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A Review on Evaluation of the Effectiveness of Agricultural Extension Services in Adapting to Climate Change among Subsistence Farmers

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

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ABSTRACT

The effectiveness of agricultural extension services in facilitating climate change adaptation among subsistence farmers, assessing their impact on agricultural productivity and sustainability. Agricultural extension services are pivotal for disseminating knowledge and innovative practices among farmers, essential for adjusting to and mitigating the impacts of climate change. The review highlights several successful regional interventions, such as the adoption of drought-resistant crops

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and water-efficient technologies, and provides a comparative analysis of various approaches to illustrate differing regional needs and outcomes. Despite these successes, significant challenges remain. Resource constraints, both financial and human, severely limit the reach and effectiveness of these services. Socio-cultural factors, including resistance to change and gender disparities, further inhibit the adoption of new practices. Additionally, policy and institutional barriers, such as inadequate frameworks and poor stakeholder coordination, complicate the effective delivery of services. To address these issues, the review suggests tailored, location-specific solutions that consider local climate threats and cultural practices, and calls for an increase in the capacity of extension agents through enhanced training and resources. Policy recommendations focus on strengthening support mechanisms for subsistence farmers and refining policy interventions to better support extension frameworks. The review identifies significant research gaps, particularly in the integration of traditional knowledge with modern techniques and the long-term impacts of extension services, which require further exploration to develop more effective adaptation strategies. Overall, while agricultural extension services have made notable strides in assisting farmers to adapt to climate change, substantial improvements and sustained efforts are needed to fully realize their potential in securing India's agricultural productivity against the backdrop of an increasingly unpredictable climate.

Keywords: Climate; adaptation; sustainability; innovation; farmers.

1. INTRODUCTION

Agriculture represents a crucial sector in the global economy, contributing significantly to the gross domestic product (GDP) of many developing countries and providing the primary means of livelihood for over 60% of India's population [1]. The importance of agriculture extends beyond economic metrics, deeply intertwined with the socio-cultural fabric of rural communities. Subsistence farming, where farmers grow food primarily for consumption by their household rather than for sale, forms the backbone of Indian agriculture. These farmers rely heavily on the natural environment, with minimal use of modern farming techniques or inputs such as fertilizers and pesticides, which makes them highly vulnerable to changes in their surroundings. Climate change poses severe risks to agriculture through increased temperatures, erratic rainfall, and more frequent extreme weather events like droughts and floods (Table1). For India, these changes are not just predictions but current realities. The Indian Network for Climate Change Assessment (INCCA) report notes significant impacts such as a marked shift in rainfall patterns and an increase in average temperatures, which could reduce wheat production by up to 6% even with moderate changes in the climate scenario [2]. These shifts threaten the productivity of Indian agriculture, particularly impacting subsistence farmers who lack the resilience and resources to adapt effectively.

Table 1. Climate change impacts on agriculture

Aspect	Description	Impact on Agriculture	Mitigation Strategies
Temperature Changes	Increase in global temperatures leading to altered growing seasons	Reduced crop yields, heat stress on livestock, increased evaporation rates	Development of heat-tolerant crop varieties, improved irrigation practices
Precipitation Patterns	Changes in rainfall distribution, intensity, and frequency	Water scarcity, altered soil moisture levels, increased risk of floods and droughts	Efficient water management, rainwater harvesting, drought-resistant crops
Extreme Weather Events	Increased frequency and severity of storms, hurricanes, and extreme weather events	Crop damage, soil erosion, loss of livestock, disruption of supply chains	Disaster preparedness, resilient infrastructure, crop insurance schemes
CO_2 Concentration	Higher atmospheric CO_2 levels influencing photosynthesis and plant growth	Initially may enhance growth in some crops, but long-term impacts are uncertain, nutrient imbalances	Carbon sequestration, reduction of greenhouse gas emissions, sustainable farming practices
Pest and Disease	Changes in pest and disease prevalence and	Increased crop losses, higher pesticide usage,	Integrated pest management, biological

