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# The Role of Information and Communication Technology in Enhancing the Effectiveness of Agricultural Extension Programs Worldwide: A Review

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## ABSTRACT

The role of Information and Communication Technology (ICT) in enhancing the effectiveness of agricultural extension programs in India, providing a comprehensive examination of its integration and impacts. Agricultural extension services are crucial for imparting vital agricultural knowledge

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and practices among farmers to improve productivity and sustainability. The adoption of ICT tools such as e-learning platforms, mobile applications, Geographic Information Systems (GIS), and real-time monitoring technologies has revolutionized these services, offering unprecedented access to information and advisory services directly to farmers. The review highlights significant advances, including the deployment of mobile communication tools and social media platforms that enhance interaction between farmers and agricultural experts. However, the implementation of ICT in agricultural extensions is not without challenges. Infrastructural limitations, economic constraints, cultural and social barriers, and policy and regulatory issues pose significant hurdles. Future perspectives suggest that emerging technologies like artificial intelligence, the Internet of Things, and blockchain could further influence agricultural practices positively. Policy recommendations emphasize the need for robust digital infrastructure, enhanced regulatory frameworks, and increased focus on research and development to mitigate gaps and foster a conducive environment for the adoption of ICT. By addressing these challenges and opportunities, India can better leverage ICT to bolster its agricultural sector, thus ensuring higher productivity, improved sustainability, and greater food security. This paper underscores the transformative potential of ICT in agriculture, advocating for strategic initiatives to maximize its benefits across the Indian agricultural landscape.

*Keywords: ICT; extension; innovation; sustainability; productivity.*

## 1. INTRODUCTION

Agricultural extension programs play a pivotal role in global agriculture by facilitating the transfer of knowledge, technologies, and agricultural practices to farmers and agricultural stakeholders. These programs are critical for improving agricultural productivity, ensuring food security, and enhancing rural livelihoods [1]. In many developing countries, including India, extension services are essential for addressing challenges such as resource management, market access, and adapting to climate change. According to the Food and Agriculture Organization (FAO), effective agricultural extension services are linked to increased crop yields, enhanced farmer income, and the sustainable use of natural resources [2]. The evolution of Information and Communication Technology (ICT) over the past few decades has significantly impacted various sectors, including agriculture. In India, the incorporation of ICT in agriculture began gaining traction in the late 1990s, aligning with global trends toward digitalization [3]. ICT tools such as mobile phones, the internet, satellite imaging, and Geographic Information Systems (GIS) have transformed traditional farming practices by providing farmers with timely and accessible information on weather forecasts, market prices, and new farming techniques. The increasing penetration of smartphones and the internet in rural areas has further catalyzed the integration of ICT in agricultural extension services. The Indian government's initiatives, such as the Digital India campaign launched in 2015, have aimed to create a digitally empowered society and knowledge economy, placing a strong emphasis on rural and agricultural development through technology [4].

The primary objective of this review is to examine the role of Information and Communication Technology (ICT) in enhancing the effectiveness of agricultural extension programs in India. This paper aims to identify and analyze the various ICT tools and methodologies being implemented in Indian agricultural extension services, evaluate their impacts, discuss the challenges faced, and offer insights into future trends and opportunities in this sector. By focusing specifically on India, this review seeks to provide a comprehensive overview of how ICT can address unique local challenges and contribute to the overall enhancement of agricultural productivity and sustainability.

