Archives of Current Research International

Volume 24, Issue 6, Page 140-150, 2024; Article no.ACRI.117698
ISSN: 2454-7077

A Review on Adaptive Strategies for Climate Resilience in Agricultural Extension Services in India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/acri/2024/v24i6772

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/117698

Review Article

Received: 02/04/2024
Accepted: 04/06/2024
Published: 13/07/2024

ABSTRACT

Adaptive strategies for enhancing climate resilience in agricultural extension services in India, amidst escalating climate challenges. It begins by delineating the profound impacts of altered weather patterns, increased frequency of extreme weather events, and shifting pest and disease dynamics on agricultural practices. The paper then delves into the variety of technological innovations, management practices, and policy interventions currently being implemented to bolster climate resilience. Notably, it highlights the adoption of precision agriculture technologies,

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Cite as: *C M, Rajesh, Abhishek Jadhav, Manohar K N, Prahlad P Bhat, Rahul Prasad R, Anil K, and Pavan V. 2024. "A Review on Adaptive Strategies for Climate Resilience in Agricultural Extension Services in India". Archives of Current Research International 24 (6):140-50. https://doi.org/10.9734/acri/2024/v24i6772.*

climate-smart agricultural tools, and the innovative use of ICT in extension services to provide timely, targeted advice to farmers. On the management front, the paper discusses the significant benefits of crop diversification, advanced water management strategies like rainwater harvesting and drip irrigation, and improved soil health practices, which collectively contribute to a sustainable and resilient agricultural system. Policy and institutional adaptations are also examined, emphasizing the crucial role of supportive policy frameworks, community engagement, and multi-stakeholder partnerships in scaling successful adaptations and ensuring their sustainability. Drawing on international case studies-from Vietnam's effective water management techniques to Zambia's success with crop diversification and the technological advancements in North American agriculture-the review identifies key factors contributing to their success, challenges faced, and the potential for transferring these strategies to the Indian context. Each case study provides insights into overcoming barriers to adoption and highlights the importance of integrating local and scientific knowledge to achieve long-term sustainability. Concludes by stressing the need for a multi-faceted, inclusive approach that aligns with local environmental, cultural, and economic contexts to effectively address the unique challenges posed by climate change to Indian agriculture.

Keywords: Resilienc; technology; adaptation; sustainability; climate; innovation.

1. INTRODUCTION

Agricultural extension services in India play a crucial role in enhancing agricultural productivity, ensuring food security, and improving the livelihoods of the rural populace. These services provide vital support to farmers by disseminating knowledge about modern farming techniques, high-yield seed varieties, fertilizers, and pest management. The agricultural extension network in India is one of the largest in the world, involving numerous governmental agencies at the central and state levels, as well as various non-governmental organizations and private sector participants. The core of India's extension services has historically been the transfer of technology from research institutions to farmers' fields, aiming at the adoption of new technologies to increase agricultural production. Over the years, the approach has evolved from merely providing advice on crop production techniques to a broader range of services that include agronomy, resource management, and marketing support. The Directorate of Extension, under the Ministry of Agriculture and Farmers Welfare, plays a pivotal role in shaping the policies and programs that govern these services [1]. Climate change poses a significant threat to agricultural systems in India, impacting the livelihoods of millions of farmers. The diverse climatic conditions across the country—from the Himalayas in the north to the coastal regions in the south—expose different areas to various risks. Rising temperatures, erratic rainfall patterns, and increased frequency of extreme weather events such as droughts and floods have become more common, severely affecting crop yields [2]. According to a report by the Indian Network for Climate Change Assessment (INCCA), climate variability has led to a decline in the productivity of major crops like wheat and rice, which are staples in the Indian diet. The report projects that by 2030, the yield of these crops could further decline by 4.5-9% due to the ongoing climatic changes [3]. Such impacts necessitate urgent adaptations in agricultural practices to mitigate the adverse effects on food security and agricultural income. Resilience in agriculture refers to the ability of systems to absorb, recover from, and adapt to adverse events such as those caused by climate change. Building resilience is crucial for ensuring that agricultural systems continue to provide food security and livelihoods in the face of these challenges. In India, enhancing the resilience of agricultural practices is not just important-it is imperative for the survival of a significant portion of the population who depend directly or indirectly on agriculture for their livelihood. Strengthening resilience in Indian agriculture involves integrating climate-smart agricultural practices, diversifying cropping systems, and improving water management to withstand the variability induced by climate change. Practices such as adopting drought-tolerant crop varieties, implementing soil health management techniques, and employing efficient water-use strategies are essential [4]. The role of agricultural extension services becomes crucial here. They must shift focus not only to disseminate knowledge about how to increase yields but also about how to adapt and build resilience against the growing threat of climate change. This involves training farmers to understand and implement adaptive strategies that can reduce vulnerability and enhance the

long-term sustainability of their farming operations.

