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The Impact of Climate Change on Geographical Indications: Ensuring Authenticity in Shifting Climates

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Climate change poses unprecedented threats to Geographical Indications (GIs) legally protected designations identifying products as originating from specific regions with distinctive characteristics. This study examines how climate variability impacts GI product quality, yield, and market viability through systematic analysis of six GI-registered agricultural products from India: Cumbum Paneer Grapes, Authoor Betel Leaves, Sholavandhan Betel Leaves, Kanyakumari Matti Banana, Navara Rice, and Palakkadan Matta Rice. Our findings identify five recurring climate-GI vulnerability mechanisms: hydrological misalignment, thermal stress and phenological disruption, soil degradation, pest and disease expansion, and chemical composition alteration. Current Indian GI governance frameworks lack post-registration monitoring systems and climate adaptation support mechanisms. We propose a Climate-Adaptive GI Management Framework incorporating three pillars: (1) formalized monitoring of climate variables and product quality; (2) support for climate-smart agricultural practices prioritizing product quality; and (3) enhanced policy instruments integrating climate resilience into GI governance. Drawing from the European Union's bioclimatic GI model, we recommend India strengthen legal frameworks to embed climate resilience monitoring into GI certification standards. This research makes original contributions through explicit articulation of climate-GI vulnerability typologies and practical monitoring and adaptation protocols currently absent from Indian GI policy and academic literature. The study concludes that GI protection systems, when integrated with climate-adaptive measures, can serve as effective instruments for sustainable rural development and food security in the face of climate change.

Keywords: Climate Change, Geographical Indications, Terroir, Sustainable Agriculture, GI Resilience

Geographical Indications (GIs) represent a unique form of intellectual property protection for products with distinctive qualities directly linked to their place of origin. Within the framework of intellectual property law, GIs are granted to products originating from specific regions and bearing characteristics fundamentally associated with that geography. The connection between product identity and geographical location creates intrinsic value recognized by both consumers and markets. A GI designation protects not merely a brand name but rather the collective cultural, agricultural, and environmental heritage embodied in a product.

India has emerged as a leader in GI protection, with over 650 registered GIs distributed across agricultural products, handicrafts, and manufactured goods. The economic and social significance of GIs in India is substantial: they preserve agricultural biodiversity, support rural livelihoods for approximately 68.84% of the rural population engaged in farming and traditional crafts, and facilitate market access for traditionally marginalized producer communities[1]. However, GI systems are inherently vulnerable to environmental disruption because their defining characteristics depend upon specific climatic conditions, soil composition, water availability, and ecosystem dynamics. Climate change presents an unprecedented challenge to this system.

Rising temperatures, altered precipitation patterns, shifting soil characteristics, emerging pest dynamics, and extreme weather events directly undermine the environmental conditions upon which GI product quality depends. A GI product that loses its defining characteristics due to climatic transformation ceases to merit the protection granted to it. For instance, if climatic shifts render it impossible to produce tea with the distinctive aromas and flavours that define Darjeeling tea, the GI designation loses practical meaning.

Existing literature examines GIs from legal, cultural, and economic perspectives, yet systematic investigation of climate change impacts on GI

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systems remains limited[2]. Furthermore, Indian GI governance frameworks lack integrated climate resilience requirements or post-registration monitoring protocols to track climate-induced quality degradation. This research addresses this gap by: (1) systematically analyzing climate vulnerabilities in six GI-registered agricultural products; (2) developing a typology of climate-GI vulnerability mechanisms; (3) proposing practical monitoring and adaptation protocols; and (4) recommending enhanced policy instruments that integrate climate resilience into GI certification standards.

