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Climate change and food security in India: A systematic review of social vulnerability, agricultural risk, and policy responses

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Abstract

Climate change has emerged as one of the most significant threats to global food systems, particularly in developing economies where agriculture remains highly climate-sensitive and socio-economically critical (Intergovernmental Panel on Climate Change, 2023; Wheeler & von Braun, 2013) ^[1, 2]. India represents a crucial case in understanding the climate–food security nexus due to its large population, dependence on monsoon-based agriculture, and persistent socio-economic inequalities (Aggarwal, 2008; BIRTHAL *et al.*, 2014) ^[3, 4]. This review systematically examines the literature on the impact of climate change on food security in India, with particular emphasis on social vulnerability, agricultural risk, and policy responses. Using a PRISMA-based systematic review framework, 231 studies published between 2000 and 2026 were analyzed from major academic databases, including Scopus, Web of Science, and ScienceDirect (Moher *et al.*, 2009) ^[5]. The review synthesizes evidence across the four dimensions of food security: availability, accessibility, utilization, and stability (Food and Agriculture Organization, 1996) ^[6]. Findings indicate that rising temperatures, erratic rainfall, groundwater depletion, and extreme climatic events are significantly affecting agricultural productivity, food prices, livelihood security, and nutritional outcomes in India (Lobell *et al.*, 2011; Mishra *et al.*, 2020; Rosenzweig *et al.*, 2014) ^[7, 8, 9]. The review further demonstrates that climate change acts as a risk multiplier by intensifying existing structural vulnerabilities related to poverty, inequality, gender, and regional disparities (Adger, 2006; Morton, 2007) ^[10, 11]. Smallholder farmers, women, and marginalized communities face disproportionate risks due to limited adaptive capacity (Morton, 2007; Vermeulen *et al.*, 2012) ^[12]. The study identifies critical research gaps, including inadequate attention to food utilization, weak interdisciplinary integration, and limited regional analysis. The paper argues that ensuring food security in India under climate change requires a transition from production-centric approaches toward integrated food systems resilience (Ericksen, 2008; Fanzo *et al.*, 2018) ^[13, 14]. Policy priorities include climate-resilient agriculture, social protection, technological innovation, and institutional strengthening.

Keywords: Climate change, food security, India, social vulnerability, agricultural risk, climate adaptation, policy response, food systems

1. Introduction

Climate change is increasingly recognized as one of the most significant threats to human development, environmental sustainability, and global food systems in the twenty-first century (Intergovernmental Panel on Climate Change, 2023; Brown & Funk, 2008) ^[1, 15]. Anthropogenic greenhouse gas emissions have accelerated global warming, producing major changes in climatic systems, including rising temperatures, changing precipitation patterns, and increased frequency of extreme weather events such as droughts, floods, cyclones, and heatwaves (IPCC, 2023; Rosenzweig *et al.*, 2014) ^[9, 1].

The implications of climate change extend far beyond environmental degradation. They are deeply intertwined with issues of livelihoods, poverty, inequality, and social vulnerability (Adger, 2006; Vermeulen *et al.*, 2012) ^[10, 12]. Nowhere is this relationship more evident than in food security, where climate change is reshaping food systems through multiple direct and indirect pathways (Gregory *et al.*, 2005; Wheeler & von Braun, 2013) ^[16, 2].

Food security exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets dietary requirements and food preferences for an active and healthy

life (Food and Agriculture Organization, 1996) [6]. Food security comprises four interrelated dimensions:

- Food Availability
- Food Accessibility
- Food Utilization
- Food Stability

Climate change threatens all four dimensions simultaneously (FAO, 2008; Gregory *et al.*, 2005) [16, 17]. India presents a particularly important case for understanding the climate–food security nexus. As the world’s most populous country, India must ensure food security for over 1.4 billion people while navigating significant environmental and socio-economic challenges (World Bank, 2022) [18]. Agriculture remains central to India’s economy, rural livelihoods, and food systems. Nearly half of India’s workforce depends directly or indirectly on agriculture (Bithal *et al.*, 2014; Kumar, 2011) [4, 19].

