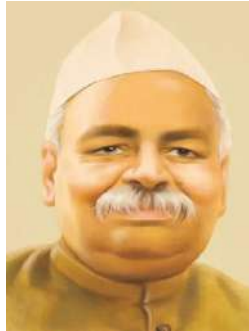


Himalayan Popular Lecture

Ladakh Series- 6th



Climate, Agriculture, and Food Security Variability in Pathway

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Climate Agriculture, and food security variability in pathways

Introduction

Climate change has emerged as one of the defining challenges of the 21st century, with profound implications for human survival, natural ecosystems, and socio-economic development. Among the sectors most directly affected, agriculture stands out as both highly vulnerable to climate variability and a significant contributor to greenhouse gas emissions. The global food system—which includes production, transportation, processing, storage, and consumption—feeds the majority of the world’s population and provides livelihoods to more than one billion people. However, this system is increasingly exposed to disruptions caused by climatic stresses such as rising temperatures, irregular precipitation, extreme weather events, and shifting agro-ecological zones.

The Intergovernmental Panel on Climate Change (IPCC AR6, 2023) has reported with high confidence that climate change is already undermining global food security. The evidence is visible in declining crop yields, shrinking arable land, water scarcity, and the growing unpredictability of seasonal cycles. For example, in regions dependent on monsoon rains such as South Asia, erratic rainfall patterns have severely affected agricultural output and food supply stability. Similarly, prolonged droughts in Africa and heatwaves in Europe have demonstrated how climate anomalies can disrupt farming and supply chains at local, regional, and global levels.

Agriculture’s Sensitivity to Climate Variability

Agriculture is fundamentally shaped by environmental conditions, soil fertility, water availability, temperature, and seasonal rhythms. Any shift in these conditions can have

cascading effects on crop productivity, livestock health, and overall food system resilience. Unlike industries that can relocate or adapt through technological substitution, farming communities are geographically bound and rely heavily on localized weather and ecological patterns. This makes agricultural systems exceptionally sensitive to even modest climate variations. The slow, long-term changes such as global warming, glacial retreat, and gradual shifts in rainfall distribution alter planting calendars, reduce soil moisture, and expand pest and disease ranges. At the same time, sudden extreme events, floods, cyclones, landslides, and wildfires, cause immediate and severe damage, often resulting in total crop losses, destruction of agricultural infrastructure, and displacement of rural populations. Both types of impacts, gradual and abrupt, contribute to heightened vulnerability and uncertainty within farming systems.

Implications for Food Security

The food security is multidimensional, encompassing four key pillars: availability, accessibility, utilization, and stability. Climate change threatens each of these dimensions.

- ❖ Availability is reduced when crop yields decline due to heat stress, water scarcity, or soil degradation.
- ❖ Accessibility is compromised as food prices rise, limiting the ability of vulnerable populations to purchase nutritious foods.
- ❖ Utilization is affected when climate change alters the quality and nutritional value of crops, or when diseases associated with warmer climates spread.
- ❖ Stability is undermined by the increasing unpredictability of agricultural production and global supply chains.

The situation is further complicated by non-climatic drivers such as geopolitical conflicts, economic instability, and pandemics, which interact with climate stress to intensify food insecurity. For instance, the war in Ukraine disrupted global grain and fertilizer supplies, while

the COVID-19 pandemic exposed weaknesses in supply chains and labor markets. These overlapping crises demonstrate that food security is increasingly shaped by interconnected global risks.

Pathways of Variability

The variability in climate-agriculture-food security pathways can be understood through multiple lenses. On one hand, climate change amplifies risks—reducing yields, increasing costs, and straining farmer livelihoods. On the other hand, it creates new opportunities for adaptation and innovation. For example, the expansion of C4 crops like maize and millets into previously unsuitable regions, or the promotion of drought-tolerant varieties, reflects how agriculture can respond dynamically to changing conditions. Similarly, conservation agriculture practices—such as crop rotation, minimal tillage, and mulching—offer strategies to build resilience by improving soil health and water retention. However, these adaptive strategies are not without challenges. Shifting from water-intensive crops like rice to less-thirsty alternatives require major changes in dietary preferences, cultural practices, and market systems. Moreover, small and marginal farmers, who form the backbone of food production in developing countries, often lack access to financial resources, extension services, and crop insurance mechanisms needed to implement such transitions.