Geographical Indications: Conceptual and Legal Framework

Definition and Core Concepts

The World Intellectual Property Organization (WIPO) defines a geographical indication as 'a sign used on products that have a specific geographical origin and possess qualities, reputation, or other characteristics that are due to that origin.'[3] The Indian Geographical Indications of Goods (Registration and Protection) Act, 1999 (Section 2(e)) provides a detailed statutory definition: a GI is 'an indication which identifies such goods as agricultural goods, natural goods or manufactured goods as originating, or manufactured in the territory of a country, or a region or locality in that territory, where a given quality, reputation or other characteristics of such goods is essentially attributed to its geographical origin.'[4]

The European Union definition further clarifies that the geographical link must occur in at least one stage of production, processing, or preparation[5]. This definition emphasizes a critical concept: GI protection depends upon maintaining a demonstrable causal connection between the product's distinctive characteristics and the defined geographical territory. Three elements constitute this connection: (1) specific geographical location or territory; (2) distinctive product qualities, reputation, or characteristics; and (3) a causal nexus attributing those qualities to the geographical origin, whether through climate, soil, altitude, traditional practices, or combinations thereof.

Examples illustrate this framework: Darjeeling tea derives its distinctive floral notes and light colour from the high-altitude, misty conditions of the Darjeeling district in West Bengal[6]; Monsooned Malabar coffee requires the humid monsoon winds of the Malabar Coast for its specific flavour profile; Kangra tea from Himachal Pradesh develops its distinctive character through a combination of altitude, seasonal rainfall patterns, and processing methods unique to the region. In each case, climate represents not a peripheral feature but rather a foundational element of the product's GI-protected identity.

Historical Development of GI Protection in India

Prior to 1999, India lacked statutory protection for geographical indications. The Basmati rice controversy exemplified the necessity for formal GI protection. In 1997, the U.S. Patent and Trademark Office granted RiceTec Inc., a Texas-based corporation, a patent for purportedly new basmati rice varieties (marketed as 'Texmati', 'Kasmati', and 'Jusmati'). India challenged this patent, asserting that basmati was not an invention but rather a distinctive traditional rice variety cultivated in specific sub-Himalayan regions for millennia through traditional agricultural methods[7]. The patenting threatened India's market share of basmati rice exports, particularly in European markets.

Similarly, the Darjeeling tea controversy saw international producers marketing tea as 'Darjeeling' despite production outside the specified geographical region. Authentic Darjeeling tea producers faced unfair competition and market dilution[8]. These crises prompted the Indian Parliament to enact the Geographical Indications of Goods (Registration and Protection) Act, 1999, which came into effect on September 15, 2003. Darjeeling tea became the first Indian product to receive GI protection in 2004-2005, serving as a landmark recognition of India's commitment to protecting traditional products.

The Act established the Geographical Indications Registry (overseen by the Controller General of Patents, Designs, and Trademarks) to administer GI registrations[9]. The statute reflects three primary objectives: (1) preserving national geographical indicators and protecting producer interests; (2) preventing unauthorized use and protecting consumers from deception; and (3) promoting GI-protected products in trade markets to generate economic prosperity. To date, India has registered over 650 GIs across agricultural products, handicrafts, and manufactured goods, making it one of the world's largest GI repositories.

Research Methodology

Research Design and Data Sources

The study employs a systematic mixed-methods approach combining secondary source analysis with qualitative case study methodology. All data derive from secondary sources including peer-reviewed journal articles, government reports, GI registry documentation, international convention texts, and documented farmer testimonies and producer organization records. Primary research was not conducted; instead, the study synthesizes existing evidence into a coherent analytical framework examining climate-GI interactions.

Data analysis proceeded through three iterative phases: (1) systematic literature review of climate impacts on agriculture and terroir-dependent products; (2) comprehensive review of GI registration documents and producer organization records for the six selected products; and (3) thematic coding and analysis of climate vulnerabilities, adaptation strategies, and policy gaps. All sources were assessed for reliability, with priority given to official government data, peer-reviewed research, and documented producer organization statements.

The study acknowledges important limitations: reliance on secondary sources constrains the ability to conduct primary interviews with producers or agricultural experts; documentation of climate impacts on some GI products remains incomplete; and attributing specific yield changes to climate change (versus other variables such as market conditions or pest outbreaks) requires cautious interpretation.