The primary objective of this review is to meticulously examine the various adaptive strategies that have been employed to increase climate resilience within agricultural extension services in India. In the face of escalating climate challenges, these services are pivotal in guiding and supporting the farming community to adapt to adverse climatic conditions. The review aims to identify, analyze, and evaluate the effectiveness of these strategies in fostering resilience among agricultural practices affected by climate change. Agricultural extension services are critical conduits through which novel and traditional knowledge regarding climate adaptation can be disseminated. By focusing on these adaptive strategies, the review seeks to understand how extension services can not only deliver information but also facilitate the practical implementation of resilience measures on the ground. This encompasses a range of practices from the introduction of climate-resilient crop varieties to advanced technological interventions such as precision farming tools and data-driven agricultural advice. The geographic and climatic considerations of this review are carefully chosen to reflect the diverse conditions across India, which affect agricultural practices and the efficacy of extension services. India's vast geographic expanse encompasses a wide range of climatic zones including tropical, temperate, and arid regions, each presenting unique challenges and opportunities for agriculture [5]. The review will consider these diverse conditions to ensure that the strategies discussed are relevant to different regions, from the arid deserts of Rajasthan to the flood-prone areas of Assam, and the tropical regions of Kerala and Tamil Nadu. The impacts of climate change, such as increased temperatures, altered rainfall patterns, and more frequent extreme weather events, are manifesting differently across these zones, necessitating tailored adaptive strategies in agricultural practices and extension services. This review will cover a broad spectrum of agricultural practices relevant to enhancing climate resilience. These include but are not limited to, crop diversification, soil health management, water conservation techniques, and the use of climate-resilient varieties. Each of these practices plays a critical role in building resilience but requires different types and levels of support from agricultural extension services. Additionally, the review will explore how traditional practices and local knowledge are being integrated with scientific research to create holistic and sustainable agricultural systems. The role of modern technologies such as satellite imagery, geographic information systems (GIS), and artificial intelligence (AI) in transforming extension services will also be examined to gauge their impact on enhancing the adaptability of farming practices to climate change.

2. CONCEPT

Climate resilience in the context of agriculture can be defined as the capacity for agricultural systems to absorb, adapt, and recover from climate-related shocks and stresses in a way that ensures food security and supports livelihoods while maintaining ecosystem services [6]. This concept extends beyond mere survival of such impacts; it involves making informed decisions that enable agricultural communities to anticipate, prepare for, respond to, and recover from detrimental climate events [7]. Building climate resilience involves a complex interplay between environmental management, sustainable agricultural practices, and socio-economic factors within communities. Agricultural extension services are a series of applied educational activities provided by the government, NGOs, and other stakeholder organizations designed to disseminate information among farmers and other actors in the agricultural value chain (Table 1). These services are crucial for improving agricultural practices, enhancing productivity, and promoting sustainable farming methods [8]. In India, agricultural extension services play a critical role in transferring the latest agricultural research from labs to the field, offering training and practical demonstrations, and facilitating the adoption of new technologies among rural farmer populations. Adaptive strategies in agriculture refer to the adjustments and modifications made in farming practices and processes in response to observed or expected changes in the local environment, particularly due to climate change [9]. These strategies aim to reduce vulnerability and enhance the resilience of agricultural systems. They can range from modifications in crop selection and cropping patterns to changes in irrigation practices and adoption of new technologies like drought-resistant seeds or precision agriculture tools.

