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Ongoing Impact of El Niño on India's Socio-Epidemiological Landscape: Climate-Induced Health Vulnerabilities, Resource Scarcity, and Community Resilience

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Abstract

El Niño, recurring ocean-atmospheric climatic events associated with abnormal warming of the sea surface temperatures in the equatorial Pacific Ocean, are critical drivers of global and regional climate, including the Indian monsoon. This review presents a critical appraisal of its current socio-epidemiological impacts in India, with a focus on climate-induced health risks, resource constraints and adaptive capacities. It integrates knowledge on El Niño-related climatic disruptions and their downstream effects on disease burden, malnutrition and socio-economic burden, along with community-based and institutional adaptation. The study suggests that El Niño-related climate extremes - such as extreme heatwaves, droughts and erratic precipitation patterns - lead to an increase in the incidence of vector-borne and water-borne diseases, along with malnutrition. In addition, water and food scarcity exacerbates socio-economic disparities, particularly among rural and urban slum dwellers, women and children. While progress has been made in climate-proofing agriculture, water management and public health, there remain significant gaps in integrated climate-health research, policy translation at the local level, and epidemiological surveillance. The review suggests a multi-disciplinary and holistic approach is needed to curb the socio-epidemiological effects of El Niño in India.

Keywords: El Niño, climate variability, socio-epidemiology, health vulnerability, resource scarcity.

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1. INTRODUCTION

El Niño is a key component of the El Niño-Southern Oscillation (ENSO) cycle, which exhibits quasi-periodic variability in ocean and atmospheric conditions in the tropical Pacific Ocean. It involves the warming of ocean temperatures in the central and eastern Pacific Ocean, leading

to the weakening of trade winds with subsequent shifts in global-scale circulation patterns like the Walker Circulation [1]. These variations affect global climate systems through teleconnections, that is, long-range climatic connections, which in turn affect the rainfall, temperature, and extreme-weather events of various parts of the world [2].