Selection of Case Study Products

Six GI-registered agricultural products from India were selected for systematic case analysis: Cumbum Paneer Grapes, Authoor Betel Leaves, Sholavandhan Betel Leaves, Kanyakumari Matti Banana, Navara Rice, and Palakkadan Matta Rice. These products were selected according to five explicit criteria (Table 1):

Data Analysis Framework

For each case study product, analysis examined: (1) climate parameters defined as critical for maintaining GI-defining characteristics; (2) documented evidence of climate change in production regions; (3) documented impacts on product quality and yield; (4) adaptation strategies employed or proposed by producers; and (5) policy and governance gaps hindering effective climate resilience. Thematic coding identified recurring vulnerability mechanisms: hydrological misalignment, thermal stress, soil degradation, pest expansion, and chemical composition alteration.

Climate Change Impacts on Terroir and Geographical Indications

Terroir, Climate, and Product Quality

The concept of 'terroir' encompasses the totality of environmental conditions affecting agricultural product quality: climate, soil, topography, biodiversity, and human practices. GI-protected products are fundamentally terroir products; their distinctive characteristics emerge from inseparable interactions between environmental conditions and production methods accumulated through generations[10]. For example, the distinctive fruity and floral notes of Darjeeling tea derive from specific combinations of altitude (600-2000 meters), monsoonal precipitation patterns, temperature fluctuations, and soil composition of the Darjeeling region.

Climate functions as a primary terroir component. It determines: (1) growing season length and phenological timing; (2) water availability through precipitation and soil moisture; (3) temperature regimes affecting biochemical processes that produce flavour compounds, aromas, and nutritional profiles; (4) solar radiation influencing photosynthesis and secondary metabolite production; and (5) pest and disease pressure through temperature and humidity effects on pathogen lifecycles[11]. Measurable changes

Table 1 — Criteria for analysing GI registered agricultural products

Criterion	Rationale
Climate Sensitivity	Products demonstrate documented sensitivity to specific climatic variables (temperature, rainfall, soil moisture) experiencing measurable change in production regions
Documentation Availability	Sufficient secondary source documentation exists regarding climate impacts, producer concerns, and quality changes
Geographical Diversity	Products originate from different regions and elevation zones allowing examination of diverse climate change manifestations
Product Typology	Products represent different agricultural categories enabling analysis across diverse typologies and vulnerabilities
Producer Concerns	Documented evidence exists of producer organizations expressing concerns about climate-induced quality degradation

in any of these parameters directly alter the chemical and sensory properties of products, thereby threatening their GI status.

Recent empirical research documents these mechanisms. Studies on wine grapes demonstrate that warming temperatures alter phenolic ripeness independently of sugar accumulation, changing flavour profiles and harvest timing[12]. Research on tea quality shows that temperature variations affect chlorophyll content, amino acid composition (particularly L-theanine), and polyphenol production[13]. Investigations of spice crops document that water stress alters essential oil composition and alkaloid concentrations, fundamentally changing sensory and medicinal properties.

Climate Change Manifestations in GI Production Regions

Global climate models project significant changes in temperature and precipitation regimes, with pronounced impacts in South Asia and India specifically. Observed trends over the past four decades show: (1) warming of approximately 0.30-0.52°C per decade across India, with greater warming in mountainous regions; (2) increasing precipitation variability, with delayed monsoons, erratic rainfall distribution, and increased frequency of extreme precipitation events; (3) soil moisture stress in agricultural regions due to increased evapotranspiration; and (4) ecosystem disruptions including shifting pest and pathogen ranges, altered flowering times, and changes in pollinator activity[14]

The implications for GI production regions are profound. Agricultural zones characterized by specific climatic envelopes (temperature, precipitation, soil moisture) are shifting geographically. Plants require progressively altered management practices (irrigation timing, pest monitoring, processing methods) to maintain traditional quality standards. In extreme cases, current production locations may become climatically unsuitable for traditional GI product cultivation within 20-50 years.

GI Systems and Sustainable Agriculture

While GI systems face climate challenges, they simultaneously offer advantages for sustainable agricultural development. GI protection incentivizes producers to maintain or enhance product quality through traditional and environmentally sensitive methods, creating economic value for ecological stewardship[15]. When GI protection functions effectively, producers capture price premiums (typically 40-100% above commodity prices) that justify investments in sustainable practices.