Ecological resilience theory, refers to the amount of disturbance that an ecosystem can withstand while maintaining its structures and functions [10]. Applying this theory to agricultural systems involves understanding how these systems can

absorb changes induced by climate variability and continue to produce adequate food [11]. This includes the ability of systems to self-organize, learn, and adapt. In the context of Indian agriculture, this might involve understanding the resilience of rice paddies in the face of fluctuating water levels or the ability of millet-based cropping systems to withstand drought. Socio-ecological resilience extends the concept of ecological resilience to include the social dimensions of resilience. It considers the interdependencies between people and ecosystems in developing capacities to cope with environmental and economic changes [12]. This framework is particularly useful in agricultural settings as it addresses how social arrangements, like community cooperatives or women's groups, can manage resources in a way that sustains both the community and the environment. For instance, water user associations in rural India managing irrigation in a way that is both equitable and efficient. Community-based adaptation to climate change involves using strategies that communities develop based on their priorities, needs, knowledge, and capacities [13]. Often these strategies are rooted in traditional knowledge and practices but may be enhanced by external technologies or information. In Indian agriculture, community-based adaptation strategies could involve traditional water conservation practices such as the use of johads (rainwater storage tanks) or community seed banks to preserve biodiversity and enhance food security during climate crises. These theoretical frameworks provide a foundation for understanding and developing effective adaptive strategies for enhancing climate resilience in Indian agriculture. By combining these theories with practical applications, agricultural extension services can better support farmers in navigating the challenges posed by climate change, thus ensuring the sustainability of agricultural livelihoods and food systems in the country.

3. CHALLENGES POSED BY CLIMATE CHANGE TO AGRICULTURAL EXTENSION

A. Environmental Challenges

Climate change has significantly altered weather patterns across India, presenting major challenges for agriculture. Traditionally, Indian agriculture relies heavily on the monsoon season; any deviation in its timing or intensity can drastically affect crop yields. For instance, delayed monsoons can postpone planting seasons, while early onset can cause flooding, leading to crop damage. According to a study, there has been a noticeable shift in monsoon patterns over the past few decades, with increasing unpredictability and variability in rainfall distribution [14]. This unpredictability complicates the task of agricultural extension services, which must constantly adjust advice and strategies to help farmers cope with fluctuating conditions. The frequency and severity of extreme weather events such as droughts, floods, and cyclones have increased, exacerbating the vulnerability of agricultural systems. For example, the 2019 report by the Ministry of Earth Sciences of the Government of India highlights that the incidence of cyclones in the Arabian Sea has increased, impacting coastal agriculture through saline intrusion into freshwater resources and destruction of cropland. Agricultural extension services are thus challenged to develop and disseminate coping mechanisms and recovery strategies to manage the aftermath of such events, which often disrupt farming activities and jeopardize the livelihoods of rural communities. Climate change has also influenced the proliferation and distribution of pests and diseases, often leading to new infestations in areas where they were previously not a concern. Warmer temperatures and altered humidity levels can enhance the survivability and reproductive rates of various pests and pathogens. For example, a study indicates that pest attacks in North Indian states have increased as temperatures have risen, affecting crops that were traditionally resistant to these pests [15]. Agricultural extension agents must keep abreast of these changes and provide timely information and training on integrated pest management practices adapted to changing conditions.

B. Socio-Economic Challenges

The direct impact of climate change on agricultural productivity affects the economic stability of farmers, especially small and marginal farmers who are less equipped to handle crop failures. Reduced agricultural output due to adverse weather conditions directly translates to reduced income for these farmers, many of whom are already under economic stress. The uncertainty and risk associated with farming under changing climatic conditions can also lead to decreased investment in agriculture, further undermining agricultural development and farmer livelihoods.