Towards Sustainable Pathways

Addressing the variability in climate-agriculture-food security pathways requires an integrated and multi-scalar approach. Scientific research must be combined with traditional knowledge systems to create context-specific solutions. Policy frameworks should support climate-smart agriculture, ensure equitable access to resources, and build robust safety nets for vulnerable communities. At the same time, markets and institutions must incentivize sustainable farming practices and promote diversification within food systems. The equally important is the recognition that climate change is not solely a threat but also a catalyst for innovation. From

developing climate-resilient crop varieties to embedding indigenous farming practices into modern agricultural systems, new frontiers are emerging that can transform vulnerabilities into opportunities. By embracing adaptation, fostering resilience, and prioritizing inclusivity, pathways towards a sustainable and food-secure future can be charted

Agriculture and Climate Sensitivity

Agriculture is inherently sensitive to climate variability, as crop productivity and farming systems depend directly on temperature, precipitation, and seasonal cycles. Even small shifts in climatic conditions can influence planting dates, crop growth, and harvest yields. For instance, rising temperatures can accelerate crop maturation but often reduce yields and nutritional quality, while unpredictable rainfall increases the risk of both droughts and floods. Soil fertility and water availability, which are critical for sustaining agriculture, are also jeopardized by climate-induced processes such as erosion, salinization, and groundwater depletion. The climate change intensifies these vulnerabilities by introducing greater uncertainty and frequency of extreme events, thereby threatening food security and rural livelihoods. Regions dependent on rainfed agriculture, particularly in developing countries, face heightened risks due to limited adaptive capacity and reliance on traditional practices. Livestock systems are equally affected, with heat stress reducing animal productivity and forage availability. Furthermore, climate-sensitive pests and diseases are expanding their range, exacerbating crop and livestock losses. The strong interdependence between climate and agriculture highlights the urgent need for adaptive strategies such as resilient crop varieties, efficient irrigation, conservation agriculture, and integration of indigenous knowledge. Ensuring sustainable farming under changing climatic conditions is crucial for long-term food security and ecosystem stability. The sensitivity of agriculture can be understood in two dimensions:

1. **Slow Shifts** – gradual warming, shifting rainfall zones, and changes in soil moisture.

2. **Extreme Events** – sudden floods, flash droughts, cyclones, and landslides that cause direct losses.

These factors complicate agricultural decision-making, reduce productivity, and threaten food security.

Severity of Changes and Impacts on Agricultural Economy

Extreme Events

Extreme weather events have devastating consequences on farming systems.

- ❖ **Permanent loss of cultivated land** due to landslides and flash floods in mountainous regions.
- ❖ **Crop damage** from submergence in flood-prone states like Punjab and Bihar.
- ❖ **Destruction of infrastructure**, including irrigation systems, storage facilities, and rural markets.

Economic and Social Impacts

- ❖ Loss of employment opportunities for agricultural laborers.
- ❖ Rising input costs and reduced profitability for farmers.
- ❖ Poorly structured or ineffective crop insurance mechanisms exacerbate vulnerability.

These cumulative effects reduce the resilience of rural communities and widen socio-economic inequalities.