## 2. BACKGROUND

Agricultural extension services are a series of educational activities that aim to improve the efficiency and productivity of the agricultural sector by promoting modern agricultural practices and technologies among farmers and agricultural stakeholders. These services are critical in facilitating the transfer of knowledge from technical experts to farmers, thereby enabling better decision-making and improved agricultural practices [5]. In India, agricultural extension services include a variety of programs such as training workshops, on-field demonstrations, farm visits, and the provision of informational resources. The scope of these services extends beyond mere technology transfer, encompassing the improvement of rural livelihoods, promotion of sustainable agricultural practices, and enhancement of food security [6]. The history of agricultural extension in India dates back to the early 20th century during the British colonial period. Initial efforts were primarily focused on demonstrating better agricultural practices through 'model farms' managed by the government [7]. After independence in 1947, the focus shifted to more structured and widespread extension programs. The establishment of the Indian Council of Agricultural Research (ICAR) in 1929 and its subsequent reorganization post-independence laid the groundwork for modern agricultural extension services, which were primarily delivered through state-run agricultural universities and local government bodies. The significant expansion of agricultural extension in India occurred with the introduction of the Green Revolution in the 1960s. This period saw the rapid adoption of high-yield crop varieties and increased use of chemical fertilizers and irrigation, necessitating extensive extension services to educate farmers about these new technologies [8]. The Training and Visit (T&V) system, introduced in the 1970s, further professionalized extension services in India, although it faced criticism for being top-down and not sufficiently responsive to local farmers' needs [9].

Information and Communication Technology (ICT) encompasses a broad range of technologies used for communication, data processing, and information management. In the context of agriculture, ICT includes tools such as mobile phones, computers, the Internet, satellite systems, and various software applications that help in disseminating information and facilitating communication [10]. The use of ICT in agriculture allows for real-time data collection and dissemination, enhanced access to market and weather information, and improved communication between farmers and extension agents. Globally, the integration of ICT in agriculture has been recognized as a transformative tool to enhance the delivery of extension services. Countries around the world, especially those in the developing regions, have adopted various ICT tools to overcome barriers of distance, time, and cost in reaching out to a large number of farmers [11]. For instance, in Africa, mobile phones have been widely used to deliver market prices and weather forecasts directly to farmers, significantly impacting their decision-making and income levels [12]. In Asia, countries like China and India have pioneered the use of more sophisticated ICT tools, including GIS for precision agriculture and mobile apps for agricultural advisories [13]. In India, specific initiatives such as Kisan Call Centers and the e-Choupal system have revolutionized how extension services are delivered. Kisan Call Centers, for example, provide a direct line of communication between farmers and agricultural experts, allowing for timely and accessible support [14]. Similarly, e-Choupal leverages the Internet and local meeting points to create a digital aggregation point for information on weather, market prices, and new farming techniques [15]. The integration of ICT in agriculture globally reflects a shift towards more interactive, participatory, and farmer-centric extension services, leveraging technology to tailor solutions to local agricultural challenges. This approach not only enhances the effectiveness of extension programs but also contributes to the sustainability and resilience of agricultural systems. In India, the potential and impact of ICT in agricultural extension are significant, given the country's diverse agricultural practices and the pressing need to address issues of rural poverty and food security.

## 3. METHODOLOGY

To compile a comprehensive review of the role of Information and Communication Technology (ICT) in enhancing the effectiveness of agricultural extension programs in India, a meticulous literature search was conducted across several academic databases and online sources. The primary databases used for this research included: Web of Science: As a multidisciplinary database, Web of Science provided peer-reviewed articles, conference papers, and book chapters relevant to both ICT and agricultural extension. Scopus: Known for its extensive range of scientific articles, Scopus was instrumental in sourcing recent studies and reviews pertaining to the integration of technology in agriculture. PubMed: This database was particularly useful for accessing studies linking agricultural practices influenced by ICT with public health outcomes. Agricultural & Environmental Science Database: Specific to agricultural sciences, this database offered targeted articles on agricultural extension services and the role of ICT. Google Scholar: To ensure comprehensive coverage, Google Scholar was used to retrieve grey literature, including government reports, policy briefs, and unpublished theses that are often omitted in traditional academic databases. Keywords used in the search process included combinations and variations of: "ICT in agriculture", "agricultural extension", "India", "digital tools in agriculture", "farmer outreach", and "agricultural technology". The selection criteria for literature included: Relevance to the integration of ICT in agricultural extension services. Publications from the year 2000 onwards to focus on contemporary technologies and strategies. Preference for studies conducted in or focused on the Indian context. Inclusion of both empirical research studies and comprehensive reviews. The analytical framework for this review was structured to assess the literature systematically and to draw meaningful conclusions regarding the impact of ICT on agricultural extension in India. The analysis was segmented into several components: Descriptive Analysis: Initial sorting involved categorizing the collected articles based on their focus areas, such as types of ICT tools used in extension services, regions of study, and primary outcomes measured (e.g., yield improvement, knowledge gain, economic impact). Thematic Synthesis: Articles were further analyzed to identify common themes and trends in how ICT tools are being deployed within agricultural extension programs. This included examining case studies, pilot projects, and large-scale implementations. Comparative Analysis: Comparisons were made between different types of ICT tools in terms of their accessibility, effectiveness, and scalability. Additionally, insights were drawn by comparing India's initiatives with global practices to highlight unique challenges and innovative solutions. Impact Assessment: The data were synthesized to evaluate the overall impact of ICT on agricultural extension services, focusing on measurable outcomes such as farmer satisfaction, adoption rates of agricultural technologies, and improvements in agricultural productivity. Gap Analysis: Identification of research gaps and areas lacking sufficient evidence helped outline recommendations for future research and policy-making.