Indian agriculture is characterized by multiple structural vulnerabilities, including high dependence on monsoon rainfall, fragmented landholdings, groundwater dependence, ecological degradation, and the predominance of smallholder farming systems (Aggarwal, 2008; Mishra *et al.*, 2020) [3, 8]. These vulnerabilities make India highly sensitive to climatic disruptions. Recent years have witnessed increasing climate-related disruptions across India, including severe heatwaves in northwestern India, recurrent droughts in central India, floods in eastern India, and cyclonic disturbances in coastal regions (IPCC, 2023; World Bank, 2022) [18, 1]. These events have direct implications for agricultural productivity and food systems.

However, the impacts of climate change on food security in India cannot be understood solely through agricultural production losses. Climate change acts as a risk multiplier, exacerbating existing socio-economic inequalities and deepening food insecurity among vulnerable populations (Adger, 2006; Morton, 2007) [10, 11].

Smallholder farmers, women farmers, landless laborers, tribal populations, and low-income households face disproportionate climate risks due to limited adaptive capacity and institutional access (Morton, 2007; Vermeulen *et al.*, 2012) [11, 12].

Despite growing scholarly interest, the literature on climate change and food security in India remains fragmented. Existing studies largely focus on agricultural productivity and crop yield impacts, while relatively limited attention has been paid to broader food system resilience, social vulnerability, and policy effectiveness (Ericksen, 2008; Fanzo *et al.*, 2018) [13, 14].

This paper addresses this gap by systematically reviewing the literature on climate change and food security in India through a social science lens. The study places particular emphasis on social vulnerability, agricultural risk, and policy responses.

2. Objectives of the Study

This study is designed to systematically evaluate the growing body of literature on climate change and food security in India. The review is guided by major debates in food systems research, climate vulnerability, and socio-economic resilience (Gregory *et al.*, 2005; Ericksen, 2008; Vermeulen *et al.*, 2012) [16, 13, 12]. The specific objectives are:

- To review literature on climate change and food security in India.
- To analyze climate impacts across the four dimensions of food security.
- To examine social vulnerability and agricultural risk.
- To identify major research gaps.
- To suggest policy responses for improving resilience.

These objectives align with contemporary scholarship emphasizing integrated food systems analysis rather than production-centric approaches (Fanzo *et al.*, 2018; Ingram, 2011) [14, 20].

3. Theoretical Framework

This review draws on four complementary theoretical perspectives to understand the complex relationship between climate change and food security in India:

- Food Security Framework
- Entitlement Theory
- Vulnerability Framework
- Political Ecology

Together, these frameworks provide a multidimensional analytical lens for understanding food insecurity as an environmental, social, economic, and political phenomenon (Adger, 2006; Ericksen, 2008) [10, 13].

3.1 Food Security Framework

The Food Security Framework provides the foundational lens for understanding the multidimensional nature of food insecurity. According to the Food and Agriculture Organization, food security consists of four dimensions: availability, accessibility, utilization, and stability (FAO, 1996; FAO, 2008) [17, 6]. Climate change influences these dimensions in different ways:

- Availability via production losses
- Accessibility via income and price shocks
- Utilization via nutritional decline
- Stability via long-term uncertainty

This framework has become central to climate-food security studies globally (Gregory *et al.*, 2005; Wheeler & von Braun, 2013) [16, 2].

3.2 Entitlement Theory

Entitlement Theory, developed by Amartya Sen, argues that hunger often results not from lack of food availability but from failures in access and entitlement systems (Sen, 1981) [21].

This perspective is highly relevant in the context of climate change. Climate shocks reduce:

- Production-based entitlements
- Income-based entitlements
- Labor-based entitlements

Thus, food insecurity emerges from weakened access mechanisms rather than absolute food shortages alone (Sen, 1981; Devereux, 2007) [21, 22]. This framework is especially relevant in India, where food insecurity often reflects socio-economic inequality rather than aggregate food scarcity.

3.3 Vulnerability Framework

The Vulnerability Framework is central to understanding climate-related food insecurity.

