Review Paper:

A study on the effects of El Nino and global warming in India: Climatic changes, issues and challenges

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Abstract

El Nino is a climatic phenomenon that constantly increases temperatures at the ocean level in the middle and eastern Pacific Ocean, which influences worldwide weather patterns. Global warming is the progressive increase in the Earth's average surface temperature caused by human activity, primarily the release of greenhouse gases, which alters the climate and has other severe environmental effects. Both El Nino and global warming have profound effects on India. El Nino disrupts the monsoon, leading to droughts or excessive rainfall, while global warming exacerbates this, intensifying heat waves and altering precipitation patterns.

This study explores how El Nino and global warming affect India's economy and society. It examines their impact on agriculture, water resources, public health, the environment and livelihoods. Further, this study highlights the need to implement effective measures across sectors to strengthen climate resilience and to provide better coping with the impacts of El Nino, safeguarding socio-economic systems and promoting sustainable development.

Keywords: El Nino, global warming, climate, agriculture, water, health.

Introduction

El Nino and global warming are two significant factors affecting the world's climate, significantly influencing India. El Nino results from hot ocean water in the central and eastern Pacific Oceans, which alters global weather patterns[3]. The Earth's average temperature is rising due to global warming, brought on by an increase in greenhouse gases in the atmosphere[20]. When these two factors combine, they can cause severe changes in the climate. India is mainly affected by these changes due to its diverse climate and heavy reliance on agriculture. The monsoon season brings most of the country's rainfall and is crucial for farming.

However, El Nino often leads to weaker monsoons, causing droughts, while its counterpart, La Nina, can result in heavier rains and floods. With global warming making these weather patterns more intense, the effects can be even more severe[10]. Since India has a large geographic area and diverse terrain, its climate is challenging to generalize and it comprises of a wide range of meteorological conditions. Six major climatic subtypes are found nationwide: wet tropical regions with rainforests in the southwest, island territories, alpine tundra and glaciers in the north and arid deserts in the west[9]. Additionally, many areas experience distinct microclimates. India experiences four distinct seasons: the Pre-Monsoon (March-May), the Monsoon (June-September), the Post-Monsoon (October-November) and the winter (December-February). Geographically, India's climate is significantly influenced by the Thar desert in the northwest and the Himalayas in the north, which play a crucial role in shaping the culturally and economically vital monsoon season[9].

The Himalayas shield India from chilly winds in Central Asia and the Tibetan plateau, the world's largest and tallest mountain range. As a result, while much of India is hot during the summer, the same barrier keeps North India warm or only slightly frigid throughout the winter. While the local topography of India greatly influences its climate, a weather pattern originating off the coast of South America can also significantly affect the country's weather. As shown in figure 1, the El Nino phenomenon, which is becoming more robust, can affect India's southwest monsoon from June to September. Reduced monsoon rainfall in India is associated with El Nino, characterized by increasing surface temperatures in the Pacific Ocean.

In addition to the El-Nino weather pattern, global warming is profoundly affecting India, manifesting in increasingly extreme weather events and shifts in climate patterns[20]. Over the past 30 years, global warming has accelerated, with temperatures rising alarmingly. This period has witnessed some of the warmest years on record, with each decade since the 1980s being successively warmer than the last[13]. As depicted in figure 2, most of the land areas have experienced more rapid warming than most ocean areas, with the Arctic exhibiting the fastest warming rates among various regions. Furthermore, it is evident that the pace of warming observed in recent decades far exceeds the average rate observed since the beginning of the 20th century.

Heatwaves are becoming more frequent and severe due to rising temperatures, especially in the north and central areas, posing serious health risks and reducing agricultural productivity. The monsoon season, crucial for India's agriculture, has become more erratic, with some areas experiencing intense rainfall leading to floods while others face prolonged droughts[11]. Melting glaciers in the Himalayas threaten water security for millions. Coastal regions are vulnerable to rising sea levels, leading to erosion and displacement of communities. Urban areas face

worsening air quality and heat island effects, exacerbating public health challenges[15].