While this review provides a detailed examination of ICT in agricultural extension services in India, there are several limitations to consider: Geographical and Cultural Context: The findings may not be universally applicable outside of India due to varying cultural, economic, and geographical conditions which can influence the effectiveness and adoption of ICT solutions. Variability in Data Quality: Given the diversity of sources, including grey literature, the quality and rigor of data vary. Some sources may not have undergone peer review, potentially affecting the reliability and validity of the data. Rapidly Changing Technology Landscape: The fast pace of technological change means that some of the data may quickly become outdated. New advancements in ICT could offer different opportunities and challenges than those discussed in the current literature. Publication Bias: There is a potential for publication bias, where positive outcomes are more likely to be published than studies with negative or inconclusive results, skewing the overall analysis towards seemingly more successful applications of ICT. Limited Longitudinal Data: Many studies are cross-sectional and do not provide long-term data on the sustainability and long-term impact of ICT interventions in agricultural extension services.

## 4. ROLE OF ICT IN AGRICULTURAL EXTENSION PROGRAMS

The integration of Information and Communication Technology (ICT) into agricultural extension programs in India has revolutionized the way agricultural services are delivered (Table 1). This transformation is evident in several key areas, particularly in enhancing learning and training, as well as improving communication channels between farmers and agricultural experts. Below, we explore these aspects in detail, highlighting specific technologies and their impacts. E-learning platforms and mobile applications have become central to the delivery of educational content in agricultural extension services in India. These digital tools address several challenges associated with traditional face-to-face training methods, including the reach, cost, and timing of educational programs. E-learning platforms such as the Government of India's e-KrishiShiksha and AgMOOCs provide an array of online courses tailored to the needs of the agricultural community. These platforms offer courses on sustainable farming practices, pest management, crop rotation, and much more, which are crucial for enhancing the knowledge base of farmers across vast geographic areas [16]. Mobile training applications, on the other hand, leverage the widespread availability of smartphones to deliver targeted training directly to farmers. Apps like KisanSuvidha and IFFCO Kisan offer features ranging from weather forecasts, agricultural advisory, market prices, to detailed instructional content on crop care, directly on farmers' mobile devices. These apps are designed to be user-friendly and are often available in multiple regional languages, thereby