According to the Intergovernmental Panel on Climate Change, vulnerability depends on three major components:

- Exposure
- Sensitivity
- Adaptive capacity (IPCC, 2014; IPCC, 2023) [1, 23]

This framework helps explain why similar climate events produce unequal food security outcomes across regions and communities.

For example, two farming households exposed to the same drought may experience very different food security outcomes depending on irrigation access, income, institutional support, and social capital (Adger, 2006; Morton, 2007) [10, 11].

3.4 Political Ecology Perspective

Political ecology emphasizes that environmental risks are shaped by power relations, inequality, and institutional structures.

Climate vulnerability is therefore not purely climatic but socially produced (Adger, 2006) [10].

This perspective is critical for understanding why marginalized groups including women, tribal populations, and smallholder farmers face disproportionate food insecurity under climate change (Vermeulen *et al.*, 2012) [12]. Political ecology strengthens this review by situating climate-food insecurity within broader questions of social justice and governance.

4. Methodology

This study employs a Systematic Literature Review (SLR) methodology to critically examine the literature on climate change and food security in India.

The systematic review approach was chosen because it enables rigorous identification, screening, evaluation, and synthesis of relevant scholarly work while minimizing selection bias (Tranfield *et al.*, 2003) [24]. The review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, widely recognized in interdisciplinary research for ensuring transparency and replicability (Moher *et al.*, 2009) [5].

4.1 Search Strategy

Relevant literature was collected from leading academic databases to ensure comprehensive coverage of peer-reviewed research.

Databases searched included:

- Scopus
- Web of Science
- ScienceDirect
- Google Scholar
- SpringerLink
- Search strings included combinations of:

- Climate Change AND Food Security AND India
- Climate Variability AND Agriculture AND India
- Climate Change AND Nutrition Security AND India
- Climate Risk AND Indian Agriculture

These databases were selected because they provide broad coverage of climate science, food systems, geography, and social science research.

4.2 Inclusion and Exclusion Criteria

Studies were selected using predefined criteria.

Inclusion Criteria

- Peer-reviewed journal articles
- Institutional reports
- Government policy documents
- English-language studies
- Published between 2000 and 2026
- India-focused studies

Exclusion Criteria

- Duplicate records
- Non-English studies
- Opinion pieces
- Studies with weak thematic relevance

This ensured that only high-quality and relevant studies were included.

4.3 Screening Process

The screening process followed four stages:

- Identification
- Screening
- Eligibility
- Inclusion

Initial database search yielded 9,692 records.

After duplicate removal and screening:

- Duplicates removed: 2,134
- Records screened: 7,558
- Full-text studies assessed: 684
- Final studies included: 231

The systematic screening ensures inclusion of high-quality and relevant literature for robust synthesis (Moher *et al.*, 2009) [5].

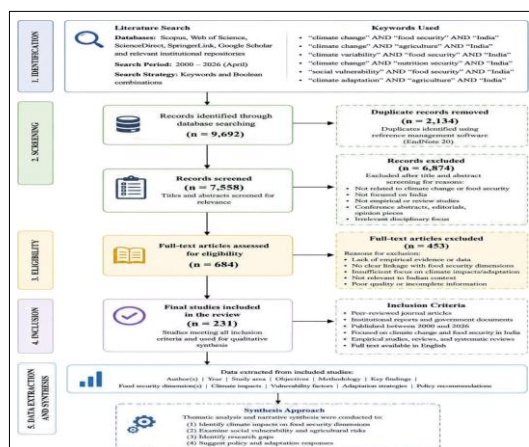


Fig 1: Methodological Flow Diagram of the Systematic Literature Review

5. Literature Review

The literature on climate change and food security in India has expanded considerably over the past two decades. Earlier studies focused primarily on agricultural productivity and climate sensitivity of crops. However, recent literature increasingly adopts broader food systems and vulnerability perspectives (Gregory *et al.*, 2005; Ericksen, 2008; Fanzo *et al.*, 2018) [16, 13, 14]. The review identifies five dominant themes:

- Climate impacts on agricultural productivity
- Food availability challenges
- Food accessibility and affordability
- Nutrition and food utilization
- Food system stability and adaptation

A major finding is that the literature remains heavily skewed toward agricultural productivity and food availability, while food utilization and social vulnerability remain comparatively underexplored (Ingram, 2011; Vermeulen *et al.*, 2012) [20, 12].