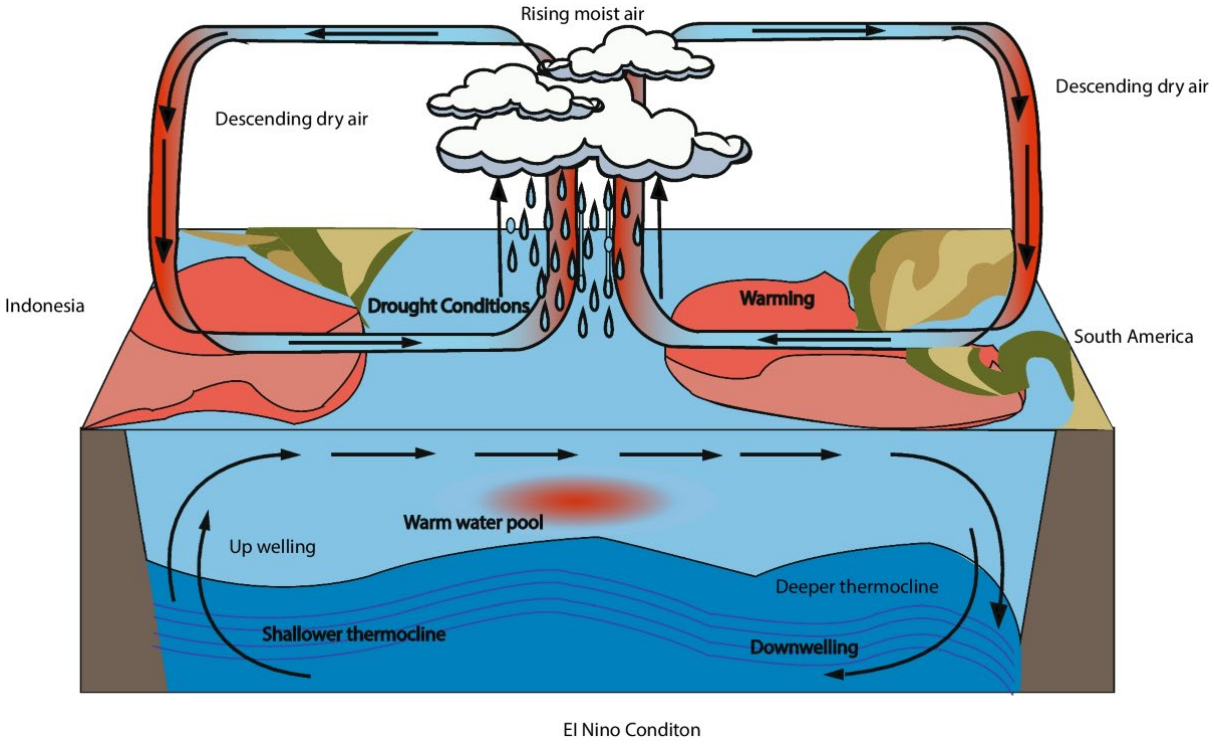

Figure 1: El Niño Condition

El Niño's effects are not limited to the Pacific Ocean; they also affect continents like Asia, Africa and the Americas, both in terms of the environment and human systems [1]. In the South Asian region, especially in India, El Niño significantly affects the southwest monsoon, which accounts for almost 70-80% of the annual rainfall. El Niño events frequently bring about weak moisture-laden winds, which cause poor monsoon rainfall, leading to droughts, low crop yields, and water scarcity [3].

Additionally, El Niño also affects temperature patterns, often leading to the onset of extreme heatwaves and droughts. Such changes in climate conditions not only influence environmental stability but also have a far-reaching impact on agriculture, water supply, energy consumption, and human health [4]. The growing overlap between El Niño events and human-induced climate change has also contributed to the increased variability and unpredictability of impacts, complicating efforts to predict and adapt to the resulting challenges [5].

Therefore, El Niño is a key source of climate variability and has significant implications, especially in developing nations such as India, where socio-economic activity is closely linked to climate. Knowing its dynamics and effects is crucial to tackle new challenges in environmental sustainability, health and socio-economic vulnerabilities.

1.1 Background of the Study

The link between ENSO and the Indian monsoon has been well documented. In the past, major El Niño events have been linked to reduced rainfall during the Indian monsoon, which has resulted in droughts and crop failures. The Indian monsoon is very dependent on sea surface temperatures and pressure gradients, which are largely influenced by ENSO [6].

There has been an increase in the magnitude and frequency of climate anomalies in recent decades, attributed to global warming. This has led to increasing variability in the monsoon system, such as delayed onset, spatial variability and sudden cessation. As a result, India has seen an increase in extreme weather events such as droughts, heatwaves, and occasional heavy rainfall, which have impacts on environmental sustainability and human health [7].

The socio-economic fabric of India also exacerbates the impacts of such variability. Many people are engaged in climate-sensitive activities such as agriculture, livestock and fisheries. Moreover, population density, urbanization and disproportionate access to resources like water, health and sanitation, further compound the effects of climate variability. These factors result in a complex interaction between environmental factors and health, giving rise to what is known as a socio-epidemiological problem [8].

1.2 Objectives of the Review

This review aims to:

- Examine the relationship between El Niño and India's climatic variability
- Analyze the socio-epidemiological consequences of climate-induced disruptions
- Assess the implications of resource scarcity on health and socio-economic stability
- Evaluate community resilience and adaptation strategies
- Identify research gaps and suggest future directions

1.3 Importance of the Topic

El Niño's effects have been exacerbated by the increasing frequency and intensity of extreme climate events, and have become a key focus of modern environmental and public health studies. Comprehending its socio-epidemiological impacts is crucial for effective mitigation, adaptation and policy responses [9].

This is an important topic in many areas:

- **Public Health:** Climate-sensitive diseases are on the rise, demanding better monitoring and preparedness
- **Sustainable Development:** Climate change risks food, water and economic security
- **Disaster Risk Reduction:** Vulnerability can be reduced with early warning and adaptation

- **Policy Development:** Informed policies are required to integrate climate, socio-economic and health sectors

In short, analysing the on-going El Niño effects in India offers key insights into the links between climate, health and socio-economic vulnerability, and hence helps build a better understanding of sustainable development in a climate change world [10].

2. CLIMATIC VARIABILITY AND ENVIRONMENTAL DISRUPTIONS

El Niño events have a significant impact on India's climate, largely through the weakening of the southwest monsoon that provides the country with the bulk of its rainfall. El Niño events are marked by warmer-than-average sea surface temperatures in the Pacific Ocean, which affect the normal circulation of air, known as the Walker circulation, thereby decreasing moisture transport to the Indian subcontinent. This results in reduced rainfall, a delayed start to the monsoon, and uneven rainfall distribution across India. Such monsoon variability affects the environment in India. Droughts reduce the amount of surface water and groundwater recharge, thus reducing the strength of the hydrologic cycle [11].

At the same time, erratic rainfall patterns, with long dry periods broken by short periods of intense rainfall, lead to less efficient water use. These patterns make water storage more difficult and enhance runoff, contributing to water stress. From an agro-ecological perspective, these changes have profound impacts on soil and crop productivity. Lower precipitation results in decreased soil moisture content, essential for plant growth, especially in rain-fed farming areas, which are prevalent in many parts of India. Higher temperatures during El Niño years also result in increased evapotranspiration, which reduces the amount of water available in the soil and exacerbates water scarcity for crops. This not only reduces productivity but also increases the risk of crop losses, thus impacting food security and livelihoods.