**Table 1. Role of ICT in agricultural extension programs**

| Aspect | Description | Examples | Impact |
|---|---|---|---|
| Information Dissemination | ICT facilitates the widespread dissemination of agricultural information to farmers, including weather forecasts, pest management advice, market prices, and best practices. This enables farmers to make informed decisions about their crops and livestock. | SMS services, mobile apps, and social media platforms are commonly used to deliver timely and relevant information directly to farmers. Agricultural websites and online forums also play a significant role. | Improved decision-making leads to increased productivity and profitability for farmers. Real-time information helps in reducing crop losses due to weather and pest infestations. |
| Capacity Building | ICT tools are used for training and capacity building of farmers. E-learning platforms, online courses, and virtual training sessions help farmers gain new skills and knowledge without the need to travel long distances. | E-extension platforms offer courses on modern farming techniques, sustainable agriculture, and advanced irrigation methods. Interactive voice response (IVR) systems provide on-demand information and training. | Enhanced skills and knowledge among farmers lead to the adoption of innovative farming practices, improving overall agricultural productivity and sustainability. |
| Market Access | ICT improves market access by connecting farmers directly with buyers, reducing the number of intermediaries. E-commerce platforms and mobile trading apps enable farmers to sell their products at better prices. | Mobile-based market information services, online marketplaces, and digital trading platforms facilitate direct transactions between farmers and buyers. ICT also enables farmers to access market trends and demand forecasts. | Increased income for farmers due to better prices and reduced transaction costs. Greater market reach and the ability to negotiate better terms improve the economic viability of farming. |
| Advisory Services | ICT provides personalized advisory services to farmers, addressing specific issues related to crop management, soil health, and livestock care. These services are often available 24/7, providing continuous support to farmers. | Mobile advisory apps, teleconferencing with agricultural experts, and chatbots that offer real-time assistance. Farmer helplines and dedicated agricultural advisory websites also contribute to personalized support. | Enhanced problem-solving capabilities for farmers, leading to more effective management of agricultural resources. Continuous support helps in mitigating risks and improving farm productivity. |
| Data Collection and Analysis | ICT tools facilitate the collection and analysis of agricultural data, which is crucial for research and policymaking. Data from remote sensing, GPS, and IoT devices provide valuable insights into crop health, soil conditions, and weather patterns. | Use of drones for aerial imaging, GPS for precise field mapping, and IoT sensors for real-time monitoring of soil moisture and crop growth. Data analytics platforms process and interpret this data for actionable insights. | Data-driven decision-making enhances the efficiency and effectiveness of agricultural practices. Policymakers can develop targeted interventions based on accurate and timely data, leading to |

| Aspect | Description | Examples | Impact |
|---|---|---|---|
| | | | improved agricultural policies and programs. |
| Networking and Collaboration | ICT fosters networking and collaboration among farmers, researchers, and extension workers. Online communities and social networks enable the sharing of knowledge and experiences, promoting collective learning and innovation. | Agricultural forums, social media groups, and online collaboration platforms like WhatsApp and Facebook groups where farmers can interact with experts and peers. Virtual conferences and webinars also facilitate networking. | Strengthened farmer communities and increased collaboration lead to the dissemination of best practices and innovative solutions. Peer learning and support enhance the adoption of new technologies and practices. |
| Financial Services | ICT facilitates access to financial services, including credit, insurance, and subsidies. Digital banking, mobile payment systems, and fintech solutions make it easier for farmers to access financial resources. | Mobile banking apps, digital wallets, and online loan application platforms. ICT also supports the implementation of crop insurance schemes and direct benefit transfers (DBT) to farmers. | Improved financial inclusion and security for farmers. Access to credit and insurance mitigates risks and supports investment in modern agricultural practices, leading to enhanced productivity and resilience. |

*[Source-16,17,19,23,25]*

increasing their accessibility and utility to farmers in remote areas [17]. The adoption of Virtual Reality (VR) and Augmented Reality (AR) technologies in agricultural training and education is relatively new in India but has shown promising potential. VR and AR can simulate real-life agricultural scenarios that help farmers visualize complex processes and understand practical aspects of farming without being physically present on the farm. For instance, Amrita Vishwa Vidyapeetham, a university in India, developed an AR application that helps farmers in identifying pest attacks on crop fields [18]. These immersive technologies are not only helpful in training but are also instrumental in planning and executing farm practices with precision.

### 4.1 Improvement in Communication Channels

Mobile phones have emerged as a critical tool in improving the communication channels between extension agents and farmers. With mobile penetration rates continuing to climb across rural India, various initiatives have been launched to capitalize on this trend. Services like voice messages, SMS-based advisories, and interactive voice response systems (IVRS) are used widely to disseminate timely and relevant information to farmers. The Kisan Call Center initiative, for example, utilizes mobile communication to provide real-time expert advice to farmers, covering diverse topics from weather conditions to crop prices and farming techniques [19]. Social media platforms have also been effectively harnessed to improve farmer access to information and peer support. Platforms like WhatsApp, Facebook, and YouTube are extensively used by farming communities to share knowledge, discuss issues, and spread awareness about successful farming practices. For example, Digital Green, an international non-profit organization, uses YouTube to share video success stories from various farmers, which not only educates but also motivates farmers to adopt new practices [20]. Despite the rise of digital technologies, traditional media channels like radio and television remain influential in rural India. Radio programs tailored for agricultural audiences offer weather updates, news on crop prices, and agricultural advice. Similarly, television broadcasts such as the DD Kisan channel are dedicated to delivering agricultural content that includes expert discussions, documentaries on advanced farming techniques, and interviews with agronomists. These media channels are crucial for reaching older generations of farmers who may have limited access to or familiarity with digital tools [21].

