El Niño: Understanding its Impact on Indian Agriculture

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ABSTRACT

El Niño is a naturally occurring climate phenomenon associated with the warm phase of the El Niño–Southern Oscillation (ENSO), characterized by abnormal warming of sea surface temperatures in the central and eastern Pacific Ocean. Although it originates far from India, El Niño significantly influences the southwest monsoon, often resulting in below-normal rainfall, higher temperatures, prolonged dry spells, and increased frequency of droughts. These climatic anomalies adversely affect agricultural productivity by delaying sowing, reducing crop yields, increasing irrigation demand, intensifying pest and disease incidence, and threatening water resources and food security. The severity of its impacts varies depending on interactions with other climatic systems such as the Indian Ocean Dipole (IOD) and Madden-Julian Oscillation (MJO). The article highlights climate-smart adaptation strategies, including crop diversification, adoption of drought-tolerant varieties, efficient water management, conservation agriculture, and integrated farming systems to enhance resilience against climate variability. It also emphasizes the growing role of artificial intelligence (AI), remote sensing, satellite observations, and digital advisory platforms in improving seasonal weather forecasting, early warning systems, and location-specific agro-

advisories for farmers. Strengthening institutional support through agencies such as IMD, ICAR, and State Agricultural Universities, along with enhancing farmer awareness and access to climate information, is essential for building sustainable, climate-resilient, and productive agricultural systems in India.

INTRODUCTION:

India is an agrarian country where agriculture supports the livelihood of nearly half of the population and contributes significantly to food security and the national economy. The southwest monsoon, which provides approximately 70-75 percent of the country's annual rainfall, is critical to Indian agriculture's success. Any change in the timing, distribution, or quantity of monsoon rainfall has a direct impact on crop production, water resources, livestock, fisheries, and the socioeconomic well-being of millions of farming households.

El Niño originates in the tropical Pacific Ocean, its effects spread across continents via atmospheric circulation, influencing rainfall, temperature, droughts, floods, and agricultural productivity. India is particularly vulnerable to El Niño due to its reliance on rainfall over irrigation. During El Niño years, India has experienced below-average monsoon rainfall, prolonged dry spells, heat waves, declining reservoir levels, and decreased crop productivity. El Niño's impact on the Indian monsoon can be influenced by other climatic systems such as the Indian Ocean Dipole (IOD) and Madden-Julian Oscillation (MJO), so it does not always result in drought.

Climate change has increased the frequency of weather extremes, bringing renewed attention to El Niño. Scientists have made advances in seasonal forecasting, satellite observations, artificial intelligence (AI), and digital climate advisory services, which now provide farmers with early warnings and help reduce agricultural losses.

What is El Niño?

The term **El Niño**, meaning *"The Little Boy"* or *"Christ Child"* in Spanish, was first used by fishermen along the coasts of Peru and Ecuador who observed unusually warm ocean waters around Christmas. Scientists discovered that the warming was caused by the El Niño-Southern Oscillation (ENSO), a major contributor to global climate variability.

El Niño is the warm phase of ENSO, marked by abnormal warming of sea surface temperatures in the central and eastern equatorial Pacific Ocean. Under normal circumstances, strong easterly trade winds push warm surface waters towards Indonesia and northern Australia, while cold, nutrient-rich water rises near the western coast of South America via a process known as upwelling. During El Niño, trade winds weaken and warm water moves eastward across the Pacific Ocean. This shift disrupts normal ocean circulation and changes atmospheric pressure, cloud formation, and rainfall distribution across much of the world.

El Niño is not caused by climate change, but rather occurs naturally. It typically occurs every two to seven years, lasts nine to twelve months, and can be predicted several months in advance. Although it is a natural event, its effects are exacerbated when it coincides with rising global temperatures caused by climate change. El Niño and global warming often cause record-breaking temperatures, prolonged heat waves, droughts, floods, and increased stress on agriculture and natural resources.

How Does El Niño Develop?

El Niño begins with changes in atmospheric circulation over the tropical Pacific Ocean. During normal years, easterly trade winds blow continuously from South America to Indonesia, pushing warm surface water westward. Warm water accumulates in the western Pacific, while cooler water from deeper ocean layers rises along the South American coast via upwelling. This circulation allows for abundant rainfall in Indonesia and northern Australia while keeping the eastern Pacific Ocean relatively dry.