El Niño's environmental impacts also provide conditions for the onset of droughts and heatwaves. Extended periods of dryness lead to a loss of vegetation, increasing the risk of soil erosion and degradation. Ultimately, this leads to desertification, especially in semi-arid and arid zones. Heatwaves, compounded by warming temperatures, compound these effects by accelerating evaporation and putting pressure on water supplies. India is one country that experiences uneven effects from El Niño. Central and northwestern parts of the country, including states like Rajasthan, Madhya Pradesh and parts of Maharashtra, are more vulnerable to drought because of their semi-arid regions and reliance on monsoon rains. By contrast, coastal areas and northeastern states are less affected or, in some cases, have unusual rainfall patterns due to a combination of ocean and atmospheric influences [12].

2.1 Monsoon Variability and Rainfall Anomalies

El Niño exerts a considerable influence on the onset, strength and spatial distribution of the Indian monsoon. El Niño years typically result in rainfall deficits, which can cause extended dry periods and uneven rainfall distribution. At times, some areas can receive brief periods of heavy rainfall, leading to flooding despite rainfall deficits.

Table 1: Impact of El Niño on Monsoon Characteristics [13]

Monsoon Parameter	El Niño Effect	Resulting Impact
Onset of Monsoon	Delayed	Shorter crop cycle
Rainfall Intensity	Reduced	Drought conditions
Spatial Distribution	Uneven	Regional imbalance
Rainfall Pattern	Erratic	Flood–drought cycle

2.2 Temperature Extremes and Heatwave Intensification

El Niño events are closely linked with higher land and ocean temperatures, which boost the frequency, duration and intensity of heatwaves in India. El Niño events bring about a weakened monsoon circulation and a decrease in cloud cover, which permits more sunlight to penetrate the Earth's atmosphere, resulting in warming. This leads to sustained heatwaves, especially during the pre-monsoon and onset of the monsoon.

Temperature increases have several cascading impacts on the environment and society. A key effect is the escalation of evapotranspiration, which speeds up the process of moisture loss from land, water and plants. This aggravates water scarcity, especially in arid areas, and lowers crop yields by disrupting the growing season and requiring more water for irrigation.

Cities are particularly affected by the urban heat island effect, as urban surfaces (concrete, asphalt) have higher heat absorption and retention, which leads to higher temperatures than the surrounding rural areas. Lack of ventilation, vegetation, and densely populated areas worsen the effect of heat stress in urban areas. Consequently, urban residents, particularly those in slums, are more vulnerable to heat-related diseases, such as heatstroke, heat exhaustion and cardiovascular issues.

Further, temperature extremes affect energy consumption, driving up the use of cooling apparatuses like air conditioners and fans. This can place stress on electricity grids, potentially resulting in blackouts that compound the adverse effects of heatwaves. In summary, temperature extremes associated with El Niño not only have environmental implications but also threaten human health, infrastructure and productivity [14].

2.3 Hydrological Cycle Disruptions

Rainfall variability during El Niño events greatly affects the water cycle in India. Changes in rainfall patterns impact the quantity, quality and distribution of water resources. This has a direct impact on river flows, with reduced rainfall leading to reduced runoff and river recharge.

El Niño years result in lower water levels in reservoirs and dams, essential for irrigation, water supply for human consumption and hydroelectric energy generation. This poses a problem for

water managers, who must ensure sufficient water for irrigation and domestic use. In many areas, particularly those with canal irrigation systems, water shortages can result in crop losses.