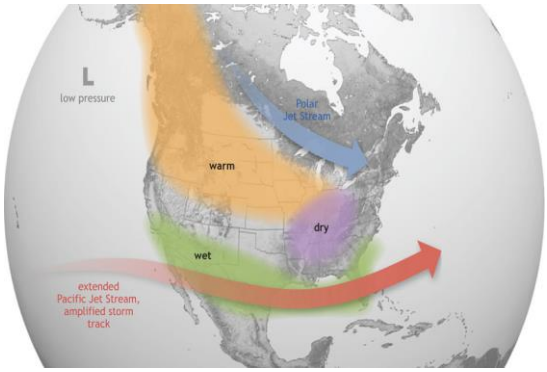

Fig. 1: El-Nina circulation

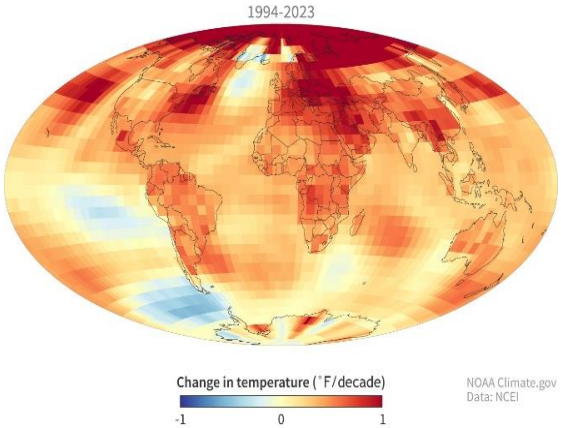

Fig. 2: Global warming in the past 30 years[13]

Carbon emissions, primarily from burning fossil fuels and deforestation, are significant contributors to global warming[10]. Burning fossil fuels such as coal, oil and natural gas, emits carbon dioxide into the atmosphere. Carbon dioxide and other greenhouse gases capture solar heat, steadily increasing the Earth's surface temperature. We see growing sea levels, melting polar ice caps, more robust and powerful heat waves and changing weather patterns. To mitigate these effects and to protect the environment for future generations, carbon emissions must be reduced by transitioning to renewable energy sources, increasing energy efficiency and implementing environmentally friendly land-use strategies.

As shown in figure 3, the annual global carbon dioxide emissions from 1940 to 2023 have followed a notable trend of steady increase, reflecting the growing reliance on fossil fuels and industrial activities[24]. Particularly after the mid-20th century, emissions began to escalate rapidly due to industrialization, urbanization and the expansion of transportation networks.

Figure 4 shows that the warmest years globally, from 1880 to 2023, have consistently demonstrated a trend of increasing temperatures, reflecting the impact of climate change over the past century[23]. While specific years vary, the general pattern shows a rise in global temperatures, with notable periods of accelerated warming in recent decades. In 2023, an extreme El Nino event led to a nearly 1.2^0C increase in the global average temperature compared to the 20th-century norm. Additionally, the preceding ten years were among the warmest on record.

The impact of these climatic changes on India is profound. Disrupted monsoon patterns can lead to poor crop yields, affecting the food supply and the livelihoods of millions of farmers[9]. Furthermore, global warming makes severe weather events like heatwaves and cyclones more frequent and intense, increasing risks to the population and the economy[14]. This study aims to explore how El Nino and global warming contribute to the changing climate. It identifies the key issues arising from El Nino events and global warming including their implications for agriculture, water resources, public health and socio-economic well-being. Further, it discusses the challenges faced by India in responding to these climatic changes including adaptation strategies to build climatic resilience and to promote sustainable development.

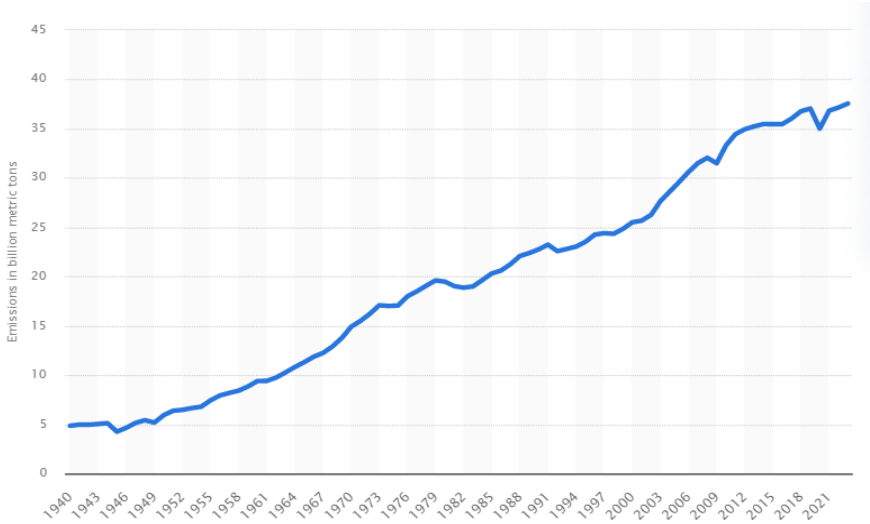

Fig. 3: Global carbon emissions 1940-2023[24]