### 4.2 Data Management and Decision Support Systems

Geographic Information Systems (GIS) have become integral to modern agricultural practices in India, enhancing the precision and efficiency of farming. GIS technology assists in the management of agricultural resources by providing spatial data that can be critical for decision-making. The data includes information about soil types, soil health, water sources, and topography, which is vital for effective land management and crop planning. In India, the use of GIS in agriculture has been promoted through various government initiatives. For example, the Bhuvan-GIS platform, developed by the Indian Space Research Organization (ISRO), provides satellite imagery and thematic maps that are useful for various applications in agriculture such as crop acreage and yield estimation, drought assessment, and soil health mapping [22]. These capabilities allow for a more targeted approach to farming, potentially reducing costs and increasing crop yields by facilitating optimal use of fertilizers and better water management. Cloud-based data storage solutions offer another dimension of data management that enhances the scalability and accessibility of agricultural data. In the context of India, cloud storage allows for the centralization of agricultural data from diverse sources, which can be accessed by farmers and extension workers on demand. This is particularly important in a country where many regions still suffer from infrastructure constraints that limit physical storage and computing capabilities. One significant application of cloud-based solutions is the Digital India Land Records Modernization Programme (DILRMP), which aims to modernize management of land records, minimize scope of land/property disputes, enhance transparency, and facilitate digital access to land records data [23]. This integrated system uses cloud storage to help farmers access updated land records, apply for loans, and receive government subsidies, thereby streamlining agricultural operations and government services. Big data analytics in agriculture involves analyzing vast amounts of data to derive insights that can lead to more informed agricultural practices and policies. In India, big data is used to analyze patterns in climate data, crop performance, pest infestations, and market trends, helping predict agricultural outputs and optimize supply chains. Organizations like Microsoft have partnered with local entities to develop AI and big data solutions tailored for Indian agriculture. The "Project FarmBeats" integrates big data from various sources, including sensors and drones, to provide actionable insights to farmers [24]. Such analytics help in predicting crop yields, determining optimal planting seasons, and identifying potential pest outbreaks, all of which significantly contribute to agricultural efficiency and sustainability.

### 4.3 Monitoring and Evaluation

Real-time monitoring tools are critical in ensuring the effectiveness of agricultural practices and interventions. These tools include sensors, satellites, and drones, which collect data continuously from the field. In India, the use of these technologies is growing, as they offer timely and accurate data that help in monitoring crop health, soil moisture levels, and water usage. The deployment of drones, for example, has enabled precision agriculture by allowing farmers to monitor crop health from above, detect irrigation problems, and even apply pesticides selectively [25]. This approach not only saves time and resources but also reduces environmental impact by minimizing the overuse of chemicals. Impact assessment models using ICT are vital in evaluating the outcomes of agricultural policies and practices. These models leverage data collected via various ICT tools to assess the impact of different agricultural interventions on crop yields, farmer income, and environmental sustainability. One notable implementation of ICT in impact assessment is through mobile-based surveys and applications that gather feedback directly from farmers about various agricultural programs. The Indian government's AgriMarket mobile app and the mKisan portal are examples where such data is collected and analyzed to assess and improve government services and information dissemination to farmers [26].

