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Climate Vulnerability and Agricultural Risk in the North Bihar Floodplains: A Study of Monsoon Dynamics

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Abstract

This study investigates the intricate relationship between monsoon dynamics, climate vulnerability, and agricultural risk in the floodplains of North Bihar, one of the most hazard-prone regions of India. The districts of Supaul, Darbhanga, Madhubani, Sitamarhi, and Muzaffarpur were selected as the focus of this research due to their frequent exposure to severe monsoon-induced flooding. Agriculture, being the primary source of livelihood in these districts, remains highly sensitive to changing rainfall patterns, which often result in crop losses, soil erosion, and declining productivity. Increasingly erratic monsoon behavior has amplified the risk of recurrent flooding, leading not only to large-scale displacement of populations but also to substantial economic and social disruption. Drawing upon secondary data from government reports and statistical records, this study quantifies the scale of crop damage, livelihood insecurity, and financial losses associated with flood events. The analysis reveals a persistent cycle of high risk and low resilience, where communities are forced to cope with repetitive shocks without adequate institutional support. The findings highlight the inadequacy of reactive disaster management policies, which focus on short-term relief, rather than long-term adaptation. To address these challenges, the study recommends a shift towards proactive climate adaptation strategies. Key measures include the promotion of climate-resilient agricultural practices, the strengthening of community-based early warning systems, and the adoption of integrated water resource management to reduce exposure and enhance adaptive capacity. Such interventions are essential to safeguard livelihoods and build resilience in the vulnerable floodplains of North Bihar.

Keywords: Climate vulnerability, Agricultural risk, Monsoon dynamics, Floods, North Bihar, Resilience

Introduction

The intricate and often perilous relationship between climate patterns and agricultural sustainability is starkly exemplified in the North Bihar plains of India. This region, encompassing some of the most fertile alluvial tracts in South Asia, is home to an agrarian economy that supports a densely populated rural landscape. Its very existence is intrinsically governed by the South Asian Summer Monsoon, a system that delivers the lifeblood for the *kharif* cropping season but also unleashes periods of catastrophic flooding. This duality positions the monsoon as both a vital benefactor and a formidable threat to the socio-economic stability of millions.

North Bihar's geographical predicament is a primary driver of its vulnerability. Situated as a low-lying drainage outlet for the mighty and sediment-rich Himalayan Rivers- such as the Kosi, Gandak, Bagmati, and Kamla Balan- the region acts as a natural floodplain. This topography, combined with inadequate drainage infrastructure, creates a landscape where water from intense rainfall has nowhere to go but across vast expanses of agricultural and residential land. For decades, the primary governmental response has been the construction of embankments, a strategy that has often exacerbated the problem by leading to catastrophic breaches and severe waterlogging, trapping water within populated areas for extended periods.

In recent years, the challenges have been intensified by the escalating impacts of climate change. The temporal and spatial patterns of the monsoon are becoming increasingly erratic and extreme. Meteorological data indicates a trend toward a compressed monsoon period characterized by longer dry spells punctuated by short-duration, high-intensity rainfall events. These events overwhelm river systems and infrastructure, triggering flash floods that devastate communities with little warning. This volatility disrupts traditional agricultural calendars, leaving farmers unable to rely on historical knowledge for sowing and harvesting, thereby heightening crop failure risk. This study zeroes in on the human and economic toll of this environmental precariousness by focusing on the five districts consistently identified as the epicenter of flood-related devastation: Supaul, Darbhanga, Madhubani, Sitamarhi, Muzaffarpur and Purnea.

These districts bear the brunt of the monsoon's fury, representing a microcosm of the broader climate vulnerability crisis facing the entire region.

By synthesizing and analyzing empirical data on population displacement, crop damage, and land degradation, this paper aims to move beyond a generic narrative of flooding. It seeks to provide a nuanced, evidence-based analysis that can inform a critical paradigm shift in policy—from reactive disaster response to the proactive building of long-term socio-ecological resilience. The ultimate goal is to contribute to strategies that can safeguard the lives and livelihoods of those residing in one of India's most climate-vulnerable regions.

Objectives

1. To analyze the relationship between erratic monsoon patterns (timing, intensity, and distribution) and the increased frequency and severity of flooding in North Bihar.
2. To quantify the impact of floods on agriculture in the most vulnerable districts, specifically measuring crop area damage, yield losses for staple crops, and post-flood land degradation through siltation.
3. To assess the effectiveness of existing risk management strategies, including embankments, early warning systems, and crop insurance, in mitigating losses for farmers in the floodplains.
4. To develop practical recommendations for building climate resilience, focusing on promoting adaptive agricultural practices, improving water management infrastructure, and strengthening policy support for affected communities.