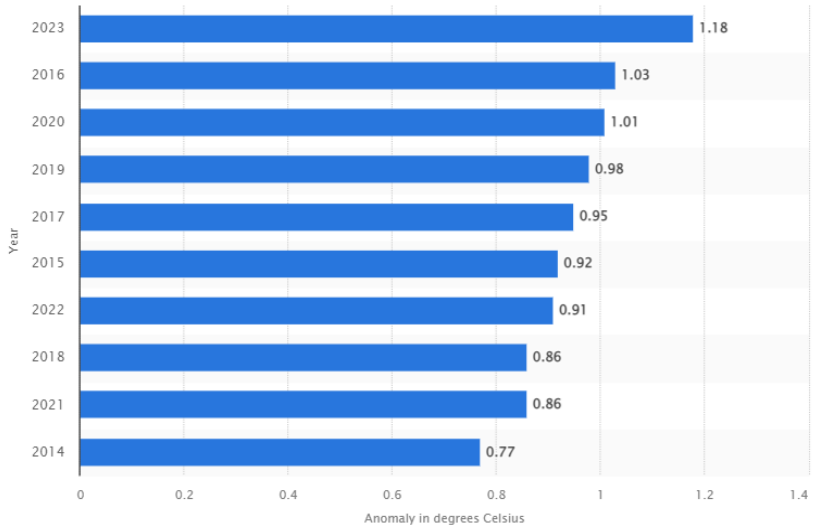

Fig. 4: Worlds Warmest years 1880-2023[23]

Major El-Nino events in India

Several notable El Nino events have significantly impacted India's climate, particularly by disrupting the monsoon season and causing droughts[16]. Here are some of the most impactful El Nino events in Indian history.

- **1918-19 El Nino:** This event was one of the most severe droughts of the early 20th century in India. The drought led to widespread crop failures, food shortages and severe economic hardships.
- **1972-73 El Nino:** This event coincided with a major drought in India, leading to significant monsoon deficits. The drought affected agricultural output, causing food shortages and economic difficulties.
- **1982-83 El Nino:** A strong El Nino event led to a below-average monsoon season in India. Reduced rainfall affected crop production and water resources, causing stress in rural and agricultural sectors.
- **1987-88 El Nino:** Another significant drought year for India, this El Nino event severely affected the southwest monsoon. The drought led to reduced agricultural yields and water shortages, affecting millions of people.
- **1997-98 El Nino:** As one of the strongest El Nino events of the 20th century, it caused significant climatic disruptions worldwide. In India, it led to a weaker monsoon season and widespread drought conditions. However, the overall impact on agriculture was somewhat mitigated due to better preparedness and irrigation infrastructure.
- **2002-03 El Nino:** This event led to one of the worst droughts in recent Indian history. The monsoon season saw a significant deficit, resulting in severe agricultural losses, water shortages and economic strain.
- **2009-10 El Nino:** This event was associated with a weak monsoon season in India. The monsoon rainfall was significantly below average, leading to drought conditions in many parts of the country and affecting food production.
- **2015-16 El Nino:** Among the strongest El Nino events on record, it led to a notably deficient monsoon in India. The reduced rainfall resulted in drought conditions, affecting agricultural productivity and water availability across the country.
- **2018-19 El Nino:** Mild to moderate El Nino conditions affect the monsoon. Some regions experienced below-average rainfall, affecting crop yields.
- **2023-24 El Nino:** The 2023-24 El Nino has brought in substantial monsoon deficit, coupled with agricultural and economic impacts, underscores the need for improved forecasting, resource management and adaptive strategies to cope with such events in the future. The summary of the major El Nino events in India is presented in table 1.

Changes in climate: Throughout the past century, India's climate has seen significant changes including swings in temperature, precipitation patterns and the intensity and frequency of severe weather happening[9]. These shifts significantly affect the nation's agriculture, water supplies, health and general socio-economic stability. Here is an overview of these observed changes.

Temperature Changes - Overall Warming: Average temperatures across India have increased over the past century[2]. The average annual mean temperature in the country from 1901 to 2023 showed a significant increasing trend of 0.66°C per century (Figure 5). In 2023, there were significant increasing trends in both maximum and

minimum temperatures, with increases of 1.01°C and 0.31°C per century respectively.