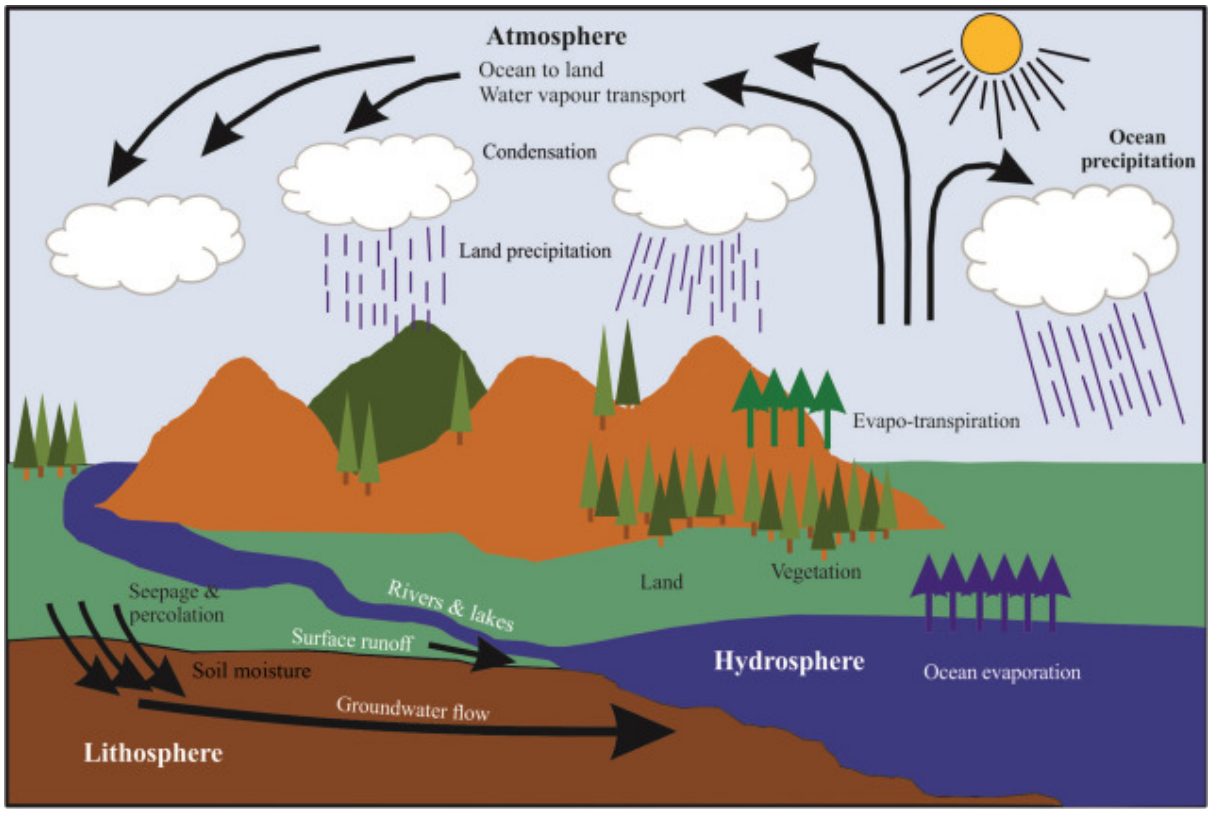

Figure 2: Hydrological Cycle [15]

Water tables, which act as a buffer during droughts, are also adversely affected. Decreased aquifer recharge and enhanced extractions to meet water demands lead to significant aquifer depletion. This is especially problematic in groundwater-dependent states, where water tables can drop, resulting in water scarcity.

In addition, changes in the water cycle impact water quality. Reduced river and reservoir levels can increase the risk of pollution. In rural and peri-urban zones, this often results in the use of unsafe water sources, thus increasing the risk of water-borne diseases.

2.4 Ecosystem Degradation and Biodiversity Loss

El Niño-induced climatic stress has profound effects on India's ecosystems and biodiversity. Variations in temperature and rainfall affect the structure and functioning of ecosystems, impacting plants and animals.

Drought conditions with reduced precipitation cause vegetation to dry, forest productivity to decline and forest fires to increase. This can lead to forest loss and ecosystem imbalances. Drought in grassland and semi-arid regions leads to decreased plant productivity, which can impact on herbivore populations and, in turn, the predators that rely on them.

For animals, climate variability can be very damaging. Altered habitat conditions, water availability, and food distribution may require species to relocate or adapt, or experience population loss. Some species may also relocate towards human settlements in search of food, posing a threat for human-wildlife interactions.

Drought also impacts aquatic ecosystems, with lower water levels in rivers, lakes and wetlands changing aquatic habitats and endangering fish species and other biodiversity. Wetland loss also affects migratory birds and ecosystem services like water filtration and flood mitigation.

In the long term, these impacts lead to phenomena like land degradation and desertification, especially in arid areas. Biodiversity loss reduces ecosystem resilience, making it more challenging for ecosystems to adapt to climatic disturbances. This, in turn, leads to a vicious cycle of reduced ecosystem capacity to support human well-being and maintain environmental sustainability [16].

2.5 Climate-Induced Health Vulnerabilities

El Niño's impacts on the environment result in a broad spectrum of health hazards, both physical and socio-economic. These are diverse and multidimensional, resulting from both direct and indirect exposures to climatic variability and extremes through environmental and social channels.

The direct impacts include heat-related diseases. Longer exposure to elevated temperatures can result in dehydration, heat exhaustion and heatstroke, especially for outdoor workers, the elderly and people with existing health conditions. Higher temperatures also worsen respiratory and heart conditions [17].