## 5. CASE STUDIES

### 5.1 Success Stories from Developed Countries

The adoption of ICT in agricultural extension programs has led to numerous success stories in developed countries, illustrating the transformative potential of these technologies. In the United States, precision agriculture has become the norm rather than the exception. Technologies such as GPS for field mapping, drones for aerial imaging, and IoT devices for soil moisture monitoring are extensively used. For

**Table 2. Role of tools of ICT application for agricultural development in India**

| ICT Tools | Description |
|---|---|
| E-choupal | E-choupal, launched in June 2000 by ITC’s Agri-Business Division, empowers Indian farmers through the Internet. It addresses challenges such as weak infrastructure and numerous market intermediaries, enhancing the competitiveness of Indian agriculture. The model helps farmers escape the cycle of low investment and productivity by providing valuable information and market access. However, infrastructure inadequacies like power supply and telecom connectivity, as well as the need to impart internet skills to first-time users, pose significant challenges. |
| Ikisan Project | The Ikisan initiative by the Nagarjuna group offers a one-stop information resource for Indian farmers, providing online content on crops, management techniques, fertilizers, pesticides, and more. It includes the ikisan.com website and village-level technical centers, offering market updates, product information, and weather forecasts. The project connects farmers with each other, suppliers, and consumers worldwide, enhancing information flow and market access. |
| Kisan Call Centres (KCCs) | Launched in 2004 by the Department of Agricultural and Co-operation, KCCs use technologies like desktop computers, high bandwidth telephone lines, and teleconferencing to deliver extension services in local languages. The objective is to provide free agricultural knowledge to farmers, making information readily available as needed. |
| Village Knowledge Centres | Initiated by the M.S. Swaminathan Research Foundation in 1998, these centers aim to provide sustainable food security in rural Pondicherry. They offer technical information on agricultural inputs, help procure quality seeds, provide daily market prices, and advise on crop rotation and fertilizer use. |
| Gyandoot Project | Implemented in January 2000 in Dhar district, Madhya Pradesh, Gyandoot is a government-to-citizen intranet-based service portal. It links the government and villagers through information kiosks, providing benefits of IT directly to rural areas. The network focuses on people, content, services, and server to enhance rural communication and information access. |
| Agmarknet | The AGMARKNET project is an e-governance portal aimed at strengthening interfaces among government organizations, farmers, industry, policymakers, and academic institutions. It provides information on prices, arrivals, commodity varieties, grading, market reforms, weather, and more, catering to diverse stakeholder needs. |
| Warana Wired Village | Initiated in 1998 by the Prime Minister’s IT Task Force, this project aims to increase the efficiency and productivity of the sugarcane cooperative in Warana. It provides a wide range of information and services to 70 villages, including crop and market price information, employment schemes, and educational opportunities. |
| eNAM | The National Agriculture Market (eNAM) is an online trading platform for agriculture and related products in India. It improves price discovery and market efficiency by removing information imbalances between buyers and sellers, and enhances real-time price discovery based on actual demand and supply. |
| mKisan | This SMS portal provides agricultural practice information to farmers. The Interactive Voice Response System (IVRS) and Pull SMS services allow farmers and stakeholders to receive broadcast messages and web-based services on their mobiles without internet access. |

*[Source= Extracted from the portals of E-Choupal, IKisan Project, KCCs, VKCs, Gyandoot Project, AGMARKNET, Warna Wired Villag, eNAM, and mKisan.]*

instance, the use of variable rate technology (VRT) allows farmers to apply fertilizers and chemicals at variable rates across a field, significantly reducing input costs and enhancing yield [27]. In the Netherlands, a leader in agricultural innovations, the use of ICT extends beyond farming to encompass entire supply chains. The Dutch company Koppert Biological Systems uses advanced data analytics to improve pest control strategies in greenhouses, effectively reducing the use of chemical pesticides while maintaining high crop yields [28]. This approach not only supports sustainable agriculture practices but also serves as a model for integrating ICT into agricultural operations comprehensively.

### 5.2 Adaptation and Challenges in Developing Countries

Developing countries, while striving to integrate ICT in agriculture, face distinct challenges. In India, despite the progress and initiatives, there remain substantial obstacles [Table 2]. Connectivity issues, limited digital literacy among farmers, and the high cost of technology are significant barriers. However, the adaptation of ICT in these settings has also led to innovative, low-cost solutions tailored to local needs. The e-Choupal initiative by ITC Limited provides computers and internet access to rural areas, allowing farmers to access timely information on weather and market prices and to place orders for agricultural inputs. This initiative has not only improved the efficiency and transparency of the supply chain but has also empowered farmers by giving them more control over their sales and a better understanding of the market dynamics [29]. In Africa, mobile technology has revolutionized agricultural extension. In Kenya, the mobile application iCow enables farmers to track their cows' gestation periods and access veterinary tips, significantly improving dairy management and productivity [30]. This example shows how mobile phones, widely accessible across developing countries, can be effectively used to deliver extension services.