Challenges: Coupling Climate with Other Global Factors

The crisis of agriculture and food security cannot be attributed to climate change alone; rather, it is intensified by multiple geopolitical, economic, and social disruptions that act in combination with environmental stress. The war in Ukraine, for example, severely disrupted global grain and fertilizer supplies, leading to unprecedented spikes in food prices and making essential agricultural inputs inaccessible for many developing nations. At the same time, the COVID-19 pandemic left long-lasting impacts by disrupting labor availability, restricting food

transportation networks, and reducing household incomes. These shocks exposed the vulnerability of global supply chains and highlighted the dependence of many regions on imports for food and fertilizers. As a consequence, the number of people suffering from acute food insecurity rose sharply, from 135 million in 2019 to 345 million across 82 countries by mid-2022. The intersection of climate-induced risks with political conflicts and health crises magnifies global instability, making food systems fragile and deeply vulnerable to cascading disruptions.

Future Risks to Food and Nutrition Security

The future of global food and nutrition security is increasingly uncertain under the pressures of climate change. Among the most at-risk sectors is fruit and vegetable production, which plays a crucial role in ensuring balanced diets and preventing malnutrition. These crops are particularly sensitive to environmental stressors such as prolonged heatwaves, irregular rainfall, declining water resources, and emerging pest outbreaks. Even modest declines in production can have disproportionate effects on dietary diversity, as fruits and vegetables are vital sources of micronutrients and vitamins. In India, climate change threatens all four dimensions of food security. Availability is at risk due to declining yields of staple cereals like rice and wheat, alongside traditional crops such as millets and pulses. Accessibility is undermined by rising food prices, which disproportionately affect low-income households that already spend much of their earnings on food. Utilization is jeopardized as dietary diversity diminishes, leading to deficiencies in essential nutrients and higher risks of undernutrition. Stability, the backbone of food security, is increasingly compromised as extreme weather and unpredictable supply chains generate volatility in both local and global markets. These risks call for urgent interventions. Research and innovation must prioritize climate-resilient crop varieties, efficient water management, sustainable farming practices, and policies that enhance

nutritional outcomes. Without timely action, climate change may not only reduce food availability but also erode public health by worsening hidden hunger and malnutrition.

Research Needs

The current research in India provides strong evidence that climate change negatively affects all dimensions of food security, yet critical gaps persist that must be addressed to strengthen resilience. Globally, the Intergovernmental Panel on Climate Change (IPCC, 2023) and the Food and Agriculture Organization (FAO, 2021) emphasize that agriculture and food systems face systemic risks, but research often remains narrowly focused on yield declines and production losses. In India, similar trends are visible: most studies examine staple cereals such as rice and wheat, while traditional and underutilized crops, including millets, pulses, and indigenous landraces, receive limited attention despite their proven resilience to drought, heat, and poor soils. These crops also hold potential for ensuring dietary diversity and food security in climate-stressed regions, yet their adaptive value remains underexplored. Another major gap lies in understanding how climate change affects food utilization and nutritional stability. While productivity research is abundant, relatively few studies examine how rising temperatures, altered rainfall, or pest outbreaks affect nutrient content, dietary quality, and health outcomes. Globally, research has shown that elevated CO₂ levels may reduce protein, zinc, and iron concentrations in cereals, a concern highly relevant for India's large population dependent on plant-based diets. Additionally, indigenous knowledge systems, ranging from seed conservation and mixed cropping to water harvesting, remain undervalued in scientific discourse despite their proven role in enhancing local resilience. Addressing these gaps requires integrating global insights with local realities, ensuring that adaptation strategies safeguard not only crop yields but also biodiversity, nutrition, and cultural heritage. Expanding research in these areas will generate holistic, inclusive solutions that strengthen the long-term sustainability of India's food systems.

Adaptation Strategies for Climate-Smart Agriculture

The adapting agriculture to the realities of climate change requires a comprehensive, multi-dimensional approach that combines advances in modern science with the strengths of traditional knowledge. A key strategy involves the introduction of new crop species and varieties suited to emerging climatic conditions. In India, for example, the government has promoted the cultivation of nutri-cereals like millets, which are naturally drought- and heat-tolerant and have recently been rebranded as “superfoods” to improve nutrition and resilience. Crop rotation also plays a crucial role, as seen in the rice–wheat systems of the Indo-Gangetic Plains, where introducing legumes into rotations improves soil fertility and reduces pest cycles. Integrated Pest Management (IPM) is being applied in states like Andhra Pradesh under Community Managed Natural Farming, which emphasizes biological control and soil health restoration over synthetic chemicals. Diversification of food systems is equally vital: farmers in semi-arid regions of Rajasthan and Maharashtra are combining cereals, pulses, oilseeds, and livestock to spread risks and ensure nutritional balance.