Weather conditions have a major impact on vector-borne diseases. Alterations in temperature and humidity levels provide suitable conditions for the survival of disease vectors like mosquitoes. As a result, the spread of diseases like dengue, malaria and chikungunya is heightened, especially in areas where sanitation and water management systems are inadequate.

Water-borne diseases are a result of water scarcity and poor water quality. In a drought, lack of water often leads to the use of unclean water sources, which can cause diseases like cholera, diarrhea and typhoid. Poor sanitation also contributes to the risks [18].

Malnutrition is a result of agricultural and food supply chain disruptions. Agricultural losses and low productivity result in reduced food stocks and price increases, reducing access to healthy food. This particularly affects children and the poor, resulting in malnourishment, stunting, and compromised immunity [19].

The health risks associated with these vulnerabilities are not equally borne by the population. Children, the elderly, women, and economically marginal populations are disproportionately affected due to lack of access to health services, substandard living conditions and lower resilience. Furthermore, the combination of environmental challenges and socio-economic

inequalities exacerbates health vulnerabilities, making climate-related health vulnerabilities a pressing health issue.

Table 2: Health Impacts Associated with El Niño [20]

Health Issue	Climatic Trigger	Major Impact
Heatstroke	High temperature	Increased mortality
Dengue/Malaria	Humidity & stagnation	Disease outbreaks
Diarrheal diseases	Unsafe water	High morbidity
Malnutrition	Crop failure	Child undernutrition

2.6 Resource Scarcity and Socio-Economic Stress

El Niño exacerbates the shortage of basic resources like water and food. Crop failure affects livelihoods, causing economic hardships and poverty.

Water scarcity leads to:

- Over-extraction of groundwater
- Conflicts over water access
- Disproportionate impacts on women and disadvantaged groups

Lack of food leads to inflation, less diverse diets and malnutrition. Also, distress in rural areas can lead to urban migration, which further stresses the urban infrastructure and services.

Table 3: Resource Scarcity and Socio-Economic Effects [21]

Resource	Impact	Socio-Economic Outcome
Water	Scarcity	Migration, conflict
Food	Reduced production	Price rise, hunger
Income	Agricultural loss	Poverty increase
Employment	Reduced rural jobs	Urban migration

3. METHODOLOGIES AND FINDINGS

This section provides an overview of the important research methods adopted for studying the socio-epidemiological effects of El Niño events in India and critically reviews the findings of these methods. The interdisciplinary nature of the research topic has led to the use of a broad range of research approaches including climate science, epidemiology, socio-economics and spatial analysis. These approaches aid in examining the inter-relationship between climate, health and socio-economic factors [22].

3.1 Methodologies Used in Existing Research

A range of different methods have been used to study the impact of El Niño and climate variability on health. These methods differ in scale, data sources and analytical methods used.

1. Climate Data Analysis

Analysis of climate data is the starting point for understanding the physical processes and impacts of El Niño. Scientists use historical records of sea surface temperature (SST) anomalies, air pressure fluctuations, and ENSO indicators like the Oceanic Niño Index (ONI) and Southern Oscillation Index (SOI) to detect El Niño events and their magnitude [23].

These climate variables are then compared with rainfall data of the Indian monsoon sourced from meteorological agencies to study rainfall anomalies. Statistical time-series analysis is commonly applied to identify statistical links between ENSO and monsoon. Furthermore, satellite climate monitoring offers detailed spatial and temporal information about temperature, rainfall, vegetation and soil moisture, allowing for more accurate environmental monitoring.

These approaches can capture broad-scale climatic trends, but may lack the resolution to capture local (district) variations, which are essential for a comprehensive understanding of regional effects.

2. Epidemiological Studies

Epidemiological methods are commonly employed to study the link between climatic variability and diseases. Data on temperature, rainfall, and humidity is correlated with disease data using time-series and regression analyses [24].

Data on health outcomes is often sourced from hospital databases, public health surveillance and government databases, with a focus on morbidity and mortality from climate-sensitive diseases like dengue, malaria, heatstroke and diarrheal diseases. Inter-annual and seasonal changes in disease outbreaks are compared with El Niño to determine patterns and associations.

Such research gives an indication of the direct and indirect health effects of climate variability. But problems include inconsistent reporting of health data, under-reporting of cases and the lack of standardised datasets.

3. Socio-Economic Assessments

Socio-economic approaches seek to understand the impacts of climate variability on livelihoods, incomes, food security and migration. Typically researchers use secondary data

from agricultural production statistics, economic surveys, census reports and government documents.