Aspect	Description	Impact on Agriculture	Mitigation Strategies
Dynamics	distribution due to altered climates	spread of new pests and diseases	control methods, regular monitoring and early detection systems
Soil Health	Impacts on soil fertility, structure, and erosion rates	Decline in soil quality, nutrient depletion, reduced agricultural productivity	Conservation tillage, organic farming practices, soil restoration techniques
Water Resources	Variability in water availability for irrigation due to changing precipitation and melting glaciers	Reduced irrigation potential, competition for water resources, increased costs of water management	Efficient irrigation systems, watershed management, desalination projects
Crop Yield and Quality	Direct and indirect effects on crop growth stages, maturity, and nutrient content	Decline in yields of staple crops, reduced nutritional quality of produce	Genetic modification for resilience, crop diversification, advanced breeding techniques
Livestock Production	Heat stress on animals, changes in forage availability, and altered disease patterns	Reduced productivity, increased mortality rates, decreased milk and meat quality	Climate-controlled housing, selective breeding for heat tolerance, improved feeding practices
Socio-Economic Impacts	Effects on farmers' livelihoods, food security, and rural economies	Increased vulnerability of smallholder farmers, higher food prices, greater economic instability	Policy support, financial aid programs, education and training for climate-resilient practices
Biodiversity	Loss of species diversity and ecosystem services due to habitat changes	Disruption of pollination, natural pest control, and other ecosystem services essential for agriculture	Conservation efforts, habitat restoration, promotion of agro-biodiversity
Technological Innovations	Role of technology in adapting to and mitigating climate impacts	Adoption of precision agriculture, climate-smart technologies, and data-driven decision-making	Investment in research and development, extension services, technology transfer programs
Policy and Governance	Implementation of policies and frameworks to address climate impacts on agriculture	Creation of supportive policies, funding for adaptation measures, enforcement of regulations	International cooperation, multi-stakeholder engagement, policy alignment with climate goals

(Source: Makondo and Thomas [2])

1.1 Role of Agricultural Extension Services

Agricultural extension services play a pivotal role in supporting farmers, especially in developing countries like India. These services aim to improve agricultural productivity, increase food security, reduce poverty, and encourage sustainable agricultural practices. In the context of climate change, extension services are critical in helping farmers adapt by providing information and access to new technologies and practices. These can include climate-smart agricultural techniques such as drought-resistant crops, improved irrigation practices, and forecasting services to better prepare for weather-related anomalies [3]. Subsistence farmers in India face unique challenges due to climate change. Primarily, their dependence on rainfall makes them extraordinarily vulnerable to monsoon variability. The erratic monsoon patterns, coupled with an increase in the frequency of extreme weather events, directly threaten their crop yields and water availability. Moreover, subsistence farmers often operate on marginal lands, which are more susceptible to soil degradation, further exacerbated by climate impacts [4]. These challenges are compounded by the lack of formal education among farmers, limiting their ability to access or implement adaptation strategies without assistance. While agricultural extension services are meant to bridge the gap between research and practice, there are significant inadequacies in their current strategies, especially concerning climate change adaptation. One major issue is the 'top-down' approach prevalent in these services, where the specific local needs and conditions of farmers are often overlooked [5]. Extension services in India are plagued by limited resources, both in terms of personnel and financial support. The ratio of extension workers to farms is far below what is needed for effective coverage, particularly in remote and rural areas [6]. The existing

extension programs also lack a specialized focus on climate adaptation needs. Generic agricultural improvements are often promoted without consideration of climate-specific demands such as heat-tolerant crop varieties or water-conserving irrigation technologies. Furthermore, there is a notable disconnect in the communication channels between the researchers who develop adaptations and the extension agents who are supposed to disseminate them. This gap ensures that even available innovations reach a minimal number of affected farmers [7].