Seasonal Variations: Warming has been more pronounced during the post-monsoon (October-December) and winter (January-February) seasons compared to the summer and monsoon seasons.

Urban Heat Islands: Rapid urbanization has established urban heat islands where cities have greater temperatures than their rural counterparts.

Precipitation Changes - Monsoon Variability: The Indian monsoon, which accounts for about 70-80% of the country's annual rainfall, has shown increasing variability[2]. There has been a decline in the frequency of monsoon depressions and a shift in their tracks. As shown in figure 6, the country experienced a cumulative rainfall shortfall of 5.6% below the long-period average.

Changing Rainfall Patterns: As shown in the table 2, some regions have experienced a decrease in overall rainfall, while others have seen an increase. For instance, parts of central and northwest India have witnessed a significant increase in heavy rainfall events whereas north-eastern India has experienced a decline in rainfall[1].

Extreme Rainfall Events: These events are becoming more common and intense, resulting in more frequent and catastrophic floods.

Table 1
Major El-Nino Events

Year	Type of event	Intensity level
1918-19	Drought	Strong
1957-58	Drought	Strong
1965-66	Drought	Strong
1972-73	Drought	Strong
1982-83	Monsoon	Very Strong
1987-88	Drought	Strong
1997-98	Monsoon	Very Strong
2002-03	Drought	Moderate
2009-10	Drought	Moderate
2015-16	Drought	Very strong
2018-19	Monsoon	Moderate
2023-24	Monsoon	Moderate

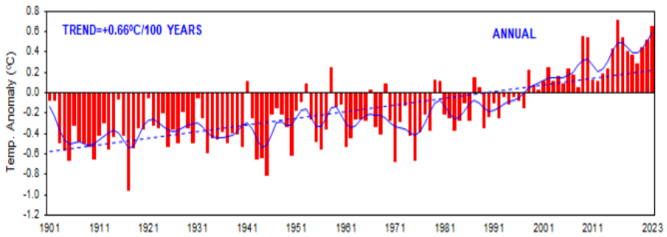

Fig. 5: Annual Average temperature 1901-2023[2]

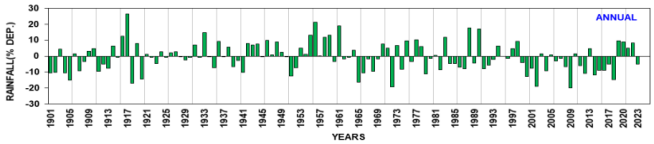

Fig. 6: Annual Average rainfall over 1901-2023[2]

Table 2
Region based rainfall report in 2023[1]

Region	Long period average (in mm)	Actual Rainfall in 2023	% Dep
All India	868.6	820.0	-5.6
North west	587.6	593.0	+1.0
Central	978.0	981.7	+0.4
East & North east	1367.3	1115.0	-18.0
South peninsula	716.2	659.0	-8.0

Extreme Weather Events: El Nino's severe weather impacts span the globe with significant breadth and depth, affecting regions variably[5]. It can trigger severe droughts in certain areas, resulting in water shortages, crop losses and increased wildfire hazards exacerbated by prolonged dry periods and elevated temperatures.

Heatwaves: The frequency, duration and intensity of heatwaves have increased, particularly in northern, central and western parts of India.

Cyclones: Trends in cyclone activity have changed in the Arabian Sea and the Bay of Bengal. The Bay of Bengal has experienced a rise in cyclone severity despite a largely steady cyclone frequency. The frequency and intensity of cyclones have increased in the Arabian Sea.

Floods: Increased heavy rainfall events have led to more frequent and severe flooding, particularly in urban areas where drainage systems are often inadequate.

Droughts: Some regions have experienced more prolonged and severe droughts due to changing rainfall patterns and increased evapotranspiration driven by higher temperatures.

Figure 7 shows an assessment of extreme weather events aiming to build an evidence based on their frequency and expanding geographic impact in the country. In 2023, India experienced its warmest August and September in 122 years[25]. The most frequently recorded events were lightning and storms (176), followed by heavy rains, floods and landslides (132) and heatwaves (49).

Impact on Agriculture

The impact of El Nino and global warming on agriculture is profound and multifaceted, posing significant challenges for farmers worldwide. El Nino events alter rainfall patterns, causing severe droughts in some regions and excessive flooding in others, both of which can lead to substantial crop losses[12]. These disruptions are compounded by global warming, which raises temperatures and exacerbates heat stress on crops, alters growing seasons and accelerates soil degradation. The food production during significant El Nino years in India is shown in figure 8. It is evident that during El Nino the food production is predominantly low.