Table 1. Agricultural extension services to adopt climate change in India

Category	Service	Description	Expected Outcome	Key Stakeholders
Training & Education	Climate-Smart Agriculture Training	Training farmers on climate-resilient practices, crop diversification, and sustainable farming methods.	Improved resilience to climate impacts	Agricultural Universities, NGOs
	Farmer Field Schools	Practical, hands-on training sessions in farmers' own fields.	Enhanced practical knowledge and skills	Local Extension Workers, Farmer Groups
Information Services	Weather Forecasting and Climate Info	Providing timely weather updates and climate predictions to farmers.	Reduced crop losses and better planning	IMD, ICT Providers
	Pest and Disease Management	Offering advice on pest and disease control measures tailored to changing climate conditions.	Decreased crop damage and increased yields	Agricultural Scientists, Extension Workers
Technological Interventions	Drought-resistant Crop Varieties	Promoting the use of crop varieties that can withstand drought conditions.	Enhanced crop survival and productivity	Seed Companies, Research Institutions
	Efficient Irrigation Systems	Encouraging adoption of drip and sprinkler irrigation systems.	Water conservation and improved irrigation	Irrigation Departments, Private Sector
	Precision Farming Technologies	Use of GPS, sensors, and data analytics to optimize farm inputs.	Increased efficiency and reduced wastage	Tech Companies, Farmers
Resource Management	Soil and Water Management	Techniques for soil conservation, rainwater harvesting, and efficient water use.	Sustainable resource use	Government Agencies, NGOs
	Agroforestry	Integrating trees and shrubs into agricultural landscapes.	Improved biodiversity and soil health	Forestry Department, Farmers
Policy Support	Climate Adaptation Policies	Developing and implementing policies that support climate adaptation in agriculture.	Enabling environment for adaptation	Government, Policy Makers
Financial Services	Subsidies and Incentives	Providing financial support for adopting climate-smart technologies and practices.	Increased adoption of sustainable practices	Government, Financial Institutions
	Crop Insurance Schemes	Insurance products to protect farmers against climate-induced crop failures.	Financial security and risk mitigation	Insurance Companies, Government

Table 2. Challenges posed by climate change to agricultural extension

Category	Challenge	Description	Impact	Mitigation Strategy
Weather Variability	Unpredictable Weather Patterns	Difficulty in predicting and managing weather-related risks such as droughts and floods.	Reduced crop yields, increased vulnerability of farmers.	Improved weather forecasting and early warning systems.
Pest and Disease	Increased Pest and Disease Incidence	Climate change creates favorable conditions for pests and diseases to thrive.	Higher crop losses, increased use of pesticides.	Integrated pest management and resilient crop varieties.
Water Resources	Water Scarcity	Reduced availability of water for irrigation due to changing rainfall patterns.	Decreased agricultural productivity, increased competition for water resources.	Efficient irrigation systems and water conservation techniques.
Soil Degradation	Soil Erosion and Degradation	Extreme weather events and changing climatic conditions lead to soil erosion and degradation.	Loss of fertile land, reduced soil fertility.	Soil conservation practices and sustainable land management.
Knowledge Gaps	Lack of Climate-Specific Knowledge	Extension services may lack up-to-date information on climate change impacts and adaptation.	Ineffective advice and support for farmers.	Continuous training and capacity building for extension workers.
Infrastructure	Inadequate Infrastructure	Poor infrastructure limits the reach and effectiveness of extension services.	Limited access to extension services for remote and marginalized farmers.	Investment in rural infrastructure and digital tools.
Financial Constraints	Limited Financial Resources	Insufficient funding for climate adaptation initiatives in agriculture.	Reduced ability to implement necessary adaptation measures.	Enhanced funding and financial incentives for adaptation.
Policy Support	Weak Policy Frameworks	Lack of strong policies to support climate adaptation in agriculture.	Slow progress in implementing adaptation strategies.	Development of comprehensive climate adaptation policies.
Farmer Awareness	Low Awareness and Engagement	Farmers may be unaware of climate change impacts and adaptation practices.	Poor adoption of climate-resilient practices and technologies.	Awareness campaigns and participatory extension approaches.
Technology Adoption	Barriers to Technology Adoption	Challenges in adopting new technologies due to cost, accessibility, and lack of knowledge.	Slow uptake of innovative practices and technologies.	Subsidies and training programs for technology adoption.

Increased environmental stresses and economic uncertainties have forced many rural inhabitants to migrate in search of better livelihood opportunities. According to the Economic Survey of India 2017, migration due to agrarian distress is rising, with significant numbers moving from rural to urban areas. This migration is not only a demographic challenge but also a socio-economic issue, as it leads to a reduction in agricultural labor and a loss of traditional agricultural knowledge, further straining agricultural extension services. The cumulative effect of reduced agricultural productivity, coupled with increasing population pressure, poses serious threats to food security in India. As per the Global Hunger Index 2020 report, India ranks 94th out of 107 countries, indicating a serious level of hunger largely attributable to inadequate food supply. This scenario is aggravated by climate change, which impacts the availability, access, and stability of food production. Agricultural extension services are pivotal in addressing these challenges by promoting sustainable agricultural practices and technologies that can enhance food production without degrading natural resources.