The overarching objectives of this review are designed to assess the landscape of agricultural extension services in India with a specific focus on their effectiveness in supporting subsistence farmers' adaptation to climate change. This assessment aims to enhance understanding and foster the development of more robust systems capable of addressing the unique challenges posed by the changing climate. The primary objective of this review is to evaluate the effectiveness of agricultural extension services in aiding climate adaptation among subsistence farmers in India. This involves analyzing how these services have integrated climate-smart agriculture practices into their outreach and whether these integrations have translated into practical farmer resilience against climate variability. Effectiveness will be measured based on several indicators including the uptake of recommended practices, improvement in crop yields, enhancement in water use efficiency, and overall increase in farmer knowledge about climate change and its impacts. This review also aims to identify the best practices within the existing extension frameworks that have successfully contributed to climate adaptation. Identifying these practices will involve looking at case studies where extension services have led to measurable improvements in farmer resilience to climate impacts. Concurrently, the review will identify gaps in current approaches, particularly areas where extension services have failed to meet the needs of subsistence farmers, or where improvements could enhance service delivery. This includes analyzing constraints related to resources, training, and the integration of traditional knowledge with modern scientific understanding.

The methodology for this review combines systematic approaches to literature review with meta-analysis, aimed at providing a comprehensive overview of the current status of agricultural extension services, especially in the context of climate change adaptation. The selection of studies for this review is guided by several criteria to ensure relevance, credibility, and comprehensiveness: Geographical Focus: Only studies that focus on India are considered, given the specific climatic, cultural, and socio-economic contexts that affect agricultural practices and outcomes in Indian subsistence farming. Time Frame: Studies published within the last 15 years are prioritized to ensure the review reflects current challenges and solutions in agricultural extension services related to climate change. Peer-Reviewed: Preference is given to peer-reviewed articles, government reports, and publications from reputable agricultural research institutions. This criterion ensures that the information is credible and the methodologies used in the studies are sound. Relevance to Climate Change Adaptation: The studies must specifically address aspects of climate change adaptation, whether through the development of climate-resilient farming practices, training programs, or policy implementation related to agricultural extension services. Impact Assessment: Studies that include data on the outcomes or effectiveness of extension services in terms of farmer adaptation to climate change are particularly sought. This includes quantitative measures of success such as yield improvements, economic benefits, or qualitative assessments such as farmer satisfaction and knowledge enhancement.

Data extraction from the selected studies is structured around several key components to ensure a comprehensive synthesis of available information: Study Details: Extracting basic information such as author(s), year of publication, study location, and study design. Key Findings: Focusing on the results related to the effectiveness of extension services in promoting climate adaptation practices. Methodologies Used: Analyzing the methodologies employed in the studies to assess their rigor and suitability for evaluating extension services. Challenges Identified: Gathering insights on the challenges or barriers noted in the implementation of effective extension strategies. Recommendations: Collating proposed solutions or recommendations from the studies to improve the delivery and effectiveness of extension services.

2. CLIMATE CHANGE AND ITS IMPACT ON AGRICULTURE

Climate change refers to significant changes in the patterns of temperature, precipitation, and winds that occur over several decades or longer. Scientific consensus indicates that climate change is driven primarily by human activities, especially the burning of fossil fuels, which increases concentrations of greenhouse gases in the Earth's atmosphere, leading to global warming [8]. This anthropogenic influence has been corroborated by various models and empirical studies, which consistently show a warming trend over the 20th and into the 21st century that correlates strongly with increased levels of carbon dioxide (CO_2) and other greenhouse gases. Projections from the Intergovernmental Panel on Climate Change (IPCC) suggest that if greenhouse gas emissions continue at the current rate, the global average temperature is expected to rise by 1.5°C to 2°C by the year 2050. This temperature rise is likely to result in more frequent and severe weather events, such as heatwaves, heavy rainfall, hurricanes, and droughts [9]. The global impact of these changes includes sea-level rise, changes in crop growth periods, and disruptions to biodiversity. These projections are critical as they form the basis for planning climate adaptation strategies, particularly in sectors directly affected by climate variability like agriculture.