Table 1: Literature Distribution by Theme

Theme	Percentage
Agricultural Productivity	31.2%
Food Availability	20.8%
Food Accessibility	14.7%
Food Utilization	9.1%
Food Stability, Adaptation & Policy	24.2%

5.1 Climate Change and Agricultural Productivity

Agricultural productivity remains the most extensively researched dimension in the literature (Aggarwal, 2008; BIRTHAL *et al.*, 2014) [3, 4].

Indian agriculture is highly climate-sensitive because of:

- Dependence on monsoon rainfall
- High temperature sensitivity of crops
- Groundwater dependence
- Land degradation

Empirical studies consistently report negative effects of rising temperatures and rainfall variability on crop productivity (Lobell *et al.*, 2011; Challinor *et al.*, 2014) [7, 25].

Even moderate warming may substantially reduce crop yields in India, particularly for staple crops (Aggarwal, 2008; Kumar, 2011) [3, 19].

Wheat Productivity

Wheat is one of India's most climate-sensitive crops.

Major wheat-growing states include:

- Punjab
- Haryana
- Uttar Pradesh
- Rajasthan

Wheat is highly vulnerable to terminal heat stress during grain filling (Lobell *et al.*, 2011) [7].

Research indicates that a 1 °C rise in temperature may reduce wheat productivity by 4–6% (Aggarwal, 2008; Lobell *et al.*, 2011) [3, 7].

Rice Productivity

Rice remains India's principal staple crop.

Major climate-related risks include:

- Flooding

- Drought
- Heat stress
- Monsoon variability

Rain-fed rice systems are particularly vulnerable to rainfall irregularity (BIRTHAL *et al.*, 2014; Sahu *et al.*, 2013) [4, 26].

Pulses and Horticulture

Pulses, oilseeds, and horticultural crops are increasingly vulnerable to climate variability (Paltasingh & Goyari, 2018) [27].

Major climate risks include:

- Drought
- Water stress
- Temperature extremes

These impacts affect both productivity and farm income.

5.2 Climate Change and Food Availability

Food availability refers to sufficient quantities of food produced or supplied through domestic production, imports, storage, and distribution (FAO, 1996) [6]. Climate change affects food availability primarily through agricultural production losses (Gregory *et al.*, 2005; Wheeler & von Braun, 2013) [16, 2]. Key drivers include:

- Temperature rise
- Rainfall variability
- Water scarcity
- Soil degradation
- Pest outbreaks

Projected crop losses under warming scenarios include:

- Wheat: 6–25%
- Rice: 4–15%
- Maize: 18–23%

These projections raise serious concerns for India's long-term food security (Aggarwal, 2008; Rosenzweig *et al.*, 2014) [3, 9]. Water stress further intensifies food availability risks. Groundwater depletion, reduced reservoir storage, and increased evapotranspiration create major agricultural vulnerabilities (Mishra *et al.*, 2020; World Bank, 2022) [8, 18].

5.3 Climate Change and Food Accessibility

Food accessibility refers to physical and economic access to food. This dimension depends on:

- Income
- Employment
- Food prices
- Infrastructure
- Market access

Climate change affects food accessibility through multiple pathways (Sen, 1981; Devereux, 2007) [21, 22].

Primary pathway:

Climate Shock → Crop Failure → Income Loss → Food Inflation → Reduced Access

Climate-related agricultural stress negatively affects farm income, labor opportunities, and rural purchasing power (Morton, 2007; Nelson *et al.*, 2009) [11, 28]. Smallholders and landless laborers are highly vulnerable. This supports the entitlement perspective, where food insecurity often emerges from weakened economic access rather than absolute scarcity (Sen, 1981) [21].