UNESCO conventions recognize the importance of protecting cultural landscapes—agricultural systems shaped by centuries of interaction between human communities and their environments[16]. GI systems function as legal instruments protecting these cultural landscapes. However, as climate change alters environmental conditions, the protective function of GI systems becomes insufficient without integration of climate adaptation mechanisms.

Case Study Findings: Climate Change Impacts on Six GI-Protected Products

Tamil Nadu GI Products: Grapes, Betel Leaves, and Banana

Cumbum Paneer Grapes

Cumbum Paneer Grapes are cultivated in the Cumbum Valley region of Tamil Nadu at approximately 800-1200 meters elevation. The distinctive characteristics of Cumbum grapes—particularly their sweetness, thin skin, and seedlessness—derive from the region's cool nights, specific sunshine patterns, and volcanic red loamy soil composition. Meteorological data document increasing mean temperatures and altered monsoon timing in this region over the past two decades.

Documented Impacts: Producer organizations report that grape varieties have become more water-sensitive due to earlier bud break (phenological shift) driven by warming temperatures. Increased temperature variability has extended the growing season, exposing developing grapes to unexpected rainfall events that increase disease pressure and crack risk. Soil moisture retention has declined, requiring increased irrigation frequency. Producers report that maintaining traditional production without altered practices has become increasingly difficult.

Kanyakumari Matti Banana

Kanyakumari Matti Banana, registered as a GI product, originates from the southernmost region of Tamil Nadu. This distinctive banana variety is renowned for its creamy texture, rich flavour, and cultural significance in local cuisines. The product's distinctive characteristics emerge from coastal soil characteristics, seasonal rainfall patterns, and specific cultivation practices refined over centuries.

Documented Impacts: Farmers report that increased rainfall variability has created particular vulnerability: while bananas require consistent moisture, unexpected intense rainfall events can cause

root system damage and plant lodging (falling). Off-season rainfall events damage developing fruit and increase fungal disease incidence. These impacts have shifted farmers from income generation confidence to production anxiety.

Betel Leaves: Authoor and Sholavandhan Varieties

Tamil Nadu has registered two distinct betel leaf GI products: Authoor Betel Leaves and Sholavandhan Betel Leaves. Both varieties require specific combinations of high humidity, moderate shade, and soil moisture for optimal growth. These conditions have historically been provided through the region's pattern of monsoon rains and natural shade from coconut palms and arecanut trees in integrated agroforestry systems.

Documented Impacts: Both varieties show documented sensitivity to temperature increases and humidity changes. Rising temperatures accelerate plant growth rates while sometimes reducing leaf thickness, fragrance, and nutrient content. Irregular moisture availability (interspersed dry periods within monsoon seasons) causes physiological stress affecting leaf quality. Warmer, drier conditions increase pest and disease pressure (particularly fungal infections). Some producers report needing to implement additional shade structures or irrigation to maintain traditional growing conditions, adding significant costs to production.

Kerala GI Products: Medicinal and Heritage Rice Varieties

Navara Rice

Navara Rice, also known as 'Shashtika Rice,' is an ancient medicinal rice variety native to Kerala with unique 60-day maturation. Traditional Ayurvedic texts (Ashtangahridaya, Sushruta Samhita) document its therapeutic properties for digestive, rheumatic, respiratory, and circulatory conditions[17]. The variety is now registered as a GI product, reflecting its cultural and medicinal significance. Distinctive characteristics include specific grain morphology, nutritional composition (enhanced micronutrient and polyphenol content), and rapid maturation enabling multiple cropping cycles per year under traditional conditions.

Documented Impacts: Navara Rice depends upon specific combinations of: (1) consistent photoperiod and temperature patterns that trigger timely flowering at 45-50 days post-sowing; (2) reliable monsoon moisture for standing water cultivation; (3) specific soil microbiome composition supporting rice growth and medicinal compound production. Altered monsoon timing disrupts water availability precisely when plants require it. Warming temperatures accelerate development rates, potentially shortening maturation duration and reducing nutrient accumulation. Changes in temperature and humidity patterns also alter soil microbiome composition, potentially affecting plant health and medicinal compound profiles.