At the core of these efforts lies Climate-Smart Agriculture (CSA), which promotes practices such as zero-tillage in Punjab and Haryana, drip irrigation in Maharashtra, and agroforestry systems in southern India that sequester carbon while diversifying farmer incomes. In the cold desert of Ladakh, traditional water-harvesting structures like ice stupas have been integrated with modern irrigation to address glacier retreat and water scarcity. Beyond technical practices, adaptation requires institutional support, including effective crop insurance schemes like the Pradhan Mantri Fasal Bima Yojana, as well as strengthened extension services and credit access for smallholders. By embedding indigenous knowledge, such as seed saving in tribal regions and community grazing systems in arid zones, within modern frameworks, India can transform climate risks into opportunities for innovation, sustainability, and improved livelihoods.

New Frontiers in Agriculture

Although climate change presents serious risks, it also opens opportunities to explore new agricultural frontiers that can enhance resilience and sustainability. One promising avenue is the expansion of C4 crops such as maize, sorghum, and millets into regions where they were previously unsuitable. These crops are more efficient in photosynthesis and water use, making them better adapted to rising temperatures and limited water availability. In India, the revival of millets, designated as “Shree Anna” during the International Year of Millets 2023, demonstrates their potential to replace water-intensive staples and address both nutrition and climate resilience. Similarly, the shift from rice cultivation, which consumes vast amounts of water, to less-thirsty crops like legumes and oilseeds offers a viable strategy, though widespread adoption requires overcoming cultural and dietary preferences deeply embedded in food habits. Another frontier lies in the popularization of rainfed landraces, including traditional varieties of rice still cultivated in dryland regions such as Uttarakhand. These landraces are often stress-tolerant, nutritionally rich, and culturally significant, yet remain undervalued in modern agricultural systems. Promoting their cultivation can reduce dependence on irrigation while preserving biodiversity. Additionally, conservation agriculture techniques, such as crop rotation, minimal or no tillage, mulching, and cover cropping, offer ways to restore soil fertility, conserve water, and reduce greenhouse gas emissions. These practices are already being piloted in parts of the Indo-Gangetic Plains, showing promise for scaling up.

Finally, the use of genetic resources in crops and livestock represents a critical frontier. Breeding programs that integrate modern biotechnology with traditional genetic diversity can develop varieties resilient to heat, drought, and pests. By harnessing these frontiers, agriculture can transform climate risks into pathways for long-term food and livelihood security.

Embedding Traditional Knowledge and Local Resources

Indigenous knowledge has sustained agricultural systems across diverse environments for centuries, offering practical, locally adapted solutions to environmental variability. Embedding

this wisdom into climate adaptation strategies can significantly strengthen resilience and sustainability. One approach is the development of crop insurance schemes that build upon traditional community-based risk-sharing practices, ensuring that farmers are better protected from crop losses due to floods, droughts, or pests. Equally important is the promotion of drought-resistant and climate-resilient varieties derived from local landraces, which are naturally adapted to harsh conditions and often maintain higher nutritional value than hybrid alternatives. Preserving the nutritional integrity of crops while introducing new varieties ensures that adaptation strategies support both food security and public health. In regions like the Himalayas, climate warming creates opportunities to expand crop cultivation to higher altitudes, where traditional crops such as barley, buckwheat, and potatoes can thrive under emerging climatic conditions. When combined with modern science, such as improved breeding techniques, conservation agriculture, and precision irrigation, these traditional ecological practices provide robust and culturally relevant pathways for adaptation. Integrating local resources and indigenous knowledge into formal agricultural planning not only enhances climate resilience but also preserves cultural heritage and biodiversity.

