highly susceptible to weather variations. Agriculture continues to be an important source of livelihood for a large section

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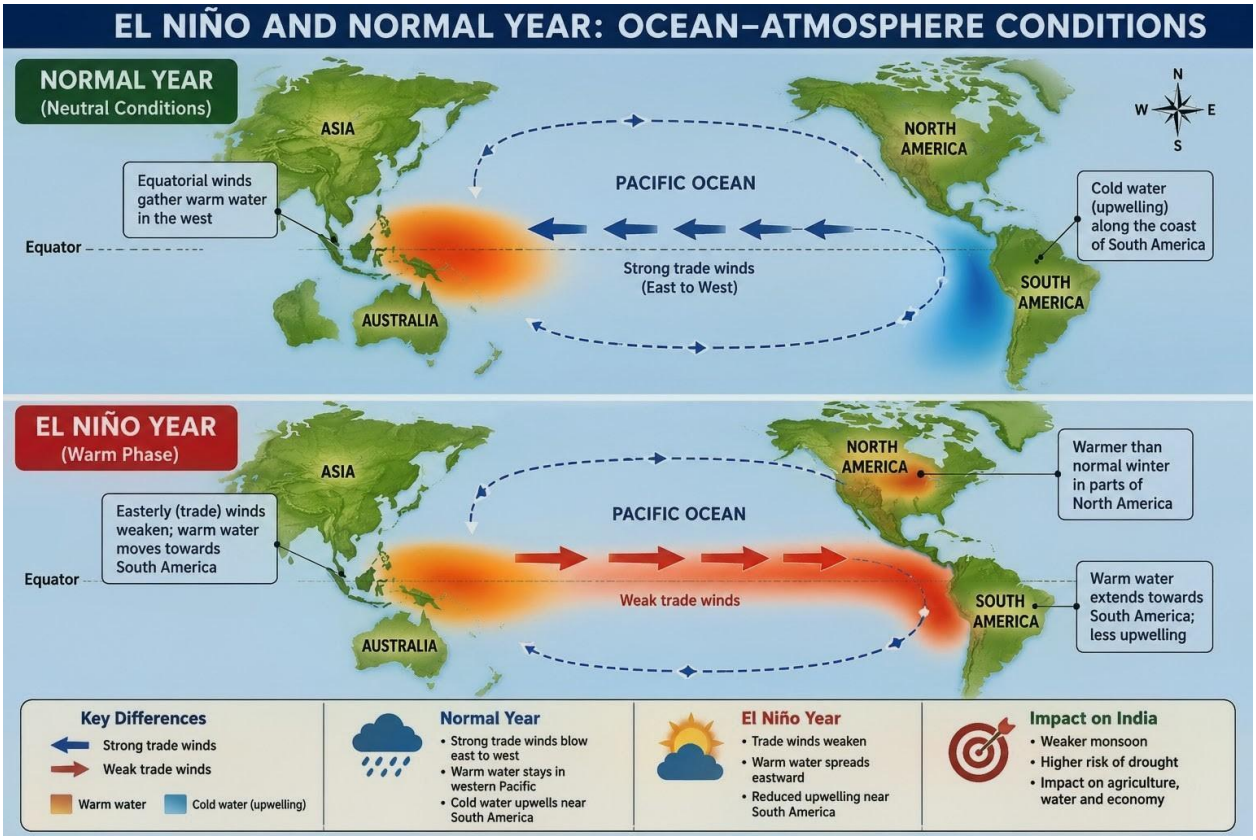
of the population and makes a considerable contribution to national food security. Agricultural productivity is very sensitive to monsoon performance, and severe changes in rainfall patterns can have adverse consequences for crop yields, farm incomes, employment possibilities and rural livelihoods. In addition, El Niño-related weather abnormalities frequently impact water availability, hydropower generation, food prices, inflationary pressures and overall economic growth. Hence, the impact of El Niño is not confined to the agricultural sector alone but extends to all dimensions of India's economic and developmental setting.



In the past, many big El Niño episodes such as 1982-83, 1997-98, 2002-03, 2009-10, 2015-16, and 2023-24 have had different impacts on India's monsoon and economy. While not all El Niño events lead to severe drought conditions, the likelihood of below normal rainfall and climate related risks generally increases during El Niño years. The increased frequency and intensity of extreme climatic events in the context of changing climate conditions have further heightened concerns for economic vulnerability and resilience. In this setting, the knowledge of linkages between climatic variability and economic systems has become more and more essential to policy makers, researchers and development practitioners. The climate-economy nexus provides a valuable framework to assess the linkages between climate threats and economic results. El Niño episodes give rise to two types of climate risks: Physical risks such as droughts, water scarcity and crop failures; Socio-economic risks such as income losses, food hunger, migration and market instability. The magnitude of these consequences relies on criteria such as regional exposure, sensitivity of sectors, adaptive capacity and institutional readiness. This has made climate risk management an important part of national development planning, especially in nations where climate-sensitive sectors are vital for economic growth and social welfare.