5.4 Climate Change and Food Utilization

Food utilization concerns:

- Nutrition quality
- Dietary diversity
- Food safety
- Health outcomes

This remains among the least studied dimensions in India (Fanzo *et al.*, 2018) ^[14].

Climate change affects utilization through:

- Reduced food diversity
- Lower dietary quality
- Micronutrient decline
- Disease burden

Rising atmospheric CO may reduce nutrient concentrations in staple crops (Tirado *et al.*, 2010) ^[29]. Affected nutrients include:

- Protein
- Iron
- Zinc

This increases risks of:

- Hidden hunger
- Child malnutrition
- Maternal undernutrition

Food utilization deserves substantially more scholarly attention in India.

5.5 Climate Change and Food Stability

Food stability refers to reliable access to food over time (FAO, 1996) ^[6]. This dimension is increasingly threatened by extreme climatic events (IPCC, 2023) ^[1]. Major disruptions include:

- Heatwaves
- Droughts
- Floods
- Cyclones

These events affect:

- Production
- Storage
- Supply chains
- Market functioning

Extreme heat is emerging as one of the largest threats to food stability in India (Rosenzweig *et al.*, 2014) ^[9].

6. Social Vulnerability and Agricultural Risk

A major finding of this review is that climate change acts as a risk multiplier (Adger, 2006) ^[10].

Climate change does not affect all communities equally. Instead, impacts vary based on:

- Income
- Social position
- Gender
- Institutional access
- Geographic location

This makes social vulnerability central to food security analysis (Morton, 2007; Vermeulen *et al.*, 2012) ^[11, 12].

6.1 Smallholder Farmers

Smallholder farmers constitute the backbone of Indian agriculture. However, they face severe vulnerability due to:

- Small landholdings
- Limited irrigation
- Low mechanization
- Weak credit access
- Poor institutional support

Climate change intensifies these vulnerabilities (Morton, 2007; Bithal *et al.*, 2014) ^[11, 4].

6.2 Gender Vulnerability

Women face disproportionate climate-related food insecurity. Key reasons include:

- Limited land ownership
- Restricted institutional access
- Unequal labor burden
- Lower adaptive capacity

Gender-sensitive climate policies remain insufficient (Vermeulen *et al.*, 2012) ^[12].

6.3 Regional Vulnerability

Climate vulnerability varies significantly across India. Highly vulnerable regions include:

Northwestern India- Heat stress affecting wheat systems (Aggarwal, 2008) ^[3]

Central India- Drought-prone agriculture (Mishra *et al.*, 2020) ^[8]

Eastern India- Flood vulnerability (World Bank, 2022) ^[18]

Coastal India- Cyclones and salinity intrusion (IPCC, 2023) ^[1]

Regional disparities strongly influence food security outcomes.

7. Research Gaps in Existing Literature

Despite significant growth in the literature on climate change and food security in India, several important research gaps remain. This review identifies major conceptual, methodological, and empirical limitations that constrain current understanding of the climate–food security nexus.

A central finding of this review is that existing scholarship remains heavily skewed toward agricultural productivity and food availability, with comparatively limited attention to food accessibility, food utilization, and food stability (Ingram, 2011; Fanzo *et al.*, 2018) ^[20, 14]. Much of the literature continues to adopt a production-centric perspective, often equating food security with crop yield outcomes. While agricultural productivity is an important component, such a narrow approach fails to capture the multidimensional nature of food insecurity.

The first major gap concerns the limited focus on food utilization and nutrition security. Existing studies largely emphasize calorie availability and crop productivity, while relatively few examine dietary diversity, micronutrient sufficiency, food safety, and nutritional outcomes under climate change (Tirado *et al.*, 2010; Fanzo *et al.*, 2018) ^[29, 14]. Given India's persistent burden of child malnutrition, maternal undernutrition, and hidden hunger, this represents a critical area requiring greater scholarly attention.