Palakkadan Matta Rice

Palakkadan Matta Rice, also known as 'Kerala Red Rice,' is cultivated exclusively in Palakkad district's distinctive black regar soil (60-80% silt and clay composition with lime content). The high water-holding capacity of this soil, combined with the district's humid tropical climate and the Palakkad Gap's unique wind patterns, produces rice with distinctive red pigmentation, nutty flavour, and documented nutritional advantages[18]. The variety has been cultivated in this specific location for centuries, with quality inseparably linked to soil characteristics and regional climate.

Documented Impacts: Two specific climate impacts threaten Palakkadan Matta Rice: (1) changing monsoon patterns have altered soil moisture dynamics, with prolonged dry spells followed by intense precipitation creating waterlogging; (2) increased soil salinity has been documented in some production areas, potentially linked to increased evapotranspiration and altered groundwater dynamics. The distinctive soil microbiome composition, which contributes to rice quality, may be adversely affected by moisture and salinity changes. Unlike some crops that can be relocated to alternative regions, Palakkadan Matta Rice depends fundamentally upon Palakkad district's specific soil composition, which cannot be duplicated elsewhere.

Synthesis: Typology of Climate-GI Vulnerability Mechanisms

Analysis of these six case studies reveals five recurring climate-GI vulnerability mechanisms (Table 2).

Discussion: Implications and Climate-Adaptive GI Governance

The GI Governance Gap

Current Indian GI governance frameworks exhibit a critical gap: while the GI Act establishes registration procedures and protects product names from misappropriation, it contains no mechanisms for

Table 2 — Five recurring climate-GI vulnerability mechanisms

Vulnerability Type	Manifestation
Hydrological Misalignment	Altered precipitation timing and intensity disrupt traditional water availability patterns (e.g., monsoon timing changes affecting rice sowing and growth; unexpected intense rainfall causing flooding and crop damage in water-sensitive crops like bananas and grapes)
Thermal Stress and Phenological Disruption	Warming temperatures alter development rates, causing premature flowering/maturation or phenological mismatches with environmental cues, changing harvest timing and quality parameters
Soil Degradation and Nutrient Cycling Disruption	Altered soil moisture, salinity, and microbial composition reduce soil fertility and alter nutrient uptake profiles, affecting product nutrition and quality
Pest and Disease Expansion	Warmer, irregular humidity patterns expand geographic ranges of crop pests and pathogens, increasing disease pressure and requiring elevated pesticide use
Chemical Composition Alteration	Altered temperature, water stress, and nutrient availability change secondary metabolite production affecting flavour, aroma, medicinal compounds, and sensory properties

monitoring whether GI products maintain their distinctive characteristics over time, nor does it address climate-induced quality degradation[19]. Post-registration monitoring systems are minimal or absent. Certification standards focus on production methods and geographical origin verification but lack periodic quality assessment to detect whether product characteristics are being maintained despite changing environmental conditions.

The governance gap becomes increasingly critical as climate change accelerates. A producer could theoretically maintain GI certification while product quality degrades substantially, without triggering any regulatory intervention. Conversely, a producer attempting to maintain traditional product quality in the face of adverse climatic conditions might need to modify practices (expanding irrigation, implementing pest management interventions), potentially putting the product at risk of de-certification if new practices are deemed to violate traditional production standards.

The case study products illustrate this gap vividly: none of the six examined GI products has formalized monitoring systems tracking climate variables, yield trends, or quality metrics over time. Governance gaps also exist regarding the adaptation-versus-tradition dilemma: GI systems are designed to protect traditional production methods, yet climate change demands adaptive modification. Policy clarity is needed regarding when and under what conditions production practice modifications can be permitted without compromising GI status.