As climate-related concerns multiply, India has instituted a range of adaptation and risk management methods for resilience building. They include drought monitoring systems, climate forecasting and early warning

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systems, expansion of irrigation infrastructure, promotion of climate smart agricultural practices, crop insurance schemes, watershed development programmes and policy initiatives focusing on sustainable resource management. In some places, these measures have helped to reduce vulnerability, but there are still big differences in the ability to adapt, how well institutions work and access to technologies that can help communities cope with climate change. The efficiency of current adaptation methods is, therefore, critical to the development of more resilient and inclusive climate governance frameworks. The paper explores the relationship between the climatic variability generated by El Niño and the Indian economy by examining climate risks, economic vulnerabilities, adaptation options and policy responses. This research is designed to evaluate the impact of El Niño on major economic sectors such as agriculture and water resources and the role of adaptation methods to mitigate the effect of climate shocks. The research integrates climatic, economic and policy perspectives and so contributes to the increasing body of literature on climate resilience and sustainable development in India.

Objectives:

The specific objectives are:

(i) to examine the impact of El Niño on monsoon variability and climate related risks in India;

(ii) assess the economic vulnerabilities associated with El Niño induced climatic anomalies;

(iii) evaluate the existing adaptation and climate risk management strategies; and

(iv) suggest policy recommendations to enhance economic resilience and climate adaptation in El Niño prone years.

The findings are expected to give useful inputs to policymakers, researchers and development organisations working to strengthen India's preparation for future climatic uncertainties and promote sustainable economic development.

Literature Review:

El Niño and Climate Variability:

The El Niño Southern Oscillation (ENSO) is, in general, considered as one of the most important ocean-atmosphere phenomena affecting global climate variability. Anomalous rise of sea surface temperatures in the equatorial Pacific Ocean, known as El Niño (the warm phase of ENSO), changes atmospheric circulation patterns and impacts precipitation regimes worldwide. The physical relationship between oceanic warming and air circulation anomalies was identified in earlier studies by Bjerknes (1969) and served as the foundation for later investigations of ENSO dynamics. Later research found that El Niño affected temperature, the distribution of rainfall, the frequency of droughts and extreme weather in many parts of the world including South Asia, Africa, Australia and Latin America. ENSO is a key driver of interannual climate variability that has been continually emphasised by climate experts. The major El Niño occurrences tend to disrupt the usual monsoon circulation patterns and have considerable hydrological and agricultural impacts in monsoon reliant countries. The growing frequency of climatic extremes under global climate change has further deepened the worries on the relationship between ENSO variability and regional climate systems.

El Niño and the Indian Monsoon:

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The association between El Niño and the Indian Summer Monsoon Rainfall (ISMR) has been widely investigated in climatological studies. Several researchers have noted a general inverse relationship between the occurrence of the El Niño phenomenon and monsoon rainfall, suggesting that the severe El Niño years are often connected with below-normal rainfall and drought conditions over India. Sikka (1980), Rasmusson and Carpenter (1983) and later Kumar et al. (1999) have shown that ENSO is an important factor in monsoon variability, but the strength of the association varies in time and space. The ENSO-monsoon association likewise has been found to be non-uniform. Some El Niño have generated severe droughts, others have resulted in just mild deficits in rainfall. This variation has been related to the interplay with other climatic phenomena, such as the Indian Ocean Dipole (IOD), Madden-Julian Oscillation (MJO) and regional air circulation patterns. But most research concur that El Niño is one of the most important indicators of monsoon performance and climate related risks in India. New research suggests climate change could affect the typical ENSO-monsoon relationship, making it harder to predict rainfall and manage water resources. Therefore, it is becoming more and more critical to understand the changing dynamics of ENSO impacts for climate risk assessment and adaptation planning.