Studies of drought-prone areas are often conducted to gain insights into the local impacts, with an emphasis on the experiences of farmers, workers and vulnerable groups. These qualitative and mixed-method studies aid the understanding of the social-economic aspects of climate change, such as coping and adaptation [25].

These evaluations offer context-specific information, but can potentially lack broader applicability because of their small-scale and small sample nature.

4. Modelling and Predictions

Predictions of El Niño effects on climate and health are increasingly made using sophisticated modeling approaches. Climate models use historical records and climate projections to project future climate change, allowing predictions of rainfall variability, thermal extremes, and extreme weather events.

Climate-health models combine climate and health data to forecast disease outbreaks under various scenarios. These models are valuable for early warning and health risk assessments.

Spatial analysis using Geographic Information Systems (GIS) is also used to map vulnerability, identify hotspots and spatio-temporal patterns of climate impacts and health effects. GIS provides data visualization to inform decisions.

Table 4: Summary of Selected Research Studies

Author Name	Topic Covered	Research Study Title
Akinkuolie, T. A., Ogunbode, T. O., & Adekiya, A. O. (2025) [26]	Climate-induced food insecurity and adaptation strategies	Resilience to climate-induced food insecurity in Nigeria: A systematic review of the role of adaptation strategies in flood and drought mitigation
McMichael, A., McMichael, C., Berry, H., & Bowen, K. (2010) [27]	Climate-related displacement and health risks	Climate-related displacement: Health risks and responses
Rosen, J. G., Mulenga, D., Phiri, L., Okpara, N., Brander, C., Chelwa, N., & Mbizvo, M. T. (2021) [28]	Climate change, livelihood transformation, and reproductive health	"Burnt by the scorching sun": Climate-induced livelihood transformations, reproductive health, and fertility trajectories in drought-affected communities of Zambia

Swarnokar, S. C., Mou, S. I., Sharmi, S. D., Iftikhar, A., & Jesmin, S. (2025) [29]	Climate risks, adaptation, and mitigation in coastal communities	Climate-induced risks, adaptation, and mitigation responses: A comparative study on climate-stressed coastal communities
Nurullah, A. B. M., Ritchie, L., Islam, S., Roshid, H. O., & Sultana, N. (2026) [30]	Climate disasters and multidimensional poverty	The Role of Climate-Induced Disaster in Multidimensional Poverty: A Systematic Review and the Multidimensional Climate–Poverty Dynamics (MCPD) Framework

The research in Table 1 shows the multiple implications of climate change on human livelihoods, health, and socio-economic well-being, especially in vulnerable areas. The selected studies share a strong association between climate-induced events (droughts, floods, displacement) and impacts on food, health and poverty. Akinkuolie et al. (2025) stress the need for adaptation measures to combat climate-related food insecurity, especially in areas vulnerable to extreme weather events. Likewise, McMichael et al. (2010) highlight the health implications of climate-induced displacement, suggesting environmental change can have profound effects on population stability and health.

Rosen et al. (2021) offer a more socio-demographic focus by connecting climate stress to livelihood and reproductive health impacts, particularly considering environmental changes' long-term effects on populations. Swarnokar et al. (2025) build on this theme by examining the climate risks in coastal areas, highlighting adaptation and mitigation measures in highly vulnerable geographical areas. Finally, Nurullah et al. (2026) add a socio-economic perspective by exploring the link between climate-induced disasters and poverty, and suggest a framework to improve understanding of the complexities of these interactions.

3.2 Key Findings from Literature

The literature reviewed shows that strong associations exist between El Niño events and socio-epidemiological effects:

- **Decrease in monsoon rainfall during El Niño years:** El Niño reduces the strength of the southwest monsoon, resulting in reduced rainfall over many parts of India. This decline is usually uneven, with delayed monsoon onset and retreat, resulting in prolonged dry periods and droughts, particularly in rain-fed farming regions.
- **Higher frequency and intensity of heatwaves:** Higher surface temperatures during El Niño years lead to increased frequency and duration of heatwaves. Drier conditions and less cloud cover also exacerbate heat, increasing heat-related health risks, especially in cities with the urban heat island effect.
- **Increase in vector-borne diseases (dengue, malaria):** Warmer temperatures and altered humidity and rainfall patterns provide a breeding ground for mosquitoes. Puddles from erratic rainfall or poor water storage practices lead to an increase in diseases such as

dengue, malaria, and chikungunya, particularly in urban and poorly governed communities.