Proposed Framework: Climate-Adaptive GI Management

Pillar 1: Post-Registration Climate Monitoring and Quality Assurance

Establish formalized monitoring systems tracking: (1) key climate variables in production regions (temperature, rainfall, soil moisture, seasonal patterns); (2) product quality metrics (chemical composition, sensory characteristics, yield per unit area); (3) production practices employed (irrigation frequency, pest management approaches, processing modifications); and (4) producer organization concerns and adaptation initiatives. Monitoring should operate on 3-5 year cycles, generating reports accessible to GI registration bodies, producer organizations, and researchers. This system would transform GI governance from 'register once and monitor only for trademark infringement' to 'register and continue environmental stewardship.'

Pillar 2: Climate-Smart Adaptation Strategies

Support producer implementation of climate-smart agricultural practices enabling product quality maintenance in the face of changing climatic conditions. These strategies should be distinguished from commodity-maximization approaches; rather, they target maintaining GI-defining characteristics while adapting to climate stress. Relevant practices include: improved water management (drip irrigation, soil moisture monitoring, rainwater harvesting), soil conservation and restoration, temperature-modulation strategies (increased shade, mulching), pest management transitions toward biological controls, agronomic innovations (revised planting dates, modified fertilization), and processing adaptations.

Critically, adaptation strategies must prioritize product quality over yield maximization. A doubled harvest of inferior-quality product benefits commodity markets but undermines GI value. Adaptation should be guided by quality standards, with yield accepted as a secondary outcome. Furthermore, adaptation strategies should be developed collaboratively between agricultural scientists and producer organizations, ensuring that technical interventions respect traditional knowledge and cultural significance of production practices.

Pillar 3: Enhanced Policy Instruments

Integrate climate resilience requirements into GI governance through policy and regulatory

instruments: (1) Amend GI regulations to explicitly incorporate climate resilience and environmental stewardship as criteria in GI protection and renewal; (2) Establish bioclimatic profiles for major GI products, defining environmental parameters essential for maintaining distinctive characteristics; (3) Create legal mechanisms permitting production practice modifications (within specified limits) when climate change necessitates adaptation, without requiring de-certification; (4) Develop climate change adaptation as a formal topic within GI producer organization capacity-building programs; (5) Integrate climate resilience into GI market promotion campaigns, emphasizing how GI protection systems support climate-adaptive agricultural development.

Original Contribution of this Research

The research contributes to academic and policy literature through: (1) Systematic typology of climate-GI vulnerability mechanisms, distinguishing five distinct pathways through which climate change threatens GI product integrity; (2) Explicit articulation of climate-GI governance gaps in Indian law and policy, identifying missing post-registration monitoring and adaptation support systems; (3) Practical monitoring protocols for tracking climate impacts on GI products; (4) Adaptation strategy frameworks prioritizing product quality and cultural heritage over commodity production; and (5) Climate-adaptive GI management framework integrating monitoring, adaptation support, and policy enhancement into a coherent system. These contributions extend beyond descriptive documentation of climate-GI interactions to propose actionable governance improvements.

Recommendations

For Policymakers and GI Governance Institutions

(i) **Establish Climate Resilience as a GI Governance Priority:** Amend the Geographical Indications of Goods (Registration and Protection) Act, 1999 to explicitly incorporate climate resilience and environmental stewardship as criteria in GI protection. Include climate change adaptation considerations in GI registration documentation, renewal processes, and enforcement mechanisms.

(ii) **Implement Post-Registration Monitoring Systems:** Establish formalized monitoring systems for GI products documenting climate variables, quality metrics, yield trends, and producer concerns at 3-5 years intervals. Collaborate with regional agricultural universities and producer organizations in protocol development. Direct GI registration fees toward ongoing monitoring administration.

(iii) **Develop Bioclimatic Profiles:** For major climate-sensitive GI products, develop bioclimatic profiles defining environmental parameters essential for maintaining distinctive characteristics. Utilize existing bioclimatic models developed in EU viticulture research and adapt them for Indian agricultural products.