Economic Impacts of El Niño in India:

There is extensive literature on the economic impact of El Niño generated weather variability. As agriculture still relies heavily on monsoon rains, changes in precipitation directly impact crop yields, rural jobs, and household income. Reports have indicated substantial declines in agricultural production, notably in rain-fed crops like rice, lentils, coarse cereals and oilseeds, during strong El Nino years. Economic research suggests the drought conditions linked with El Niño might have cascading consequences through the economy. Declines in agricultural productivity are generally associated with food supply shortages, higher food prices, inflationary pressures and larger fiscal costs for governments in terms of relief and rehabilitation spending. Researchers have shown that in India, years with large droughts have been linked to slower economic growth and a drop in agriculture gross domestic product (GDP). El Nino associated climate abnormalities impact water supplies, energy production, transportation systems and industrial activity as well as agriculture. Lower reservoir levels can limit hydropower output and restrict the availability of irrigation, while water shortages can boost competition among agricultural, household and industrial users. The repercussions are interlinked and illustrate the complexity of the climate-economy nexus and the need for integrated risk management techniques.

Climate Risk, Vulnerability and Resilience:

The notions of climate risk, vulnerability and resilience are becoming increasingly prominent in current research on climate change. The Intergovernmental Panel on Climate Change (IPCC) defines climate risk as the interplay of hazards, exposure and vulnerability. In the context of El Niño, climatic risks arise from rainfall shortfalls, droughts, water scarcity and associated socio-economic impacts. Studies of vulnerability highlight that the impacts of climate hazards are unevenly distributed between regions and among social categories. Vulnerability is influenced by factors such as dependency on agriculture, levels of poverty, access to irrigation, availability of infrastructure, and institutional capability. Several studies have shown that rain-fed agricultural regions of central, western and peninsular India are especially vulnerable to climate variability due to their weak adaptive capacity and high dependency on monsoon rainfall. Communities, institutions and economic systems' responses to climate shocks are increasingly being understood through resilience-based approaches. Research shows that resilience can be promoted through diverse livelihoods, effective resource management,

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climate information services, and enabling governance frameworks. The results have helped to a transition from reactive disaster management to proactive climate adaptation and resilience building.

Adaptation Strategies and Climate Risk Management:

Adaptation has emerged as an important element of climate policy and planning for sustainable development. A suite of adaptation techniques have been identified in the literature to reduce the negative effects of climate variability and enhance resilience. Crop diversification, drought-resistant crop types, effective irrigation systems, soil moisture conservation and climate-smart farming practices are standard measures in the agricultural sector. The literature has extensively examined interventions by institutions such as weather forecasting systems, early warning systems, crop insurance schemes and drought preparedness plans. Studies on adaptation efforts in India indicate that access to climate information and institutional support play a crucial role in enhancing farmers' capacity to cope with climatic uncertainty. The climate risk management frameworks stress the significance of scientific knowledge, governmental systems, and socioeconomic planning. Researchers say that good climate risk management needs a blend of actions across sectors like agriculture, water resources, disaster management and economic planning. There is recognition that integrated approaches are critical for reducing losses from climate change and building long-term resilience.

Policy Responses and Climate Governance in India:

India has launched many policy steps to address climate-related hazards and to improve adaptation capacity. The National Action Plan on Climate Change (NAPCC) and its missions provide an overarching framework for climate adaptation and sustainable resource management. Climate resilience goals have been increasingly mainstreamed into water conservation, renewable energy, sustainable agriculture and disaster risk reduction policies. Government activities such as crop insurance schemes, watershed improvement projects, irrigation extension initiatives and climate-resilient agriculture programmes have been implemented to minimise vulnerability and promote rural livelihoods. Yet, experts have identified major problems in policy implementation including regional differences, poor institutional coordination, financial restrictions and unequal access to adaptation resources. Recent studies underline the need for localised adaptation planning, improved climate services, greater stakeholder participation, and a stronger integration of climate issues into development policy. These proposals are informed by a growing realisation that climate governance needs to be sensitive to both the environmental and socio-economic dimensions of vulnerability.

Research Gap:

Despite the large body of literature on ENSO dynamics, monsoon variability and climate adaptation, there are many study gaps. Most of the current work has concentrated on either the climatological aspects of El Niño or on the economic consequences in particular sectors, especially agriculture. Few studies have taken an integrated climate-economy approach to analyse climate threats, economic vulnerabilities, adaptation options and policy implications at the national and regional levels. Furthermore, there has been insufficient emphasis on the spatial aspects of economic vulnerability and resilience across the diverse regions of India. The usefulness of adaptation methods and climate risk management strategies in recent El Niño occurrences, however, is not thoroughly examined. Furthermore, the growing uncertainty related to climate change requires a greater knowledge of the interaction between climatic shocks and socio-economic systems and governance structures. The current study, using an interdisciplinary approach, attempts to fill these gaps by examining the climate-economy connection in India during El Niño years. The study integrates climatic, economic and policy

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perspectives to provide a complete evaluation of climate risks, adaptation options and policy implications for building resilience and sustainable development.