2.1 Impacts on Agriculture

Agriculture is highly vulnerable to climate change. Changes in temperature and precipitation patterns affect the growth and productivity of crops directly. For example, wheat and rice yields are sensitive to high temperatures, especially during the flowering period when exposure to temperatures above 34°C for extended periods can substantially reduce yields [10]. Additionally, irregular monsoons and shifting rainfall patterns can disrupt planting cycles and irrigation schedules, further impacting crop productivity. Climate change significantly affects water resources crucial for agriculture in India. The melting of Himalayan glaciers, a critical source of freshwater for the major rivers in the northern plains, poses a risk of reducing summer flows affecting millions who depend on agriculture [11]. Increased evaporation rates due to higher temperatures could result in drier soils, reducing the land's agricultural capacity and leading to desertification in some areas. Soil health is also impacted as changes in climate promote the leaching of essential nutrients, reduce organic matter content, and increase soil salinity. Such degradation not only reduces crop viability but also forces farmers to rely more heavily on chemical fertilizers, which can further degrade soil quality and lead to long-term productivity losses.

2.2 Challenges for Subsistence Farmers

Subsistence farmers in India are particularly vulnerable to changes in weather patterns. Their reliance on rain-fed agriculture makes them susceptible to the vagaries of shifting rainfall patterns, often leading to crop failures or reduced yields [12]. Without access to adequate irrigation facilities or the economic capacity to switch to more resilient crops, these farmers face significant threats to their livelihoods. The economic impacts of climate change on subsistence farmers are severe, often trapping them in cycles of poverty and debt. Crop failures and reduced yields can lead to a lack of food security and loss of income, which is not easily recoverable for those living on the margins. Socially, the impacts are equally devastating. Migration increases as farmers move in search of better opportunities, leading to the destabilization of rural communities. Moreover, there are substantial health risks associated with increased temperatures and the spread of vector-borne diseases, further straining rural health systems. These challenges highlight the critical need for effective agricultural extension services that can help subsistence farmers adapt to the realities of climate change, thereby securing India's agricultural productivity and socio-economic stability.

3. AGRICULTURAL EXTENSION SERVICES

Agricultural extension services have been an integral part of agricultural development in India for over a century. The primary purpose of these services is to enhance agricultural production, increase food security, improve rural livelihoods, and promote sustainable agricultural practices among farmers. Historically, the development of agricultural extension in India can be traced back to the early 20th century, with the establishment of the Imperial Agricultural Research Institute in 1905 and subsequent initiatives aimed at educating farmers about the latest agricultural practices and technologies [13]. Post-independence, the focus intensified with the

Green Revolution in the 1960s, where extension services played a pivotal role in introducing high-yielding varieties of seeds and new farming techniques to Indian farmers. This period marked a significant transformation in the agricultural landscape of India, leading to increased crop production and a shift from traditional farming methods to more intensive agriculture. The core functions of agricultural extension services involve knowledge transfer, capacity building, and providing advisory services to farmers. These functions are executed through various methodologies including training sessions, on-field demonstrations, farmer field schools, and the use of information and communication technologies (ICTs) to reach a wider audience [14]. The training involves both theoretical and practical aspects, where extension agents explain the concepts and demonstrate the practices directly in the fields. Farmer field schools, a more interactive component, involve groups of farmers who engage in a season-long learning process under the guidance of extension workers. These schools are designed to help farmers learn from each other and from their own experiences in a participatory and supportive environment.

3.1 Extension Services and Climate Change

As the impacts of climate change become increasingly apparent, the role of agricultural extension services in India has evolved to include a strong focus on supporting farmers to adapt to these changes. Extension services are now critical in disseminating knowledge about climate-smart agricultural practices such as the use of drought-resistant crop varieties, water-saving irrigation techniques, and integrated pest management practices that are resilient to climate fluctuations [15]. In addition to promoting adaptive practices, extension services are also involved in implementing various government-initiated adaptation projects. For instance, initiatives like the National Mission for Sustainable Agriculture (NMSA) are designed to enhance agricultural productivity with a specific focus on ensuring the sustainability of the resources and helping farmers adapt to climate change. Extension services play a key role in these projects by facilitating the flow of information from scientists to farmers and by gathering feedback from the field to inform ongoing research and policy formulation [16]. An innovative approach that agricultural extension services in India are increasingly adopting is the integration of modern scientific knowledge with traditional agricultural practices. Recognizing the value of indigenous knowledge that farmers possess about their local environment, flora, and fauna, extension services are merging this traditional wisdom with modern science to develop practices that are both sustainable and effective in the context of climate change [17]. For example, in parts of India, traditional practices like mixed cropping and organic farming are being combined with modern techniques of soil health management and crop rotation, advised by extension workers. This integration helps in maintaining biodiversity, reducing dependency on chemical inputs, and improving soil health, which are essential for building resilience against the unpredictable changes brought about by climate change.