The impact of ICT in agricultural extension varies significantly across different regions due to varying levels of technology adoption, infrastructure development, and governmental support. In developed countries, the comprehensive integration of advanced ICT tools has led to significant improvements in productivity and sustainability. For example, in Europe, farm management software and satellite imaging are commonly used to optimize planting cycles and irrigation systems, leading to higher yields and reduced environmental impact [31]. Conversely, in developing regions like India and parts of Africa, while the impact is promising, it is often limited by the challenges previously mentioned. However, even simple technologies like SMS for weather forecasts and market prices have shown significant benefits. In India, the use of Kisan mobile services has improved the livelihoods of many farmers by providing crucial information that assists in better decision-making [32]. This analysis demonstrates that while the extent and nature of the impact vary, the overall trend shows that ICT can significantly enhance the effectiveness of agricultural extension services globally. The key to maximizing this impact lies in adapting technologies to fit local conditions and addressing the specific challenges of each region. The case studies from both developed and developing countries highlight not only the successes but also the adaptability of ICT solutions in agriculture. They show that with the right support and adaptations, ICT can be a crucial tool in solving many of the challenges faced by the agricultural sector globally, making farming more productive, sustainable, and profitable.

## 6. CHALLENGES AND BARRIERS

One of the primary obstacles to the wider adoption of ICT in agricultural extension services in India is infrastructural limitations. Despite rapid advancements in technology and increased connectivity, rural areas often suffer from inconsistent electricity supplies, inadequate internet coverage, and poor connectivity [Table 2]. This technological divide hinders the effectiveness of ICT-based extension services, which rely heavily on uninterrupted digital communication. Mobile penetration has significantly increased in rural India, the availability of high-speed internet is still limited to urban centers [33]. Additionally, the dependence on satellite and broadband services that are susceptible to environmental interference can further exacerbate connectivity issues during critical farming periods such as planting or harvesting seasons. The cost associated with acquiring, maintaining, and upgrading technology can be prohibitive for many farmers, particularly smallholders who constitute a large portion of India's farming community. The initial setup cost for technologies such as GPS devices, drones, or even basic smartphones, along with the recurring expenses of data plans, can be beyond the reach of these farmers. The investment in back-end infrastructure, such as data centers and cloud services for managing agricultural data, requires substantial government or private investment, which is not always forthcoming. The economic burden, therefore, not only falls on individual farmers but also on the state, which may struggle to fund widespread technological implementations across vast rural landscapes [32]. Cultural and social barriers also play a significant role in the adoption of ICT in agricultural extension. In many rural communities, there is a significant generational gap in terms of technology usage. Older farmers may be less inclined to adopt new technologies, preferring traditional farming methods over digital solutions. This resistance to change is often compounded by a lack of digital literacy, which makes it difficult for this demographic to understand and trust digital information sources. Gender disparities also influence ICT adoption. In many parts of India, women, who are actively involved in farming, have less access to technological resources compared to men. This disparity limits the effectiveness of ICT-driven extension services which aim to empower all farmers equally. Policy and regulatory issues further complicate the deployment of ICT in agriculture. Regulatory frameworks governing data privacy, the use of drones for agricultural purposes, and the dissemination of digital information are often outdated and not in sync with the rapid pace of technological innovation. This results in a regulatory lag that hinders the development and adoption of new technologies. The absence of clear policies regarding the ownership and sharing of agricultural data can lead to mistrust among farmers, who may be reluctant to share their data without clear assurances about its use and benefits. Additionally, the fragmentation of responsibilities among various governmental bodies can lead to inconsistent implementation and support for ICT initiatives across different regions.