Study Area:

India is a country in South Asia. It has a range of different landforms such as the Himalayas, the Indo-Gangetic plains, the peninsular plateau, deserts and coastal areas. India is very sensitive to variations in the climate because it is highly dependent on the southwest monsoon which accounts for 75-80% of annual rainfall. This monsoon-dominated climate makes agriculture, water resources, hydropower and rural livelihoods especially sensitive to variations in rainfall, particularly during El Niño years. Historically, El Niño years have been associated with droughts and sub-par monsoon performance, as in 1982–83, 1987–88, 2002–03, 2009–10, 2015–16 and 2023–24. Rajasthan, Maharashtra, Karnataka, Telangana, Andhra Pradesh and Madhya Pradesh are among the states most vulnerable to climate stress, with about half of the cultivated area being rainfed and a huge population depending on agriculture. El Niño-induced rainfall deficiencies also effect water availability, reservoir storage, groundwater recharge and hydropower generation, hurting rural and urban economies. India, with its heterogeneous economic structure, regional disparities and high sensitivity to climate is a case in point to study the climate-economy nexus, notably with regard to agricultural output, food inflation, employment and expenditures on disasters.

Data Sources and Methodology:

The present study is based on secondary data obtained from national and international sources for the period 1990-2025. Climatic data connected to the El Niño occurrences such as Oceanic Niño Index (ONI) and sea surface temperature anomalies were gathered from the National Oceanic and Atmospheric Administration (NOAA). Rainfall and monsoon data were procured from the India Meteorological Department (IMD) and agriculture information including crop production and area under cultivation were procured from the Ministry of Agriculture and Farmers Welfare. The economic indicators such as Gross Domestic Product (GDP), agricultural GDP, inflation rates and food price indices were sourced from Ministry of Statistics and Programme Implementation (MoSPI) and Reserve Bank of India (RBI).

The research design used is descriptive and analytical towards understanding the relationship between El Nino generated climate variability and economic performance of India. Changes in rainfall, agricultural production and economic indicators during big El Niño years were analysed using trend analysis. A correlation analysis was done to identify the relationship between the ENSO intensity and the monsoon variability and selected economic indicators. The effects of major El Niño episodes in different times were evaluated via comparison.

The application of spatial analysis approaches using the Geographic Information System (GIS) tools assessed climatic risks and area vulnerability. The spatial distribution of climate risk was quantified by mapping rainfall anomalies, drought prone areas and economically susceptible locations. The results are discussed within the framework of climate risk management, economic vulnerability and adaptation techniques for evaluating the effectiveness of current policy interventions and measures to create resilience in India.

Risk Assessment and Adaptation Strategies Evidence from India:

India's economy is highly dependent on the southwest monsoon and hence is exposed to considerable risks from El Niño-induced climate variability. The implications are particularly severe for agriculture, water

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resources, food security, energy production and rural lives. Assessment of climate risks, Assessment of exposure, sensitivity and adaptive ability of regions and sectors exposed to rainfall shortfalls and drought conditions during El Niño episodes.

Historically, significant El Niño events have resulted in deficient monsoon rains in numerous places of India. Reduced soil moisture, lower reservoir storage, groundwater depletion, crop losses and lower agricultural production are often the result of a lack of rainfall. These environmental shocks trigger a chain of economic effects such as lowering farm earnings, generating inflationary pressures on food prices, inducing employment disruptions and raising fiscal costs for governments through relief and rehabilitation programs. Risk assessment points to western, central and peninsular India being more vulnerable due to reliance on rain-fed agriculture and recurrent droughts. States such as Rajasthan, Maharashtra, Karnataka, Telangana, Andhra Pradesh, Madhya Pradesh and Chhattisgarh are more prone to El Niño linked climate concerns. In contrast, areas with large-scale irrigation infrastructure and diversified economic activity are more resilient.

Case Study 1

The 2002 Drought and Agricultural Losses: The El Niño event of 2002 was one of the worst climatic experiences faced by India in the recent decades. There was a significant shortfall in rainfall during the southwest monsoon, leading to dryness in many regions. Farm production fell considerably, especially in the rain-fed zones. Foodgrain output declined drastically, damaging rural incomes and increasing the economic vulnerability of farmer communities. The drought revealed the unavailability of irrigation cover and the dependence of Indian agriculture on monsoon rainfall. Crop failures, stress in livestock and water scarcity were faced by many districts in Rajasthan, Gujarat, Madhya Pradesh and Andhra Pradesh. The catastrophe brought to the fore the direct link between climate variability and agricultural productivity and the national economy.