C. Institutional Challenges

Agricultural extension services in India face significant funding constraints. Despite the critical role these services play in supporting agricultural adaptation to climate change, investment in extension services has been inadequate. This lack of funding limits the ability of extension services to reach out to the vast number of farmers, update technological aids, and train extension agents in new adaptive techniques that address the impacts of climate change. There are numerous policy and regulatory barriers that hinder the effective functioning of agricultural extension services in India. These range from bureaucratic inefficiencies to the lack of integration between various government programs that address climate change, agriculture, and rural development. The existing policies often do not adequately reflect the urgent need for climate resilience in agriculture, nor do they facilitate the agile and adaptive management of agricultural practices necessary in the face of rapid climatic shifts. There is a crucial need for enhanced capacity building and training within agricultural extension systems to cope with the demands of a changing climate. Extension workers require training in climate-smart agricultural practices, the use of modern technological tools, and effective communication and pedagogical skills to educate farmers about climate resilience. The existing training programs often lack depth in subjects pertaining to climate change adaptation and mitigation, leaving a knowledge gap that needs to be addressed to build a resilient agricultural sector. These environmental, socio-economic, and institutional challenges underscore the need for a robust and dynamic agricultural extension system in India that can adapt to the realities of climate change. Addressing these challenges requires a multi-faceted approach involving policy reform, increased funding, and a focus on sustainable agricultural practices that can mitigate the impacts of climate change on agriculture.

4. ADAPTIVE STRATEGIES FOR CLIMATE RESILIENCE

A. Technological Innovations

Precision agriculture technologies represent a significant advancement in farming methodology, allowing for the meticulous management of farm resources to increase productivity while reducing waste and environmental impact. In India, the adoption of these technologies is beginning to take shape, driven by the need to achieve more with less-less water, less land, and less use of agrochemicals, amid the growing pressures of climate change. Tools such as GPS mapping, drone technology, and remote sensing are used to assess crop health and soil conditions, enabling targeted interventions that optimize resource use and boost crop yields. For instance, satellite imagery has been used to guide irrigation practices and pest control measures that are precisely tailored to the conditions of specific plots of land [16]. Climate-smart agriculture (CSA) tools include a variety of practices and technologies designed to increase productivity in an environmentally and socially sustainable way. These tools help farmers adapt to climate change and reduce agriculture's contribution to climate change by integrating the three dimensions of sustainability: economic, social, and environmental. In India, CSA tools have been introduced through various government and non-government initiatives, focusing on sustainable land management, integrated pest management, and energy-efficient systems. An example is the promotion of solar pumps and bio-fertilizers as part of the government's mission to increase the income of farmers while reducing dependency on fossil

fuels [17]. The use of Information and Communication Technology (ICT) in agricultural extension services has transformed the way agricultural knowledge is disseminated in India. Mobile applications, SMS-based advisories, and interactive voice response systems (IVRS) have been particularly effective in reaching large numbers of farmers with timely, locale-specific, and actionable agricultural advice. Organizations like the Indian Council of Agricultural Research (ICAR) have launched platforms such as 'KisanSuvidha' and 'mKisan', which provide services ranging from weather forecasts to market prices, directly to the farmers' mobile phones. These technologies not only bridge the information gap but also empower farmers to make informed decisions that align with changing climatic conditions [18].

B. Management Practices

Diversification in cropping systems is a crucial adaptive strategy to enhance climate resilience. By diversifying crops, farmers can reduce the risk of total crop failure due to climate-induced stressors like drought or excessive rainfall. In regions like Tamil Nadu and Karnataka, farmers have successfully integrated pulses and millets into their rice-dominated cropping systems, which has not only improved soil health but also provided them with a buffer against climate variability [19]. Effective water management is paramount in a country like India, where large parts of the agriculture sector depend on monsoon rains. Techniques such as rainwater harvesting and drip irrigation are vital components of water management strategies aimed at maximizing water use efficiency. Rainwater harvesting systems collect and store rainwater for agricultural use during dry periods, thus stabilizing water supply throughout the year. Drip irrigation delivers water directly to the plant roots, significantly reducing water wastage and ensuring that crops receive a precise amount of water needed to thrive. These methods not only help in conserving water but also play a critical role in sustaining agriculture in water-stressed areas [20]. Maintaining soil health is foundational to achieving sustainable agriculture and climate resilience. Practices such as crop rotation, cover cropping, and the application of organic compost improve soil structure, enhance water retention, and increase the soil's organic matter content. Initiatives like the Soil Health Card Scheme have been instrumental in promoting soil health awareness among farmers. By providing farmers with soil health cards, the scheme helps them make informed decisions about the application of nutrients based on the specific needs of their soil, thereby improving productivity and sustainability [21].