The trade winds occasionally weaken or reverse for unknown reasons. As these winds weaken, warm surface water gradually spreads eastward into the central and eastern Pacific Ocean. The reduced upwelling prevents cold water from reaching the ocean surface, causing sea surface temperatures to rise significantly above normal. The warmer ocean releases more heat and moisture into the atmosphere, shifting tropical rainfall from the western to the central and eastern Pacific.

As the Walker Circulation, which connects the Pacific Ocean to weather systems around the world, weakens, the southwest monsoon circulation over the Indian Ocean is frequently suppressed, reducing the transport of moisture to the Indian subcontinent. As a result, many parts of India receive below-normal rainfall, particularly during the kharif cropping season. However, the response varies.

El Niño events are classified as weak, moderate, strong, or very strong based on sea surface temperature anomalies in the equatorial Pacific's Niño 3.4 region. Stronger El Niño events are more likely to impact global weather, but the intensity varies by country and season. Modern climate models, satellites, ocean buoys, and supercomputers continuously monitor Pacific Ocean temperatures, wind patterns, and atmospheric pressure to forecast El Niño several months before its peak, providing valuable lead time for governments and farmers to prepare for climate-related risks.

Important Effects of El Niño on Rainfall and Temperature in India:

1. Weakening of the Southwest Monsoon
2. Deficient Monsoon Rainfall
3. Delayed Onset of Monsoon
4. Prolonged Dry Spells
5. Uneven Rainfall Distribution
6. Rise in Air Temperature
7. More Frequent Heat Waves
8. Higher Evapotranspiration
9. Increased Water Stress
10. Regional Variability in Impacts
11. Reduced Agricultural Productivity
12. Increasing Climate Uncertainty

Important Impacts of El Niño on Crop Production:

1. Delayed Crop Sowing
2. Poor Seed Germination
3. Reduced Rice Production
4. Lower Yields of Rainfed Cereals
5. Decline in Pulse and Oilseed Production
6. Heat Stress During Flowering
7. Increased Pest and Disease Incidence
8. Greater Irrigation Requirement
9. Horticultural Crop Losses
10. Decline in Fodder Availability
11. Reduced Farm Income

12. Threat to Food Security

Impacts of El Niño on Water Resources:

1. Reduced Reservoir Storage
2. Declining Groundwater Recharge
3. Water Scarcity for Irrigation
4. Drying of Rivers and Streams
5. Lower Lake and Pond Water Levels
6. Increased Competition for Water
7. Deterioration of Water Quality
8. Higher Irrigation Demand
9. Reduced Hydroelectric Power Generation
10. Increased Frequency of Drought
11. Localized Flooding from Extreme Rainfall
12. Need for Integrated Water Resource Management

Climate-Smart Adaptation Strategies for Farmers

Climate-smart agriculture (CSA) is crucial for sustaining productivity and enhancing resilience in Indian agriculture due to the challenges posed by El Niño. This approach combines improved crop management, efficient use of natural resources, modern technologies, and climate information services to help farmers adapt to changing weather conditions while maintaining food security.

The India Meteorological Department (IMD), in collaboration with the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities, provides district-level weather forecasts and agro-advisories that enable farmers to make informed decisions regarding sowing, irrigation, fertilizer application, and pest management. One of the most effective adaptation measures is timely access to seasonal climate forecasts. Early warning systems also help farmers avoid

Another crucial adaptation tactic is crop diversification. Rather than depending only on water-intensive crops like rice, farmers in drought-prone areas can switch to short-duration, drought-tolerant crops like millets, sorghum, pigeon pea, green gram, and cowpea, which require less water, are more resilient to moisture stress, and offer both nutritional and financial advantages.

Effective water management is essential for managing droughts brought on by El Niño. Water-use efficiency can be significantly increased and water availability can be guaranteed during extended dry spells by implementing micro-irrigation systems like drip and sprinkler irrigation, rainwater harvesting, farm ponds, watershed management, and groundwater recharge. Minimum tillage, crop residue retention, mulching, and cover crops are examples of conservation agriculture techniques that help preserve soil moisture and enhance soil health.