Case Study 2

The 2009 El Niño and Economic Vulnerability: The El Niño event of 2009 produced one of the weaker monsoons in nearly four decades. Rainfall deficits were more than 20 percent in some areas and drought conditions were severe. Agricultural GDP growth eased, food prices rose and inflationary pressures strengthened. The drought hit small and marginal farmers who did not have access to irrigation and financial resources. The 2009 episode showed the wider economic consequences of climate shocks. The fall in agricultural output also led to food inflation and increased government spending on drought relief and rural support schemes. This symposium emphasised the necessity of including climate risk management in economic planning and development programs.

Case Study 3

The 2015-16 El Niño and Water Resource Stress: The intense El Nino event of 2015-16 caused major rainfall shortages in many places of India. Maharashtra endured one of the worst droughts, especially in the Marathwada region. Reservoir levels dropped dramatically, groundwater resources were depleted and agricultural activities suffered heavy losses.

In many places the drought caused serious drinking water shortages. Trains loaded with water to drought-affected places like Latur became a symbol of the issue. The seminar highlighted the increasing necessity of water resource management and climate adaptation measures in drought-affected areas. Increasing occurrence of climate-related risks has led to the implementation of various adaptation techniques to reduce vulnerability

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and enhance resilience. Adaptation efforts in India are undertaken at several levels ranging from farm level interventions, institutional processes, technology advances to legislative initiatives. Climate-smart agriculture is an important adaptation method in regions where drought is a recurrent problem. Drought-resistant agricultural varieties, crop diversification, effective irrigation systems and soil moisture conservation measures have reduced the dangers posed by climate change.

Case Study 4

Climate-Resilient Agriculture in Karnataka:

Karnataka's several districts have taken up climate-resilient agriculture methods under various government-sponsored schemes. Farmers are increasingly switching to drought resistant crops like millets, pulses and oilseeds. Micro-irrigation technologies (drip and sprinkler irrigation systems) have increased water-use efficiency and reduced vulnerability to rainfall fluctuation. Such techniques have improved resilience in agriculture and supported sustainable management of resources, especially in semi-arid areas regularly hit by droughts associated with El Niño. Watershed improvement initiatives have been crucial to improving water security and reducing drought susceptibility.

Case Study 5

Hiware Bazar, Maharashtra:

Hiware Bazar in Maharashtra is one of the best instances of community-based watershed management in India. Rainwater harvesting, groundwater recharge, afforestation and water conservation programs helped turn the community from a drought-prone settlement to a model of sustainable rural development. Hiware Bazar's success shows how local adaptation measures can greatly increase resilience to climatic shocks. Improved water supply permitted agricultural diversification, boosted farm earnings and reduced vulnerability to drought conditions associated with El Niño years. Crop insurance is an important financial adaptation measure that compensates for climate-induced losses in agriculture.

Case Study 6

Pradhan Mantri Fasal Bima Yojana (PMFBY):

Better climate prediction has helped India to better anticipate and cope with the risks of El Niño. The India Meteorological Department's seasonal monsoon forecasts enable governments, farmers and policymakers to take preparedness steps ahead of adverse climatic conditions. Improved forecasting methods allow for timely decisions on what crops to plant, when to irrigate, how to allocate water resources, and how to prepare for disasters. Increased resistance to climatic variability has been aided by the increasing use of climate information in agricultural and policy decision-making.

Insights from the Case Studies:

The case studies show that while the threat of El Nino to the Indian economy is high, successful adaptation strategies may greatly mitigate the vulnerability. For long-term resilience, irrigation infrastructure needs to be strengthened, climate-smart agriculture promoted, watershed development encouraged, crop insurance cover improved and climate forecasting systems enhanced. In addition, national and state development planning should mainstream climate risk factors. Regional gaps in adaptive ability necessitate region-specific measures in drought-prone areas and severely vulnerable districts. Greater investment in climate-resilient infrastructure, sustainable water management and institutional capacity building will be essential in protecting livelihoods

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and economic growth in future El Niño events. More generally, the Indian experience suggests that proactive adaptation and effective climate risk management can turn climate difficulties into opportunities for developing resilience and sustainable development.