- **Increase in water-borne**: diseases in drought-affected regions Less rainfall during El Niño results in water scarcity, which drives people to use unsafe or hygienically compromised water sources. Drying rivers also concentrate pollutants, causing a surge in diseases like cholera, diarrhea and typhoid in areas with poor sanitation.
- **Reduced crop productivity and food insecurity**: with droughts Droughts result in a decline in rainfall and an increase in temperature, affecting crop yields. This results in crop losses, food shortages and food price rises, which lead to food insecurity and malnutrition, particularly among the poor.

3.3 Critical Evaluation of Methodologies

Although research has been conducted on the impacts of El Niño, there are some limitations:

Reliance on secondary data sets and aggregated data sets Most research relies on secondary data sources like government reports, weather, and health data. These data are often aggregated at a national or state level, which can overlook local differences and affect the validity of results. Moreover, problems such as underreporting, inconsistencies and gaps in data may compromise the quality [31].

Few region-specific and micro-level studies There is a scarcity of micro-level studies that examine the local impacts at the district and community level. The El Niño impacts vary from region to region because of differences in geography, infrastructure, socio-economic factors, so the lack of micro-level analysis provides an incomplete picture of vulnerability and risk.

Disparate data from climate scientists and public health Most existing studies use either climatic or health data, with little integration. This lack of integration of datasets limits the ability to detect causal links between climate changes and disease, and limits the potential of climate prediction and policy-relevant research [32].

Too few longitudinal studies to evaluate long-term effects There is little longitudinal research that examines long-term effects of El Niño. The majority of studies are event-based, such as studies of individual El Niño years. This hinders the knowledge of cumulative impacts, long-term health outcomes and adaptation in the long run [33].

3.4 Comparative Summary of Methodologies and Findings

Table 5: Summary of Research Approaches and Key Findings [34]

Methodology Type	Data Source	Key Findings	Limitations
Climate Analysis	SST, rainfall data	Monsoon weakening	Limited local focus

Epidemiological Study	Health records	Disease increase	Data inconsistency
Socio-economic Study	Agricultural & income data	Resource scarcity	Lack of depth
Modeling & GIS	Spatial datasets	Vulnerability mapping	Model uncertainty

The review of different types of studies shows that each type of study offers partial information on the socio-epidemiological impacts of El Niño in India. Climate analysis studies are useful in capturing large-scale impacts such as monsoon weakening and rainfall variability. But, their use of coarse-scale data limits their capacity to explain local variations, essential for understanding regional impacts [35].

Epidemiological studies reveal significant evidence of the growth in climate-sensitive diseases, such as vector-borne and heat-related diseases. While relevant, inconsistencies in health data, under-reporting and non-standardised data limit the accuracy and comparability of these studies. Socio-economic research emphasises the wider effects of El Niño, including resource shortages, economic impacts and human migration. But these studies tend to be shallow, and fail to link environmental and health concerns, leading to a siloed approach. Risk assessment and vulnerability mapping through modeling and GIS techniques provide state-of-the-art tools. They are particularly useful for planning and decision-making. However, they are limited by model uncertainties and data quality [36].

4. DISCUSSION

This chapter brings together key insights of the study to present a holistic view of the effects of climate variability associated with El Niño on public health, resources and socio-economic status [37]. Drawing on the climatic, environmental and epidemiological aspects of the study, the discussion addresses the effects of temperature, rainfall and humidity changes on the incidence of diseases, supply of food and water, and vulnerability of different groups of people. It also explores wider implications of these findings for policy, health preparedness, and resource management, as well as current knowledge gaps and research needs to enhance resilience and adaptability to climate variability [38].

4.1 Interpretation and Analysis

The study suggests that the impact of El Niño-induced climatic variability is a key driver of epidemiological patterns, by changing temperature, rainfall and humidity, which in turn affect the transmission of climate-sensitive diseases. This impacts the vector population, water quality, and exposure, resulting in a higher prevalence of vector-borne and water-borne diseases, thus creating a link between climate variability and health. Simultaneously, resource scarcity due to water scarcity and diminished crop yields exacerbates food and water insecurity,

affecting nutritional status, and increasing vulnerability to diseases [39]. This affects economically disadvantaged populations, who often lack access to basic health care, clean water and nutritious food, thus exacerbating socio-economic disparities. Moreover, the effects of El Niño are not uniform, with children, the elderly, women and poor communities bearing a greater burden due to inadequate living conditions, low resilience, and lack of access to critical resources [40].

4.2 Implications and Significance

- **Importance of integrated climate-health policy frameworks:** The interlinkages between climate change and health effects underline the need for policies that integrate climate monitoring and public health considerations. Multidisciplinary approaches can enhance mitigation and adaptation measures to climate health impacts.
- **Need for resilient healthcare systems:** Rising climate-sensitive diseases need resilient health systems to manage outbreaks. Increased monitoring, early warning, and access to health services are crucial to minimise deaths and disease.
- **Adoption of sustainable farming practices:** Climate change impacts that affect agriculture require sustainable practices such as resilient crops, irrigation management and crop diversification to enhance food security and minimise economic risks.
- **Improved water resource management:** Better water resource management such as groundwater regulation and rainwater harvesting can help to tackle water scarcity and reduce disease transmission.