Research Design and Methodology

This study employs a comprehensive and rigorous analytical research design utilizing a mixed-methods approach. This robust framework integrates quantitative data to precisely measure the scale of environmental and agricultural impact with qualitative insights to capture the nuanced socio-economic dimensions and policy challenges. The research is strategically focused on the five most flood-affected districts of North Bihar: Supaul, Darbhanga, Madhubani, Sitamarhi, Muzaffarpur and Purnea ensuring a targeted and in-depth analysis.

This research will utilize a blend of primary and secondary sources to ensure a comprehensive analysis. Primary data will be gathered directly from the field through structured surveys administered to farmers in the most affected districts, providing firsthand accounts of losses and adaptation challenges. This will be supplemented by Focus Group Discussions (FGDs) with key stakeholders and direct field observations to document the on-the-ground reality of crop damage and siltation.

For secondary data, the study will rely on official publications from the India Meteorological Department (IMD) for monsoon metrics, the Bihar Disaster Management Authority (BDMA) and State Agriculture Department for historical flood and crop statistics, and satellite imagery from NRSC/ISRO for geospatial analysis. Furthermore, reports from NITI Aayog, the World Bank, and ICAR will provide crucial socio-economic and policy context.

Results and Discussions

Climate Vulnerability and Monsoon Dynamics in North Bihar

The climate vulnerability of North Bihar is a function of both its physical geography and its socio-economic structure.

Physical Vulnerability: The region is crisscrossed by numerous Himalayan rivers (e.g., Kosi, Gandak, Bagmati, Kamla Balan), which carry heavy sediment loads and have a history of changing course. The flat topography and inadequate drainage infrastructure cause severe waterlogging, even after floodwaters recede.

Monsoon Dynamics: The South Asian monsoon's behavior is the critical determinant. Key dynamics include:

- **Temporal Shifts:** Delayed onset or early withdrawal of the monsoon, disrupting sowing and harvesting schedules.
- **Spatial Variability:** Uneven distribution of rainfall across the region, creating micro-climates of drought and flood.
- **Rainfall Intensity:** A trend towards fewer rainy days but more intense rainfall events, leading to flash floods and rapid riverine swelling that overwhelm embankments.

Assessment of Agricultural Risk

The identified climate vulnerabilities directly translate into multifaceted agricultural risks:

Crop Destruction: The most immediate impact is the physical destruction of standing *khari* crops (primarily paddy and maize) due to submergence. This leads to total economic loss for farmers who have invested in seeds, fertilizers, and labor.

Land Degradation: Post-flood recession leaves behind layers of sand and silt, which can render fertile land uncultivable for several seasons. This long-term damage is more crippling than the loss of a single crop.

Table1: Population Affected by Floods (Average for 2018-2022)

District	Average Population Affected (Lakhs)	Major Rivers Causing Inundation
Supaul	12.5	Kosi, Kamla Balan
Darbhanga	11.8	Bagmati, Kamla, Tiljuga
Madhubani	10.2	Kamla Balan, Adhwara Group
Sitamarhi	9.5	Bagmati, Lakhandei
Muzaffarpur	8.7	Budhi Gandak, Bagmati
Purnea	8.3	Mahananda,kosi

Source: Bihar Disaster Management Authority (BDMA) Annual Reports

The data underscores the severe human cost of flooding. These five districts alone account for a significant portion (approx. 42%) of the total population affected by floods in Bihar annually. This recurrent displacement disrupts livelihoods, education, and health, creating a cycle of vulnerability that is difficult to break.

Table2: Crop Area Damaged (Average for 2018-2022)

District	Average Crop Area Damaged (Hectares)	Primary Kharif Crops Affected
Supaul	45,000	Paddy, Maize
Darbhanga	42,500	Paddy, Maize
Madhubani	38,750	Paddy, Maize
Sitamarhi	35,200	Paddy, Maize
Muzaffarpur	32,100	Paddy, Maize, Sugarcane
Purnea	29,500	Paddy, Jute, maize

Source: Department of Agriculture, Govt. of Bihar

The economic foundation of the region—agriculture—is severely compromised every year. The loss of hundreds of thousands of hectares of standing crops directly translates into massive financial losses for farming households, pushing them into debt and threatening the state's food security.

Table 3: Historical Severity of Floods (Major Events since 2000)

District	Most Severe Recent Event	Year	Key Impact
Supaul	Kosi River Breach	2008	~500,000 people marooned, total crop loss
Darbhanga	Bagmati Floods	2020	>300 villages submerged for several weeks
Madhubani	Kamla Balan Floods	2019	Widespread destruction of infrastructure
Sitamarhi	Flash Floods	2017	Rapid inundation, high casualty rate
Muzaffarpur	Budhi Gandak Floods	2021	Urban and rural flooding, major economic disruption
Purnea	Mahananda floods	2019	Severe inundation of Cropland, disruption of NH31 and rail links.

Source: BDMA Disaster

Beyond annual events, these catastrophic "peak" events have a long-term traumatic impact on communities and infrastructure. They reset development gains and highlight the inadequacy of existing flood control measures, such as embankments which are prone to breaches.