Results and Findings:

El Niño and Monsoon Variability in India:

The results suggest a significant relation between El Nino episodes and monsoon variability in India. Major El Nino years such as 2002, 2009, 2015-16 and 2023-24 were marked by below normal rainfall over broad sections of the country. The rainfall shortages were particularly acute in western, central and peninsular India where dependence on rain-fed agriculture is strong. The data suggest that atmospheric circulation instabilities generated by El Niño negatively impact monsoon currents, causing late start, protracted dry spells and erratic rainfall distribution. The association of El Niño with monsoon rainfall is not entirely linear, although generally strong El Niño periods are associated with an increase in the risk of occurrence of droughts. The recurring incidence of deficient rainfall made Rajasthan, Maharashtra, Karnataka, Telangana, Andhra Pradesh and Madhya Pradesh more climate sensitive. These results are in agreement with earlier studies which show ENSO as one of the most important drivers of interannual climatic variability in India.

Impact on Agricultural Productivity:

Results indicate that agriculture is the most sensitive sector to El Niño driven climatic abnormalities. In major El Niño years, agricultural productivity decreased due to decreased soil moisture, limited irrigation water, and higher crop stress. Rainfed crops such as rice, lentils, coarse cereals and oilseeds were worst impacted. The 2002 drought led to a steep fall in foodgrain output while the 2009 El Nino had a negative impact on kharif crop productivity in numerous states. Similar patterns were seen during the 2015-16 drought when deficits in rainfall led to reduced agricultural output and farm earnings. Small and marginal farmers suffered the most as they had little access to irrigation, financing facilities and climate-resilient technologies. The data indicate that agricultural vulnerability is a function of climate exposure in addition to socio-economic characteristics such as landholding size, irrigation coverage and institutional support. Production losses were comparatively smaller in regions with superior irrigation infrastructure and diversified agricultural systems, indicating the significance of adaptive ability in minimising climate-related risks.

Water Resource Vulnerability:

Analysis reveals water supplies are another important aspect of climate risk in El Niño years. The reduction in monsoon rainfall has a direct impact on reservoir storage, ground water recharge and river flows. The 2015-16 El Nino event saw many droughts prone areas such as Maharashtra, Karnataka and parts of central India suffer from severe water shortages. Depleting groundwater levels was a major worry in places largely dependent on groundwater irrigation. During dry spells, more groundwater was pumped out, which made the resource shortage worse and weakened long-term water security. Water shortage in metropolitan areas impacted family consumption and industrial production, revealing the links between climatic and economic systems. The findings indicate that water stress is not only an environmental problem but also an economic one, impacting agricultural production, public health, energy generation and industrial development.

Economic Consequences of El Niño Events:

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Climate shocks linked to El Niño have significant economic impacts at the national and regional level, the research shows. Lower agricultural production means slower growth in agriculture GDP, falling rural incomes and higher food price inflation. During catastrophic drought years, governments are typically forced to boost their investment on drought relief, employment generating projects and agricultural assistance measures. One of the most evident economic repercussions of rainfall shortfalls was food inflation. Supply constraints and rising market prices were exacerbated by reduced production of cereals, pulses and vegetables. Low-income households experienced these inflationary pressures disproportionately, thus raising socio-economic vulnerability. The data also suggests that climate-induced disruptions are not limited to agriculture. Water shortages will impact hydropower generation, industrial productivity and urban economic activities. Thus, El Niño episodes have economy-wide repercussions for growth, employment and development results.

Spatial Patterns of Climate Risk and Economic Vulnerability:

Spatial study reveals significant regional variations in vulnerability to climate risk and adaptive capacity within India. The most susceptible regions were western and central India, where drought-prone regions rely on monsoon rains and have inadequate water supplies. States such as Rajasthan, Maharashtra, Karnataka, Telangana and Madhya Pradesh demonstrated consistently increased climate sensitivity. By contrast, areas with large irrigation networks, diversified economic structures and stronger institutional backing have been more resilient. Punjab and Haryana were comparatively less subject to rainfall variability due to their better irrigation systems. Economically diversified states were also better able to absorb climate-related shocks than regions relying on agriculture. These results emphasise the significance of regional variation in climate risk management and adaptation planning. A uniform policy approach may not be sufficient to address the various levels of vulnerability identified across regions.

Effectiveness of Adaptation Strategies:

The results show that adaptation methods have played an important role in lowering vulnerability to El Niño-induced climatic risks. In many areas, better irrigation systems, climate-smart agriculture, watershed development initiatives, crop insurance schemes and early warning systems have boosted resilience. Examples of localised adaptation measures include success stories of watershed management in Maharashtra and climate-resilient agriculture practices in Karnataka. Similarly, seasonal climate projections by meteorology organisations have enhanced preparation of farmers and policymakers. Crop insurance policies have also offered some financial coverage for weather-induced losses, while problems of accessibility and claim processing remain. The analysis reveals that the most effective adaption options incorporate technology breakthroughs, institutional assistance and community participation . Investment in climate resilient infrastructure and sustainable management of resources can greatly prevent future losses due to climate.