4. EFFECTIVENESS OF AGRICULTURAL EXTENSION SERVICES IN CLIMATE ADAPTATION

Several regions have showcased successful agricultural extension interventions aimed at adapting to climate change (Table 2). For instance, in the state of Maharashtra, the introduction of drought-resistant varieties of sorghum and millets through extension programs has allowed farmers to maintain yields despite decreasing rainfall patterns. Similarly, in Tamil Nadu, extension services have facilitated the adoption of System of Rice Intensification (SRI) techniques that reduce water usage while increasing rice productivity [18]. Another notable example is from Andhra Pradesh, where the Community-Managed Sustainable Agriculture (CMSA) initiative was rolled out with the help of extension agents. This program encouraged the use of non-pesticidal management techniques, which not only helped in adapting to increasing pest attacks due to warmer temperatures but also improved soil health and farm biodiversity [19]. Comparative analyses of these interventions often reveal that the effectiveness of extension services varies greatly depending on the region, the specific climate threat, and the socio-economic conditions of the farmers. For example, while drought-resistant crops have worked well in semi-arid regions like Maharashtra, in the flood-prone areas of Assam, emphasis has been successfully placed on water management strategies and flood-resistant rice varieties. These differences underscore the importance of contextual and tailored approaches in extension services geared toward climate adaptation [20].

Effectiveness of agricultural extension services in facilitating climate adaptation is typically evaluated through several criteria [21].

Table 2. Effectiveness of agricultural extension services in climate adaptation

Aspect	Description	Role in Climate Adaptation	Challenges	Recommendations
Knowledge Dissemination	Distribution of information on climate-smart agricultural practices	Educates farmers on adaptive techniques, sustainable practices, and new technologies	Limited reach in remote areas, lack of localized information	Use of ICTs, localized content, collaboration with local organizations
Capacity Building	Training programs for farmers to enhance skills and knowledge	Empowers farmers to implement climate-resilient practices and technologies	Inadequate training materials, limited follow-up support	Continuous training programs, development of context-specific materials, follow-up mechanisms
Technology Transfer	Introduction and promotion of climate-resilient technologies	Facilitates adoption of innovations like drought-resistant seeds, efficient irrigation systems	Resistance to change, high cost of new technologies	Subsidies for new technologies, demonstration plots, farmer field schools
Community Engagement	Involvement of local communities in planning and decision-making processes	Encourages community-driven solutions, fosters collective action for climate adaptation	Cultural barriers, diverse community needs	Participatory approaches, inclusive decision-making, culturally sensitive interventions
Information and Communication Technologies (ICTs)	Use of mobile phones, internet, and other digital tools for extension services	Enhances access to real-time weather updates, market information, and extension advice	Digital divide, low literacy levels	Provision of user-friendly platforms, capacity building on ICT use, partnerships with telecom providers
Policy Advocacy	Influence on agricultural policies to support climate adaptation	Ensures alignment of policies with farmers' needs, promotes supportive policy environment	Bureaucratic hurdles, lack of political will	Strong advocacy networks, evidence-based policy recommendations, engagement with policymakers
Research and Development	Collaboration with research institutions to generate climate adaptation solutions	Facilitates the development and dissemination of innovative practices and technologies	Weak linkages between research and extension services	Strengthening research-extension linkages, funding for collaborative projects, farmer participatory research
Gender Inclusion	Integration of gender-sensitive approaches in extension services	Ensures that women farmers have equal access to resources, information, and decision-making processes	Gender biases, limited involvement of women in extension activities	Gender-responsive training programs, targeted support for women farmers, empowerment initiatives
Monitoring and Evaluation	Assessment of the effectiveness of extension programs in promoting climate adaptation	Provides feedback for program improvement, measures impact on farmers' adaptation capacity	Lack of robust M&E frameworks, insufficient data collection	Development of comprehensive M&E systems, regular data collection and analysis, stakeholder feedback loops
Financial Support	Provision of financial resources and incentives to support climate adaptation practices	Helps farmers invest in climate-resilient practices and technologies	Limited access to credit, high interest rates	Affordable credit schemes, microfinance options, financial literacy training
Collaboration	Building alliances	Leverages resources,	Coordination	Multi-stakeholder