A second major gap relates to the insufficient integration of social vulnerability and inequality analysis. Climate change impacts are not uniform across populations, yet many studies inadequately address how class, caste, gender, land ownership,

and institutional access shape food insecurity outcomes (Adger, 2006; Vermeulen *et al.*, 2012) ^[10, 12]. Vulnerability-sensitive research is essential for understanding differential impacts across social groups.

Third, there is a significant lack of high-resolution regional and district-level studies. India exhibits considerable agro-ecological diversity, and climate impacts vary substantially across regions. However, much of the existing literature relies on national or broad regional analyses, which often obscure localized vulnerabilities and adaptation needs (Aggarwal, 2008; Mishra *et al.*, 2020) ^[3, 8]. Greater district-level and state-level studies are necessary to support targeted policy interventions.

Fourth, the literature shows limited assessment of adaptation effectiveness. Although numerous studies recommend adaptation strategies such as climate-smart agriculture, irrigation expansion, and crop diversification, relatively few empirically evaluate their long-term effectiveness, scalability, and socio-economic feasibility (Campbell *et al.*, 2014; Zougmore *et al.*, 2016) ^[30, 31]. This weakens evidence-based policymaking.

Another important gap concerns the weak incorporation of interdisciplinary approaches. Climate change and food security

are inherently multidisciplinary issues involving environmental science, geography, economics, sociology, public policy, and nutrition science. However, existing studies often remain confined within disciplinary boundaries, limiting comprehensive understanding (Ericksen, 2008; Gregory *et al.*, 2005) ^[13, 16].

Finally, there is inadequate attention to the role of technology and digital innovation in climate adaptation. Emerging tools such as artificial intelligence, remote sensing, GIS-based risk mapping, precision agriculture, and digital advisory systems offer substantial potential for improving food system resilience. Yet these themes remain underexplored in the Indian context (Jat *et al.*, 2016) ^[32].

Addressing these research gaps is essential for advancing both academic scholarship and policy design. Future research should prioritize integrated food systems approaches that incorporate social vulnerability, regional diversity, nutritional outcomes, and adaptation effectiveness. Such an approach will provide a more comprehensive understanding of food security under climate change in India.

Table 2: Major Research Gaps in Climate Change–Food Security Literature in India

Research Gap Area	Existing Gap	Future Research Direction
Food Utilization & Nutrition Security	Limited focus on dietary diversity, food quality, and nutritional outcomes	More nutrition-sensitive climate and food security research
Social Vulnerability & Inequality Analysis	Weak integration of class, caste, gender, and institutional inequalities	More equity-focused and vulnerability-sensitive studies
High-Resolution Regional & District-Level Studies	Insufficient localized and district-level evidence	More spatially explicit regional research
Adaptation Effectiveness	Limited assessment of long-term effectiveness and scalability of adaptation strategies	More impact assessment and longitudinal studies
Interdisciplinary Approaches	Fragmented disciplinary research limits comprehensive understanding	More integrated systems-based research
Technology & Digital Innovation in Climate Adaptation	Limited focus on AI, GIS, remote sensing, and digital agriculture	More innovation-driven climate adaptation research

8. Discussion

This systematic review reveals that climate change poses multidimensional threats to food security in India through complex interactions among environmental stress, agricultural vulnerability, and socio-economic inequality (IPCC, 2023; Wheeler & von Braun, 2013) ^[2, 1]. The literature demonstrates that climate change affects not only agricultural productivity but also household livelihoods, food affordability, nutrition security, and long-term food system resilience (Gregory *et al.*, 2005; Fanzo *et al.*, 2018) ^[16, 14].

A major finding is that existing scholarship remains heavily production-centric. Most studies focus on crop yields, agricultural productivity, and food availability, while comparatively less attention is given to food accessibility, food utilization, and food stability (Aggarwal, 2008; Ingram, 2011) ^[3, 20]. This imbalance reflects a longstanding tendency to equate food security with food production. From a social science perspective, food insecurity under climate change cannot be understood solely as a production problem. Rather, it must be conceptualized as a multidimensional socio-ecological challenge shaped by inequalities in access, entitlements, institutional support, and adaptive capacity (Sen, 1981; Ericksen, 2008) ^[21, 13].