Climate-resilient crop varieties developed by State Agricultural Universities and ICAR are becoming increasingly crucial. These enhanced cultivars are resistant to heat, drought, and moisture stress, allowing farmers to sustain consistent yields in challenging weather. Furthermore, integrated farming systems that incorporate horticulture, agroforestry, fisheries, livestock, and crops diversify farm income and lessen reliance on a single business, increasing resilience to climate variability.

Digital agriculture is emerging as a powerful tool for climate adaptation. Mobile applications, satellite-based monitoring, Internet of Things (IoT) sensors, and Geographic Information Systems (GIS) provide farmers with real-time information on weather, soil moisture, irrigation scheduling, and pest outbreaks. Such technologies support precision agriculture, improve resource-use efficiency, and reduce production risks

associated with extreme weather events. Overall, successful adaptation to El Niño requires a combination of scientific weather forecasting, climate-resilient technologies, efficient water management, institutional support, and farmer awareness.

Role of Artificial Intelligence (AI) in Weather Forecasting

Artificial Intelligence (AI) is revolutionizing weather forecasting by improving the accuracy, speed, and reliability of climate predictions. Unlike conventional forecasting models that rely primarily on physical equations, AI algorithms analyse vast volumes of historical weather records, satellite observations, radar data, ocean temperatures, and atmospheric conditions to identify complex weather patterns and generate more accurate forecasts. This capability has significantly enhanced early warning systems for climate phenomena such as El Niño, cyclones, droughts, floods, and heat waves.

In India, AI supports the dissemination of location-specific agro-advisories through digital platforms developed by the India Meteorological Department (IMD), the Indian Council of Agricultural Research (ICAR), and agricultural extension agencies. Farmers receive timely information on expected rainfall, temperature, irrigation scheduling, pest and disease outbreaks, and crop management practices through mobile applications, SMS services, and digital advisory platforms. These advisories help farmers optimize sowing dates, irrigation schedules, fertilizer application, and harvesting operations while minimizing climate-related risks.

Several AI-enabled mobile applications and digital platforms are already assisting Indian farmers in making weather-informed decisions. The **Meghdoot** mobile application, jointly developed by IMD, ICAR, and the Indian Institute of Tropical Meteorology (IITM), provides district-level weather forecasts and crop-specific advisories. **Mausam**, developed by IMD, offers real-time weather forecasts, rainfall predictions, heat-wave alerts, and cyclone warnings. **Damini**, another IMD application, provides lightning alerts to enhance farmer safety during thunderstorms. Digital platforms such as **Kisan Suvidha** and the **UPL-Pragati AI advisory platform** integrate weather information with crop management recommendations, enabling farmers to take timely field-level decisions.

AI is also transforming precision agriculture through the integration of satellite imagery, drones, remote sensing, Internet of Things (IoT) sensors, and Geographic Information Systems (GIS). These technologies continuously monitor crop health, soil moisture, vegetation indices, nutrient deficiencies, and water stress, enabling early detection of drought conditions and facilitating timely interventions. During El Niño years, AI-based decision-support systems assist governments and policymakers in drought monitoring, reservoir management, crop insurance assessment, pest surveillance, and disaster preparedness (FAO, 2022; World Bank, 2021).

CONCLUSION

El Niño is one of the most influential climate phenomena affecting global weather and has profound implications for Indian agriculture. Its impact on the southwest monsoon often leads to reduced rainfall, increased temperatures, prolonged dry spells, water scarcity, and declining agricultural productivity. These changes not only affect crop production but also influence livestock, fisheries, water resources, rural livelihoods, and national food security. Although El Niño cannot be prevented, its adverse effects can be substantially reduced through scientific

preparedness, climate-smart agricultural practices, efficient water management, and timely dissemination of weather-based advisories.

The rapid advancement of artificial intelligence, satellite technology, remote sensing, and digital agriculture has greatly improved seasonal weather forecasting and climate risk management. When combined with the efforts of institutions such as IMD, ICAR, State Agricultural Universities, and agricultural extension agencies, these technologies empower farmers to make informed decisions and adapt effectively to changing climatic conditions. Strengthening farmer awareness, promoting climate-resilient technologies, and expanding access to accurate weather information will be crucial for building a sustainable, productive, and climate-resilient agricultural sector in India.

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