Discussion:

The results of this research indicate the complex relationship between climate variability and economic development in India. El Niño is a key climatic stressor impacting monsoon performance, agricultural productivity, water supply and economic stability. However, the repercussions of El Niño are not uniform and depend on regional climatic conditions, socio-economic factors and adaptive capacity.

The results complement the increasing literature that emphasises the need for resilience-based approaches to climate risk management. While climate dangers cannot be avoided, their socio-economic impacts can be significantly mitigated by proactive adaptation techniques. The study also finds that economic vulnerability

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is formed not only by exposure to climate threats, but also by the quality of governance, the availability of infrastructure, the adoption of technology and the effectiveness of institutions.

As climate uncertainty increases, enhancing climate risk governance and mainstreaming adaptation into development planning is critical to protect livelihoods and drive sustainable economic growth. The results indicate that future policy actions ought to focus on water security, scaling up climate-smart agriculture, increasing climate information services and tackling regional variations in adaptation capacity. Such steps will be important for strengthening long-term resilience and mitigating the economic effects of future El Niño episodes in India.

Policy Implementation:

A comprehensive policy framework for effective management of El Niño-related climate hazards needs to include climate adaptation, disaster risk reduction and economic planning. India has made considerable progress in building the institutional systems and policy responses to handle climate variability. Nevertheless, the rising frequency and intensity of climate-related threats require more proactive and coordinated implementation strategies.

Strengthening Climate Risk Governance:

Climate risk management must be integrated into national, state and municipal development planning. The need is to better integrate existing policy frameworks such as the National Action Plan on Climate Change (NAPCC), State Action Plans on Climate Change (SAPCCs) and disaster management regulations to ensure coordinated responses to El Niño-related climatic shocks. Strengthening institutional collaboration among meteorological agencies, agricultural departments, water resource authorities and disaster management institutions will enhance preparedness and response capabilities. Effective implementation requires multi-level governance involving national, state and local governments. Enable the local governments and Panchayati Raj Institutions to design location-specific adaptation plans based on the regional climate circumstances and socio-economic vulnerabilities.

Enhancing Climate Information and Early Warning Systems:

Climate risk management is a key component of accurate climate forecasting and timely transmission of information. The India Meteorological Department (IMD) has made substantial progress in enhancing seasonal forecasting capabilities, but more work is needed to ensure that climatic information is made available to farmers, local authorities and vulnerable groups in an accessible and practical fashion. The combination of digital technology, mobile-based advisory services and AI-powered forecasting tools can improve the transmission of climate information. By strengthening early warning systems, stakeholders would be better able to make informed decisions on crop selection, irrigation scheduling, water management and disaster preparedness in the face of adverse meteorological circumstances.

Promoting Climate-Smart Agriculture:

Agriculture is the most climate sensitive sector in India and hence requires specialised adaptation measures. Implementation of policies should focus on scaling up climate-smart farming approaches including drought resistant cultivars, crop diversification, conservation agriculture, effective irrigation methods and soil moisture management. Government programmes should be established to promote cultivation of less water-intensive crops in drought-prone areas and the promotion of sustainable farming systems to enhance resilience to

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variability in rainfall. Strengthening agricultural extension services and enhancing farmers' access to climate-resilient technology in El Niño years will be critical to minimising susceptibility.

Expanding Irrigation and Water Resource Management:

One of the worst effects of the El Niño droughts is water shortages. The effective implementation of policy should focus on increased water-use efficiency, expansion of irrigation infrastructure and integrated water resource management. Investment in micro-irrigation systems, such as drip and sprinkler irrigation, may dramatically decrease water use while sustaining agricultural yield. Rainwater harvesting, watershed development, groundwater recharge projects and reservoir management should be priority programmes, especially in the drought-prone areas of western and central India. The success stories of watershed management practices in Maharashtra and Rajasthan highlight the role of community participation in ensuring sustainable management of water resources. Scaling up such activities could increase resistance to future weather shocks.

Strengthening Financial Risk Protection Mechanisms:

Economic sensitivity to climate threats can be mitigated by financial protection measures. Crop insurance plans need further strengthening to offer timely and adequate reimbursement for climate related losses. improving openness, streamlining claim procedures and improving knowledge among farmers may improve the effectiveness of insurance systems. Governments should also improve access to climate-risk financing, agricultural lending and livelihood support initiatives for vulnerable groups. Social protection measures, such as employment guarantee schemes and targeted subsidies, can assist mitigate the socio-economic costs of droughts and agricultural losses.