The review also demonstrates that climate change acts as a risk multiplier, intensifying existing structural vulnerabilities (Adger, 2006) ^[10]. Climate-related shocks such as droughts,

floods, and heatwaves have unequal impacts because they interact with pre-existing socioeconomic inequalities (Morton, 2007; Vermeulen *et al.*, 2012) ^[11, 12].

Regional disparities emerge as a major theme. Climate risks vary significantly across India's agro-ecological zones. Northwestern India faces increasing heat stress affecting wheat production, central India experiences recurrent drought stress, eastern India remains highly vulnerable to flooding, and coastal regions face cyclones and salinity intrusion (Aggarwal, 2008; Mishra *et al.*, 2020; World Bank, 2022) ^[3, 8, 18]. The review further identifies a major gap in nutrition-focused research. Food utilization remains among the least studied dimensions despite its growing significance (Fanzo *et al.*, 2018; Tirado *et al.*, 2010) ^[14, 29].

Overall, the literature suggests that India's climate-food security challenge requires a shift from agricultural productivity-centered thinking toward integrated food systems resilience (Ericksen, 2008; Vermeulen *et al.*, 2012) ^[13, 12].

9. Policy Implications

The findings of this review have important implications for policy and governance.

Addressing climate-related food insecurity in India requires integrated and multi-level interventions that address both environmental risks and socio-economic vulnerabilities (World Bank, 2022; IPCC, 2023) ^[18, 1].

9.1 Climate-Resilient Agriculture

India must transition toward climate-resilient agricultural systems (Aggarwal, 2008; BIRTHAL *et al.*, 2014) ^[3, 4]. Priority interventions include:

- Drought-resistant crop varieties
- Heat-tolerant seeds
- Crop diversification
- Climate-smart farming practices
- Sustainable land management

Climate-smart agriculture is increasingly recognized as a key adaptation strategy (Campbell *et al.*, 2014; Zougmore *et al.*, 2016) ^[30, 31].

9.2 Water Security and Irrigation Reform

Water security is central to food security. Policy priorities include:

- Micro-irrigation
- Rainwater harvesting
- Watershed management
- Groundwater recharge
- Efficient irrigation systems

Sustainable water governance is essential for long-term resilience (Mishra *et al.*, 2020; World Bank, 2022) ^[8, 18].

9.3 Strengthening Social Protection

Climate change disproportionately affects vulnerable populations. Policy interventions should strengthen:

- Food subsidies
- Employment programs
- Crop insurance
- Social safety nets

Strong social protection can significantly reduce vulnerability to food insecurity (Sen, 1981; Devereux, 2007) ^[21, 22].

9.4 Nutrition-Sensitive Food Policy

Future food security policies must move beyond calorie security. Greater focus is needed on:

- Dietary diversity
- Micronutrient sufficiency
- Child nutrition
- Maternal nutrition

This is essential for addressing hidden hunger (Fanzo *et al.*, 2018) ^[14].

9.5 Technology and Digital Agriculture

Technology can substantially improve adaptive capacity. Promising areas include:

- AI-based climate advisories
- Remote sensing
- GIS
- Precision agriculture
- Early warning systems

Digital agriculture offers significant opportunities for resilience building (Jat *et al.*, 2016) ^[32].

9.6 Region-Specific Policy Design

Climate vulnerability differs significantly across India. Policies must therefore be region-specific and context-sensitive rather than uniform (Adger, 2006; IPCC, 2023) ^[10, 1]. Localized adaptation planning is essential.

10. Conclusion

This study systematically reviewed the literature on climate change and food security in India with specific focus on social vulnerability, agricultural risk, and policy responses. The review demonstrates that climate change has emerged as one of the most significant threats to India's food systems (IPCC, 2023; Wheeler & von Braun, 2013) ^[2, 1]. Rising temperatures, rainfall variability, groundwater depletion, and extreme weather events are increasingly affecting

- Climate-resilient agriculture
- Strong social protection
- Institutional strengthening
- Inclusive governance
- Technological innovation

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