Policy, Institutions, and Governance

The effective adaptation to climate change in agriculture cannot be achieved without supportive policies, strong institutions, and inclusive governance mechanisms. Governments, markets, and civil society must collaborate to create an enabling environment for the widespread adoption of climate-smart practices. This includes designing policy frameworks that incentivize sustainable farming through subsidies for water-efficient irrigation, renewable energy use, and organic inputs. Financial incentives can encourage farmers to adopt practices that may initially seem risky but yield long-term resilience. Strengthening agricultural extension services is equally important to ensure that farmers especially those in remote and vulnerable regions—have access to updated knowledge, technologies, and climate information. Institutional support

must also prioritize equity in resource access, ensuring that small and marginal farmers, women, and indigenous communities are not left behind in the transition to climate-resilient systems. Governance frameworks should be well-coordinated across scales, bridging global climate commitments with national policies and local implementation. This requires effective integration of scientific research with grassroots participation, enabling policies to reflect on-the-ground realities. By aligning policies, markets, and institutions, governance can transform climate challenges into opportunities for innovation, resilience, and sustainable agricultural growth.

Conclusion

Climate change has already begun to profoundly reshape agriculture and food systems, posing unprecedented risks to global and regional food security. Rising temperatures, erratic rainfall, and extreme weather events are disrupting crop yields, increasing production costs, and threatening the stability of food supply chains. These disruptions not only lead to higher food prices but also deepen nutritional insecurity, disproportionately affecting vulnerable populations such as smallholder farmers, women, and low-income households. Socio-economic consequences, including unemployment, migration, and widening inequalities, further underscore the urgency of addressing these challenges. Yet, climate change also offers an opportunity to reimagine and redesign agricultural systems for long-term sustainability. Through a combination of innovative technologies, such as climate-resilient crop varieties and precision irrigation, alongside conservation agriculture practices like crop rotation and no-tillage, farming systems can become more resilient. At the same time, policy support and institutional frameworks must ensure equitable access to resources, financial tools, and knowledge, while embedding traditional ecological knowledge into modern strategies. Future pathways must prioritize adaptive capacity, biodiversity conservation, and inclusivity. By placing sustainability at the core of agriculture, humanity can transform risks into opportunities, ensuring resilient livelihoods and secure food systems for generations to come.



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Himalayan Popular Lecture: Ladakh Series

1st Lecture: Impact of Climate Change on India's Trans Himalayan Region

(2020) by Shri C. Phunsog, IAS-Retd. (*Vice Chancellor, University of Ladakh*)

2nd Lecture: Water: Pollution and Remediation (2021) by *Prof. S.K. Mehta (Vice*

Chancellor, University of Ladakh)

3rd Lecture: Medicinal Plants Biodiversity of Cold Arid Ladakh Himalaya (2022)

by Dr. *O.P. Chaurasia (Director DRDO-DIHAR, Leh)*

4th Lecture: Exploring the Marvels of Himalaya and Shaping the Future

Environmental Research (2023) by *Shri Jigmet Takpa, IFS (Principal Chief*

Conservator of Forest (Retd.), Ladakh)

5th Lecture: Climate Change and Water Issues in Ladakh (2024) by Sri Sonam

Lotus (*Scientist E & Head, Met Centre Leh (IMD), Leh, Ladakh*)



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Objectives

- ❖ To promote alternative livelihoods for climate change vulnerable cold desert communities.
- ❖ To facilitate conservation of critical/ important cold desert habitats and biodiversity
- ❖ To strengthen and establish approaches for addressing issues of water scarcity.
- ❖ To foster climate smart communities in the trans-Himalayan landscape.

Our Mission

- ❖ Science for society,
- ❖ Networks and collaborations
- ❖ Promotion of successful models,
- ❖ Private sector engagement,
- ❖ Harness energies of local young
- ❖ Promoting use of sustainable technology