(iv) **Create Adaptation Support Programs:** Establish government-supported demonstration farms and farmer training programs focusing on climate-smart practices for GI products. Coordinate with state agricultural departments and central government agricultural programs to provide technical and financial support for climate adaptation.

(v) **Clarify Adaptation Flexibility:** Develop policy guidance clarifying when and under what conditions production practice modifications can be permitted to address climate change without compromising GI status. This flexibility is essential for maintaining GI viability while accommodating necessary adaptation.

For Producer Organizations and GI Stakeholders

(i) **Engage in Collaborative Climate Monitoring:** Participate actively in post-registration monitoring systems. Document and report climate impacts, yield changes, quality variations, and adaptation initiatives. This information is essential for evidence-based policy development.

(ii) **Develop Adaptation Strategies:** Engage agricultural scientists and extension workers in developing context-appropriate climate adaptation strategies. Prioritize product quality maintenance over yield maximization. Share successful adaptation practices across producer networks.

(iii) **Integrate Climate Adaptation into Producer Education:** Include climate change impacts and adaptation strategies as formal

topics in producer organization training and capacity-building programs. Ensure that both established farmers and new entrants understand climate risks and adaptation options.

For Researchers and Academic Institutions

(1) **Conduct Impact Research:** Undertake primary research investigating climate change impacts on major GI products. Conduct field experiments comparing traditional and climate-adapted practices in terms of product quality, environmental outcomes, and economic viability.

(2) **Develop Agricultural Technologies:** Develop agronomic innovations, crop varieties, and production technologies enabling GI product quality maintenance under altered climatic conditions. Ensure that innovations align with traditional production values and cultural significance.

(3) **Support Evidence-Based Policy:** Engage with policymakers and GI governance institutions to translate research findings into practical policy recommendations and governance frameworks.

Conclusion

Climate change presents an unprecedented challenge to Geographical Indications systems. By fundamentally altering the environmental conditions upon which GI products depend, climate change threatens not merely individual products but entire cultural, agricultural, and economic systems built around traditional regional products. Analysis of six Indian GI-protected agricultural products reveals that climate change operates through multiple vulnerability pathways: hydrological disruption, thermal stress, soil degradation, pest expansion, and chemical composition alteration. These mechanisms are not merely academic abstractions; they manifest concretely as reduced yields, quality degradation, increased production costs, and diminished farmer confidence in GI systems.

Existing Indian GI governance frameworks are inadequate to address these challenges. They lack post-registration monitoring systems, climate adaptation support mechanisms, and policy flexibility to accommodate necessary production practice modifications. This research proposes a comprehensive Climate-Adaptive GI Management Framework incorporating post-registration monitoring, climate-smart adaptation support, and enhanced policy instruments. This framework recognizes that effective GI protection in the era of climate change requires evolution beyond traditional intellectual property focus on preventing misappropriation to include active environmental stewardship and climate resilience.

The stakes are substantial. For approximately 430 registered GI products supporting millions of rural producers, the viability of these designations depends upon climate-adapted governance and support systems. Conversely, when properly designed and implemented, GI protection systems create economic incentives for sustainable agricultural practices and environmental stewardship, potentially positioning GI systems as instruments for climate change mitigation and adaptation in agricultural sectors.

Implementation of the proposed framework will require coordinated effort among governmental agencies, agricultural institutions, producer organizations, and international partners. It demands policy innovation, institutional capacity-building, and sustained commitment to protecting both agricultural productivity and cultural heritage amid environmental transformation. The alternative continuing with existing inadequate governance frameworks risks allowing GI products to progressively lose the defining characteristics that justify their protection, ultimately undermining both the GI system and the rural livelihoods it supports.

Ultimately, this research argues that Geographical Indications can serve as powerful instruments for climate-adaptive sustainable development, but only if governance systems evolve to explicitly address climate challenges. The responsibility falls to policymakers, institutions, producers, and researchers to implement the necessary reforms. The time for action is immediate; climate change impacts are already manifesting in GI production regions, and delay in policy response risks foreclosing options for effective adaptation. A climate-informed GI governance system is not merely desirable; it is essential for preserving the legacy of unique regional products for future generations.

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