4.3 Gaps and Future Research Directions

- **Insufficient micro-level studies:** Most studies are at national/regional levels, limiting knowledge of district and community-level vulnerabilities. We need more localised studies for targeted responses.
- **Lack of interdisciplinary studies:** Few studies integrate climate science, health, and socio-economic information. Interdisciplinary approaches should be used in future studies for holistic assessments.
- **Insufficient long-term health impact studies:** The focus is generally on short-term or event-level studies of El Niño. Prospective studies are needed to evaluate long-term effects.
- **Predictive modelling of climate-health:** Future research should use advanced models to predict disease outbreaks and climate impacts to inform early warning and preparedness.
- **Use of satellite and health data:** Satellite and health data can be integrated for spatial analyses and vulnerability assessments.
- **Enhancing local adaptation strategies:** Future studies should focus strengthening local adaptation planning, community engagement and indigenous knowledge systems to enhance local resilience.

5. CONCLUSION

Overall, El Niño continues to have a significant and complex influence on the socio-epidemiology of India through the exacerbation of climatic variability, disruption of ecosystems, and vulnerability of health and socio-economic factors. The monsoonal failure, temperature rise, and extreme weather events all contribute to resource shortages, outbreaks of diseases, and crop losses, which in turn impact livelihoods and health. This affects disadvantaged groups, thereby exacerbating social inequality. While adaptation measures and policies have been put in place, they have limited success due to issues of implementation, data integration and localised planning. Hence, to effectively tackle the challenges of El Niño, a multidisciplinary approach is needed to better understand the interconnected relationships between climate, health, resources and socio-economic determinants. Improving governance, building community capacities, and embracing sustainable development practices will be crucial to reduce risks and ensure sustainability under climate variability.

5.1 Summary of Main Insights and Conclusions

The review points out that El Niño is a major driver of climate variability in India, impacting the monsoon and resulting in rainfall deficits, increased temperatures, and environmental disruption. These environmental changes are inextricably linked to health impacts given that they lead to rising burdens of heat stress, vector-borne and water-borne diseases. Meanwhile, scarcity of resources is a key socio-economic issue, where the lack of water and food, due to climate variability, impacts on agriculture, income security and poverty, especially in rural areas. The impacts are disproportionate, with women, children, and the poor being more exposed and less able to adapt, and as a result, exacerbate socio-economic disparities. The review also highlights the importance of multi-disciplinary approaches, given the interlinked nature of climate, health and socio-economic considerations that demands a holistic approach across the sectors.

5.2 Reiteration of the Importance of the Review

- **Increasing importance in a changing climate:** As extreme climate events become more frequent and severe, the understanding of the impact of El Niño is becoming increasingly important for the sustainable development.
- **Importance to public health:** The review highlights the need to manage climate-sensitive diseases through enhanced surveillance, readiness and health services.
- **Significance for water resource management and food security:** The review's findings underline the need for water resource management and robust farming practices to ensure food security.
- **Value for policymakers and decision-making:** The review collates information to inform policy and decision-making through evidence-based formulations for climate adaptation.

- **Importance in enhancing community resilience:** Knowledge of socio-epidemiological vulnerability plays a role in community-based adaptation and resilience-building programs.

5.3 Recommendations

- **Strengthening climate-health surveillance systems**: Develop integrated monitoring systems that link climate data with health outcomes for early detection and response to disease outbreaks.
- **Promoting climate-resilient agriculture**: Encourage the use of drought-resistant crops, crop diversification, and efficient irrigation techniques to reduce vulnerability of farmers.
- **Improving water resource management**: Implement sustainable practices such as rainwater harvesting, groundwater regulation, and efficient water distribution systems.
- **Enhancing healthcare infrastructure and accessibility**: Expand healthcare services, particularly in rural and vulnerable regions, and improve preparedness for climate-related health risks.
- **Encouraging interdisciplinary research and data integration**: Promote collaboration between climate scientists, public health experts, and socio-economic researchers to develop comprehensive solutions.
- **Supporting community-based adaptation strategies**: Empower local communities through awareness programs, capacity building, and inclusion of indigenous knowledge in adaptation practices.
- **Policy integration and governance improvements**: Formulate policies that integrate climate change, public health, and socio-economic development to ensure holistic and sustainable outcomes.

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