Addressing Regional Vulnerabilities:

The results show that there are considerable regional differences in exposure to climate risk and adaptive capacity. Therefore, the policy implementation should be regional specific rather than a consistent national strategy. States like Rajasthan, Maharashtra, Karnataka, Telangana, Madhya Pradesh and Andhra Pradesh that are drought-prone, require focused investments in climate adaptation, water conservation and livelihood diversification. District-level climate vulnerability assessments can support policymakers by providing a better understanding of high-risk locations, and more efficient resource allocation. The planning process should include GIS-based vulnerability mapping and climate-risk monitoring systems to facilitate evidence-based decision-making.

Integrating Climate Adaptation into Economic Planning:

Climate resilience needs to be integrated into broader economic and development initiatives. Infrastructure development, urban planning, agricultural policy and water management programmes must factor in future climate hazards related with El Niño and other climatic occurrences. Investment in climate-resilient infrastructure, renewable energy systems, sustainable agriculture, and ecosystem restoration can reduce vulnerability and bring long-term economic advantages. Climate adaptation must be seen not just as an environmental need, but as a core element of sustainable economic growth and national resilience.

Towards a Resilient Climate-Economy Framework:

The results show a need to move from reactive disaster reaction to proactive climate risk management in policy implementation. Building resilience to climate shocks caused by El Niño requires coordinated effort

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across sectors, institutions and levels of governance. A comprehensive climate-economy framework that encompasses risk assessment, adaption planning, technology innovation, community participation and evidence-based policy-making can considerably improve India's ability to deal with future climatic uncertainties. This method would not only help reduce economic losses in El Niño years but also lead to sustainable development, food security, water security and long-term climate resilience in the country.

Conclusion:

The present study explored the intricate interaction between El Niño-related climate variability and the Indian economy within the framework of climate risk assessment, adaptation, and policy implications. The results show that El Niño continues to be one of the major causes of climate variability affecting the Indian monsoon, with wide-ranging implications for agriculture, water resources, food security, rural livelihoods and overall economic stability. Historical evidence from large El Niño events, particularly 2002, 2009 and 2015–16, shows that rainfall deficits and drought conditions can have a large impact on agricultural productivity, food inflation, water scarcity and economic costs for vulnerable populations.

The study finds El Niño's affects are not uniform across the country. High dependence on rain-fed agriculture, poor irrigation infrastructure and inadequate adaptive capacity make areas more vulnerable to climate related risks. Most vulnerable states are Rajasthan, Maharashtra, Karnataka, Telangana, Madhya Pradesh and Andhra Pradesh due to periodic drought spell and socio-economic sensibilities. Areas with more diverse economies, better irrigation facilities and better institutional support are more resilient to weather shocks.

The data also suggests that adaptation methods have an important influence in lowering vulnerability and boosting resilience. Climate-smart agriculture, watershed development, effective irrigation systems, crop insurance schemes and enhanced climate forecasting techniques have demonstrated substantial potential for reducing the harmful impacts of El Niño caused climate variability. Successful examples from drought-prone regions of Karnataka, Maharashtra and others have shown that community participation, technological innovation and institutional assistance can substantially enhance adaptive capacity and increase long-term sustainability.

From a policy standpoint, the study highlights the need to embed climate risk management within broader development planning. Effectively responding to El Niño-related hazards requires well-coordinated actions across sectors and levels of governance, supported by sound climate information systems, sustainable water management practices, climate-resilient agricultural systems and specific measures in vulnerable regions. Strengthening the execution of climate adaptation policies, institutional capacity and supporting region-specific resilience solutions will be key to tackling future climate issues.

With climate change projected to increase the frequency and intensity of extreme weather events, the interaction between ENSO variability and India's climate system is likely to become increasingly complex. Thus, future research should focus on generating high-resolution spatial assessments of climate vulnerability, evaluating the long-term success of adaption methods, and studying the role of emerging technologies in climate risk management. More integrated study of geospatial data, climate modelling and socio-economic evaluation can yield more complete insights into the changing climate-economy nexus.

While El Niño presents huge obstacles for India's sustainable development journey, proactive adaptation and effective climate governance can considerably lower economic vulnerability and build resilience. Building a climate-resilient economy means shifting from disaster reaction to disaster anticipation and risk management,

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underpinned by science, inclusive policies and sustainable use of resources. This method would not only enhance India's ability to deal with future El Niño occurrences, but also assist in reaching long-term goals of economic stability, environmental sustainability and climate-resilient growth.

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