Additionally, both phenomena contribute to the proliferation of pests and diseases, further threatening agricultural productivity. Livestock also suffer from heat stress and reduced feed availability due to changing crop yields. The combined effects of El Nino and global warming create a volatile agricultural environment, increasing the unpredictability of weather patterns and making it difficult for farmers to plan and manage their operations effectively.

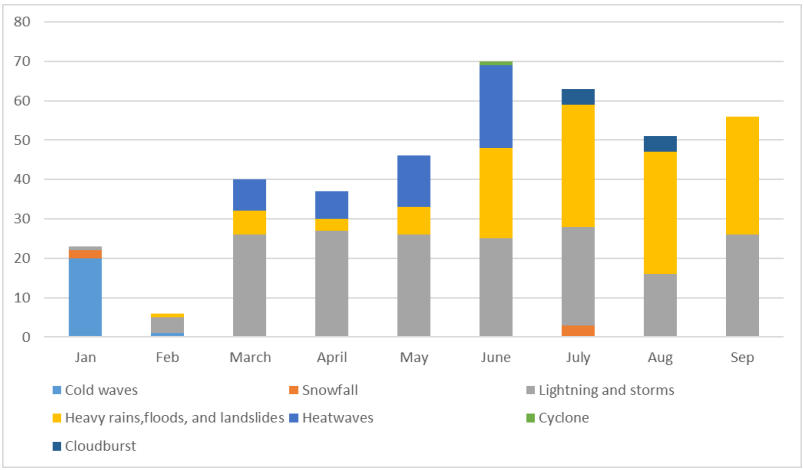

Fig. 7: Climatic events India-2023[25]

Fig. 8: India food production during El Nino years[6]

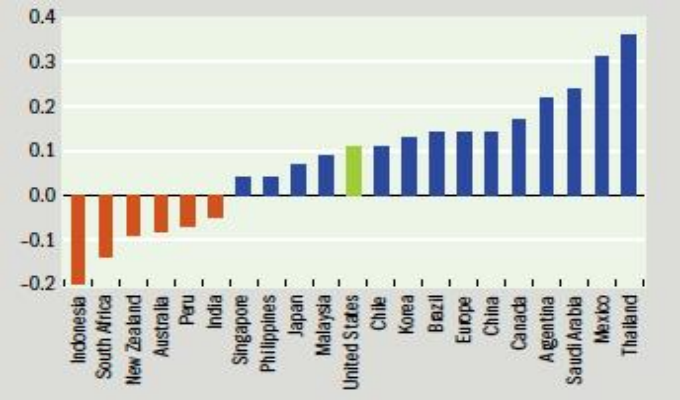

Fig. 9: Global economic activity due to El Nino[4]

Water resources: The impact of El Nino and global warming on water resources is significant and far-reaching, affecting both the availability and distribution of water. El Nino events disrupt normal rainfall patterns, causing severe droughts in some areas while triggering intense flooding in others, leading to erratic water supply and straining existing water management systems[7]. Global warming exacerbates these issues by increasing temperatures, which accelerates the evaporation of surface water and diminishes freshwater supplies. Changing precipitation patterns due to climate change result in uneven water distribution, with some regions experiencing prolonged dry spells while others face excessive rainfall, causing water scarcity or damaging infrastructure through flooding.

Additionally, the melting of glaciers and reduced snowpack, influenced by global warming, further threaten the long-term availability of water resources, particularly in regions dependent on these sources for their water supply.

Public health and environment: The impact of El Nino and global warming on public health and the environment is profound and multifaceted. El Nino events, characterized by extreme weather patterns, exacerbate the spread of vector-borne diseases such as malaria and dengue due to increased temperatures and altered precipitation, creating conducive environments for mosquito breeding[16]. Concurrently, global warming intensifies heatwaves, leading to heat-related illnesses and increasing mortality rates among vulnerable populations[8]. The resultant air quality deterioration, fuelled by higher temperatures and pollution, exacerbates respiratory conditions like asthma and bronchitis.

Environmental consequences are equally severe, with rising sea levels and coastal erosion threatening habitats and biodiversity, while altered rainfall patterns disrupt ecosystems and agricultural productivity, leading to food insecurity. Moreover, the increased frequency of extreme weather events such as hurricanes, floods and droughts further strains public health infrastructure and exacerbates environmental degradation.