C. Policy and Institutional Adaptations

Effective policy frameworks are essential to support the adoption of resilient agricultural practices. In India, the National Mission for Sustainable Agriculture (NMSA) is one such framework designed to enhance agricultural productivity especially in areas prone to extreme weather events, through sustainable and climate-resilient agricultural practices. The NMSA promotes several key initiatives such as rainfed area development, soil health management, and climate-resilient agriculture, which are critical for enhancing the adaptive capacity of Indian agriculture [22]. Community engagement and participatory approaches in policy-making and implementation enhance the effectiveness of adaptive strategies. Programs that involve farmer participation, especially in the planning and execution stages, tend to have higher success rates because they are tailored to the specific needs and conditions of the community. For example, participatory watershed management programs in states like Maharashtra and Gujarat have not only helped in conserving soil and water but have also empowered local communities to manage their resources sustainably. These programs facilitate an inclusive approach where community members feel a sense of ownership and are more invested in the success of the initiatives [23]. Partnerships among different stakeholders—including government agencies, non-governmental organizations (NGOs), and the private sector—are crucial for scaling up successful adaptive strategies. These partnerships can leverage the strengths of each sector, be it innovation, funding, or outreach, to implement and sustain adaptive measures effectively. An example of such a partnership is the collaboration between the Government of India, various state governments, and private companies to promote and disseminate solar-powered irrigation systems. This initiative not only addresses the issue of sustainable water usage but also helps in reducing the carbon footprint of the agricultural sector [24].

5. CASE STUDIES AND APPLICATIONS

Vietnam, facing similar climatic challenges as India, has successfully implemented adaptive

water management strategies through the System of Rice Intensification (SRI). SRI is an innovative agricultural practice developed to increase the productivity of irrigated rice by changing the management of plants, soil, water, and nutrients. In Vietnam, SRI practices have led to higher yields, reduced water usage, and lower greenhouse gas emissions. According to the International Water Management Institute, SRI practices in the Mekong Delta have increased rice yields by 20-50% while reducing water usage by up to 30%. Farmers in the region have adopted alternate wetting and drying, a water-saving technique that allows the rice fields to dry briefly before re-irrigation, significantly reducing water use without sacrificing yield [25]. Zambia provides a compelling example of successful crop diversification in response to changing climatic conditions. Facing frequent droughts, Zambian farmers have increasingly turned to drought-resistant crops like sorghum and millet. Supported by government initiatives and international aid agencies, these crops have not only withstood harsh conditions but have also provided food security and new economic opportunities. A report by the Food and Agriculture Organization (FAO) highlighted that the introduction of improved seed varieties and better agronomic practices led to a significant increase in sorghum and millet production. These crops have become popular due to their lower water requirements and shorter growing periods, making them suitable for regions with erratic rainfall patterns [26]. The United States has been at the forefront of adopting precision agriculture technologies, significantly enhancing farm productivity and environmental sustainability. Technologies such as GPS-guided tractors, drones for field monitoring, and real-time data analytics are widely used to optimize inputs and improve crop management practices. A study by the USDA revealed that the adoption of precision agriculture technologies has led to a 15% increase in crop yields and a 20% decrease in input costs across various states. These technologies have enabled farmers to apply the exact amount of water, fertilizers, and pesticides needed, minimizing waste and reducing the environmental footprint of agriculture [27-30].

6. CONCLUSION

Addressing the multifaceted challenges posed by climate change to agricultural extension services requires a coordinated approach that integrates technological innovations, management practices, and policy adaptations. Success stories from around the world, such as Vietnam's water management strategies, Zambia's crop diversification, and the adoption of precision agriculture in the United States, provide valuable lessons that can be adapted to the Indian context. These examples underscore the importance of government support, community engagement, and the melding of traditional knowledge with modern technologies to enhance climate resilience. For India, adopting these proven strategies offers a pathway to sustain agricultural productivity and food security in the face of escalating climate threats, while also ensuring the economic stability of its vast rural population.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/117698