Aspect	Description	Role in Climate Adaptation	Challenges	Recommendations
and Partnerships	with various stakeholders including NGOs, private sector, and government agencies	expertise, and networks to enhance the effectiveness of extension services	challenges, differing objectives	platforms, clear roles and responsibilities, regular communication and coordination

4.1 Outcome-Based Versus Process-Based Evaluations

Outcome-based evaluations focus on the results such as yield improvements, increased income, or enhanced soil health following the adoption of recommended practices. In contrast, process-based evaluations look at the effectiveness of the delivery mechanisms of extension services themselves - how well the information and technologies were communicated to the farmers, the engagement levels of the farmers, and the feedback mechanisms in place for continuous improvement of the services [22]. The major strengths of current agricultural extension strategies in India include their vast reach and the significant improvement in farmers' resilience to climate variability. Extension services have been pivotal in disseminating climate-smart agricultural practices and in enhancing farmers' adaptive capacities through skill development and access to relevant information [23]. Despite these strengths, there are notable limitations: Resource Constraints: There is often a lack of sufficient resources, including manpower and financial investment, which hampers the ability of extension services to reach all farmers effectively [24]. Inadequate Training of Extension Agents: Extension workers sometimes lack the necessary training on climate issues, which affects the quality of guidance they provide to farmers [25]. Poor Infrastructure: In many rural areas, the lack of proper infrastructure limits the frequency and quality of interactions between farmers and extension agents. Need for More Tailored Approaches: There is a need for more localized, context-specific solutions rather than one-size-fits-all approaches, considering the diverse climatic zones and farming systems across India [26].

5. CHALLENGES

Agricultural extension services in India face significant challenges due to resource constraints, impacting their effectiveness in aiding subsistence farmers' adaptation to climate change. Financial limitations are perhaps the most pressing issue, with underfunding leading to inadequate support for the extensive needs of extension programs. For instance, there is often insufficient investment in the development and dissemination of new technologies that are crucial for adapting to climate change [27]. Human resources are another critical area where constraints are evident. There is a shortage of well-trained extension agents, which affects the quality and reach of services provided. In many parts of India, one extension worker may be responsible for interacting with thousands of farmers, spreading them too thin and reducing the quality of engagement and support they can offer [28]. Material resources, such as access to modern technology and infrastructure that supports effective communication and data management, are also lacking. This gap hinders the timely and efficient delivery of services and information to farmers, particularly in remote areas where such resources could make a significant difference. Extension services in India often rely heavily on external funding from international donors or central government programs. This dependence creates sustainability issues, as programs are subject to shifts in policy or funding priorities at the national or international level. When funding dries up, projects may be abruptly discontinued, leaving farmers without necessary support and incomplete initiatives [29].

5.1 Socio-cultural Factors

Resistance to change is a significant barrier faced by agricultural extension services. Many subsistence farmers are hesitant to adopt new practices due to uncertainties about the outcomes or due to an inherent preference for traditional methods that have sustained them for generations. This skepticism is often compounded by past experiences where new technologies or practices did not perform as promised under local conditions [30]. Gender and socio-economic disparities also play a crucial role in shaping access to extension services. Women, who constitute a significant proportion of the agricultural workforce, often have less access to extension services than men. Cultural norms

and gender roles can restrict women's participation in training and extension activities, limiting their access to information and resources needed to adapt to climate change [31]. Socio-economic status further influences access to services. Wealthier farmers are more likely to receive extension services, as they have better connections and resources to obtain information. In contrast, poorer farmers, who might benefit most from extension services, are often overlooked or unable to participate due to costs associated with implementing new practices or technologies.