Socio-economic Implications: El Nino and global warming result in significant socioeconomic losses, particularly in vulnerable communities[19]. Erratic rainfall and extreme temperatures lead to crop failures and livestock losses, causing food shortages and price hikes. Extreme weather events damage infrastructure, disrupt industries and lead to job losses, especially in agriculture, fisheries and tourism. Water shortages increase operational costs for businesses, while health systems are strained by rising disease prevalence and heat-related illnesses.

Displacement due to extreme weather and rising sea levels exacerbates social and economic instability, widening the gap between wealthy and vulnerable populations. The economic activity during El Nino years in India is shown in figure 9. These varied and far-reaching impacts underscore the need for customized, region-specific strategies to effectively manage and mitigate the complex challenges posed by El Nino.

Adaptation Strategies

Mitigating the impacts of El Nino and global warming involves reducing the underlying drivers of climate change such as greenhouse gas emissions, while also implementing measures to minimize the impacts of El Nino events. Here are some key mitigation strategies.

Reducing Carbon dioxide emissions: The main contributors to global warming are greenhouse gases (GHGs) released by human activities including burning fossil fuels, deforestation and industrial processes. GHGs include carbon dioxide, methane and nitrous oxide. By adopting strategies like switching to renewable energy sources (solar, wind, hydro and geothermal), increasing energy efficiency, encouraging sustainable transportation (electric cars, public transit, cycling and walking), bolstering forest conservation and reforestation efforts and putting laws in place to restrict emissions from industrial sectors, mitigation efforts seek to lower these emissions[17].

Adopting climate friendly agricultural practices: Agriculture is a significant source of greenhouse gas emissions, mainly from animal production, rice farming and chemical usage. Mitigation techniques include adopting sustainable agricultural practices like agroforestry, sustainable agriculture and organic farming that can cut

emissions while increasing carbon absorption in soils and plants[22]. Additionally, improving livestock management techniques, optimizing fertilizer application and reducing food waste can further contribute to emissions reduction in the agricultural sector.

Enhancing energy efficiency and conservation: Enhancing energy efficiency in several areas such as industry, transportation and buildings, may drastically lower energy use and related emissions. Mitigation measures include implementing building codes and standards for energy-efficient construction and retrofits, promoting the use of energy-efficient appliances and equipment, investing in smart grid technologies and adopting fuel-efficient vehicles and transportation systems.

Promoting sustainable land use and urban planning: Land use and urban development play a vital role in both lessening climate change and adapting to its impacts. The strategies are: the safeguarding and rebuilding of natural habitats, which serve as essential ecosystem services and carbon sinks, such as wetlands, mangroves and forests.

Urban planning initiatives can focus on compact and sustainable urban design, green infrastructure, public transportation and mixed land-use zoning to reduce energy consumption, to minimize sprawl and to enhance resilience to climate-related hazards.

Investing in renewable energy and low-carbon technologies: Accelerating the shift to alternative energy sources including wind, solar, hydroelectricity and thermal power, is critical in lowering dependency on fossil fuels and combating climate change[21].

Accelerating the shift to alternative energy sources including wind, solar, hydroelectricity and thermal power, is critical in reducing the need for fossil fuels and combating climate change. Mitigation initiatives include[26]:

- Promoting investment in renewable energy infrastructure.
- Promoting the development and research of low-carbon technologies.
- Phasing out fossil fuel subsidies.

Conclusion

In conclusion, this study delves into the intricate relationship between El Nino events, global warming and their profound impacts on India's climate. Through comprehensive analysis and synthesis of climatic data and literature, we have illuminated the multifaceted challenges and issues arising from these phenomena. The findings highlight the critical need for pre-emptive efforts to reduce the adverse effects on several sectors including agriculture, water resources, public health and infrastructure. Moreover, enhancing scientific research and early warning systems is crucial for better understanding and anticipating these impacts.

Addressing the challenges posed by El Nino and global warming requires concerted efforts from policymakers, scientific communities and stakeholders across sectors to foster resilience and promote sustainable development. By taking decisive action, India can navigate these challenges and can build a more resilient and climate-resilient future.

Acknowledgement

Our heartfelt thanks go to Ministry of Earth Sciences, India Meteorological Department, Government of India, Climate Monitoring and Prediction Group, Government of India, Ministry of Agriculture and Farmers Welfare, Government of India whose reports/data are quoted and included in this research.

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(Received 19th June 2024, accepted 20th August 2024)

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