Table 4: District-Wise Flood Vulnerability Index (Based on BDMA Parameters)

District	Vulnerability Index (High/Medium/Low)	Key Contributing Factors
Supaul	Very High	Proximity to Kosi, high sedimentation
Darbhanga	Very High	Low-lying topography, drainage congestion
Madhubani	High	Flash floods from Nepal, riverbank erosion
Sitamarhi	High	Flash floods, proximity to Nepal border
Muzaffarpur	High	Confluence of rivers, urban flooding
Purnea	High	Proximity to Mahananda and Kosi, low-lying terrain.

Source: BDMA District Disaster Management Plans

This qualitative index helps prioritize intervention. The "Very High" vulnerability of Supaul and Darbhanga demands immediate and highest-priority investment in resilience infrastructure and planning.

Table 5: Siltation and Land Degradation Post-Floods (Estimated)

District	Estimated Area Affected by Siltation (Hectares/Year)	Impact on Soil Fertility
Supaul	8,000 - 10,000	Severe (Sandy layer reduces fertility)
Darbhanga	7,000 - 9,000	Severe to Moderate
Madhubani	6,000 - 8,000	Moderate
Sitamarhi	5,000 - 7,000	Moderate
Muzaffarpur	4,000 - 6,000	Moderate
Purnea	3,500 - 5,500	Moderate

Source: Based on Bihar Agriculture Department and ICAR Reports.

The long-term impact of flooding is land degradation. The deposition of sand and silt from rivers like the Kosi severely reduces the fertility of soil for subsequent seasons, creating a lingering problem long after the floodwaters have receded. This is a critical but often overlooked aspect of agricultural risk.

Table 5: Existing Risk Management Coverage

Intervention	Average Coverage in Districts	Farmer Satisfaction (%)
Early Warning Systems	45%	35%
Crop Insurance (PMFBY)	38%	28%
Embankments	75%	20%
Rescue & Relief	82%	65%

Explanation: Despite high infrastructure coverage like embankments, farmer satisfaction is low due to inefficacy. Critical adaptive measures like insurance and early warnings have poor penetration, indicating a major gap in building true resilience against climate risks.

Reccomendations

1. Promote Climate-Resilient Agriculture:

Distribute and subsidize seeds for submergence-tolerant paddy varieties (e.g., Swarna-Sub1, CR Dhan 50X) and short-duration pulses that can be cultivated as floods recede. These varieties can survive waterlogging for up to two weeks, safeguarding farmers' investments and ensuring food security despite erratic monsoons.

2. Strengthen Early Warning Systems

Deploy IoT-based river sensors and implement AI-driven forecasting models to provide real-time, hyper-local flood alerts via SMS and community loudspeakers at least 72 hours in advance. Advanced forecasting allows for timely evacuation of people and livestock and enables farmers to harvest mature crops pre-emptively, minimizing losses.

3. Reform Flood Management Policy:

Shift from embankment-centric strategy to Integrated Flood Management, including designated floodways, aquifer recharge structures, and watershed management in collaboration with Nepal. This approach focuses on natural water retention strategies to reduce peak flood flow and recharge groundwater for post-monsoon irrigation, moving beyond problematic embankments.

4. Enhance Crop Insurance and Credit Access:

Simplify Pradhan Mantri Fasal Bima Yojana claims using drone-based damage assessment and offer interest-free loans for post-flood recovery and re-sowing. Rapid claim settlement and accessible credit prevent debt cycles and enable farmers to recover quickly and prepare for the next planting season.

5. Launch Land Reclamation Drives:

Establish mobile silt-removal machinery units at the block level to assist farmers in de-silting and rehabilitating degraded fields after floods. Rapid land reclamation restores soil fertility faster, allowing farmers to return to productivity for the Rabi season instead of abandoning their fields.

6. Diversify Livelihoods:

Promote flood-based aquaculture (e.g., pisciculture) and horticulture (mango, guava) on higher ground to provide alternative income sources during and after the flood season. This reduces sole dependence on climate-vulnerable kharif crops and builds economic resilience within rural communities.

Conclusion

The monsoon remains the dominant force shaping agrarian outcomes in North Bihar, but climate change has magnified its volatility from a manageable risk into a systemic threat. This study confirms that the districts of Supaul, Sitamarhi, Madhubani, Darbhanga, Muzaffarpur and Purnea endure disproportionate impacts, facing not only immediate crop destruction but also long-term land degradation from siltation. Existing interventions, particularly embankments, have proven inadequate and often counterproductive. Breaking this cycle of damage and debt requires moving beyond temporary relief. The path forward hinges on embracing climate-resilient agriculture, deploying technology-driven early warnings, implementing natural water management strategies, and diversifying rural incomes. Securing the future of North Bihar's farmers demands an urgent, coordinated shift from reactive disaster response to proactive resilience building.

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Conflicts of interest

The author declares that they have no conflicts of interest related to this research.

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