5.2 Policy and Institutional Barriers

The policy frameworks governing agricultural extension services in India sometimes lack coherence and an integrated approach necessary for effective climate change adaptation. Policies may not be sufficiently aligned with local needs or based on outdated information, failing to address the current challenges posed by climate change effectively [32]. A lack of coordination among various stakeholders- including government agencies, non-governmental organizations, research institutions, and private sector players -often results in duplicated efforts and inefficient use of resources. Furthermore, conflicting agendas and priorities can lead to fragmented and sometimes contradictory advice being given to farmers, complicating their decision-making processes and the implementation of effective adaptation strategies [33].

6. CONCLUSION

Enhancing agricultural extension services in India is crucial for equipping subsistence farmers to effectively adapt to climate change. By tailoring solutions to specific regional needs, boosting the capacity of extension agents, and supporting these efforts through robust policy frameworks and financial support mechanisms, these services can significantly improve agricultural productivity and resilience. Addressing existing gaps in extension research and conducting long-term impact studies are also essential to ensure the sustainability and effectiveness of these services. Together, these strategies can help mitigate the adverse effects of climate change on agriculture, safeguard food security, and improve the livelihoods of millions of farmers across India, making the agricultural sector more robust and prepared for the challenges of the future.

7. RECOMMENDATIONS AND FUTURE

To improve the effectiveness of agricultural extension services, especially in the context of climate adaptation, it is crucial to develop tailored, location-specific solutions. Different regions of India face varied climatic and ecological challenges, necessitating a localized approach to agricultural extension. For example, water-saving irrigation technologies such as drip irrigation may be prioritized in arid zones like Rajasthan, while flood-resistant rice varieties could be more relevant in flood-prone areas like Assam. Developing such tailored solutions requires detailed regional assessments of climatic risks and the specific needs of the local farming communities. Extension services should work closely with local research institutions and involve local farmers in the development and testing of new technologies and practices, ensuring they are viable and culturally acceptable [34]. Enhancing the capacity of extension agents is essential to improve service delivery. This can be achieved through regular training and capacity-building programs that keep them updated on the latest agricultural research and climate-smart agriculture practices. Furthermore, increasing the number of extension agents will ensure more effective coverage and allow for more personalized attention to individual farmers' needs. Digital tools and technologies, such as mobile apps and online platforms, can be leveraged to enhance the knowledge and efficiency of extension workers. These tools can provide real-time data and access to expert advice and enable them to reach a larger number of farmers more effectively [35].

Policy interventions are crucial for strengthening agricultural extension services in India. The government should consider establishing a national framework for climate-smart agriculture that integrates extension services. This framework should provide clear guidelines and adequate funding to implement adaptation strategies effectively. Policies should also focus on institutional reforms to improve the coordination between various stakeholders involved in agricultural extension, including government departments, NGOs, research institutions, and the private sector. Establishing partnerships and collaborative networks can help harmonize efforts and pool resources, leading to more coherent and sustained extension activities [36]. Subsistence farmers often lack the resources to adopt new technologies and practices recommended by extension services.

Policy interventions should include financial support mechanisms such as subsidies, grants, and low-interest loans to help these farmers invest in climate-resilient agriculture. Additionally, policies should aim to enhance the accessibility of insurance schemes that protect farmers against crop failures due to extreme weather conditions. Social safety nets, including food security programs and emergency relief measures, can also provide critical support during adverse climatic events [37].

8. RESEARCH GAPS AND FUTURE STUDIES

There are several unexplored areas in extension research that require attention. One key area is the integration of indigenous knowledge with scientific research in developing adaptation practices [38]. More studies are needed to document and understand how traditional farming practices can contribute to climate resilience. Another area is the impact of digital technologies on extension services. While the use of ICT in extension is growing, research on its effectiveness, especially in remote and rural areas, remains limited and should be expanded [39]. Long-term impact studies are essential to understand the sustainability and effectiveness of agricultural extension services over time. Such studies can help assess whether the adaptive practices promoted by extension services lead to sustained improvements in agricultural productivity and resilience to climate change. These studies should also evaluate the socio-economic impacts of extension services on farming communities, including changes in income levels, food security, and quality of life. The findings can provide valuable insights into how extension services can be improved and adapted to meet the evolving needs of farmers in the face of climate change [40].

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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