**Table 3. Challenges and barriers in information and communication technology in enhancing the effectiveness of agricultural extension programs worldwide**

| Challenge/Barrier | Description | Examples | Impact |
|---|---|---|---|
| Digital Divide | The unequal access to digital technologies between urban and rural areas, as well as among different socio-economic groups, hampers the effectiveness of ICT in agricultural extension. | Limited internet connectivity, lack of access to smartphones, and low digital literacy among farmers in remote areas. | Exclusion of marginalized farmers from the benefits of ICT-based services, leading to a widening gap in agricultural productivity and income levels. |
| Infrastructure Limitations | Inadequate ICT infrastructure in rural areas, including poor network coverage, unreliable power supply, and lack of maintenance, restricts the use of digital tools for agricultural extension. | Frequent power outages, weak signal strength, and absence of ICT service providers in rural regions. | Reduced reliability and effectiveness of ICT tools, resulting in limited access to timely and accurate agricultural information. |
| Language and Literacy Barriers | Language diversity and low literacy levels among farmers pose significant challenges to the adoption of ICT in agricultural extension. | Lack of localized content in regional languages, and complex interfaces that are not user-friendly for low-literate farmers. | Limited understanding and utilization of ICT tools by farmers, hindering the dissemination of crucial agricultural information and advice. |
| Cost and Affordability | High costs associated with acquiring and maintaining ICT devices and services can be prohibitive for many smallholder farmers. | Expensive smartphones, high data charges, and subscription fees for digital agricultural platforms. | Financial constraints prevent farmers from accessing and benefiting from ICT-based extension services, affecting their productivity and profitability. |
| Resistance to Change | Farmers' reluctance to adopt new technologies due to cultural, social, or psychological factors can | Preference for traditional farming methods, skepticism towards digital | Slow adoption rates of ICT tools, resulting in limited impact on agricultural practices |

| Challenge/Barrier | Description | Examples | Impact |
|---|---|---|---|
| | impede the integration of ICT in agricultural extension. | solutions, and fear of technology. | and outcomes. |
| Content Relevance | The effectiveness of ICT in agricultural extension depends on the relevance and accuracy of the information provided. Generic or outdated content fails to address the specific needs of farmers. | One-size-fits-all advisory services, lack of localized and context-specific information, and outdated agricultural practices being disseminated. | Mismatch between the information provided and the actual needs of farmers, leading to poor decision-making and suboptimal farming practices. |
| Capacity Building and Training | Insufficient training and capacity-building initiatives for both farmers and extension workers limit the effective use of ICT tools. | Lack of digital literacy programs, inadequate training on the use of agricultural apps and platforms, and limited support services. | Underutilization of available ICT resources, reducing their potential to enhance agricultural productivity and extension services. |
| Policy and Regulatory Issues | Inadequate policy frameworks and regulatory support can hinder the deployment and scaling of ICT in agricultural extension. | Absence of supportive policies, bureaucratic hurdles, and lack of coordination among stakeholders. | Slow implementation and scaling of ICT initiatives, affecting the reach and impact of agricultural extension programs. |
| Data Privacy and Security | Concerns about data privacy and security can deter farmers from using ICT tools. The risk of data breaches and misuse of personal information is a significant barrier. | Lack of robust data protection measures, incidents of data theft, and misuse of farmers' information. | Erosion of trust in ICT tools, leading to reluctance in sharing data and engaging with digital platforms. |

*[Source- Thota et al 33, Singh et al 32]*

## 7. FUTURE

The future of agricultural extension in India is poised to be significantly influenced by emerging technologies that promise to increase efficiency, productivity, and sustainability. These technologies include artificial intelligence (AI), the Internet of Things (IoT), blockchain, and robotics, each offering unique benefits to the agricultural sector. Artificial Intelligence (AI): AI can profoundly impact agricultural extension by providing predictive analytics for crop management, pest control, and yield optimization. AI algorithms can analyze data from satellite images, weather stations, and on-ground sensors to offer real-time advisories to farmers, potentially transforming agricultural practices [34]. For example, Microsoft's AI-based sowing app, which has been piloted in several Indian states, advises farmers on the optimal time to sow crops based on weather conditions and soil health, leading to improved yields. Internet of Things (IoT):IoT devices can monitor crop fields and livestock, providing continuous data on various parameters such as soil moisture, nutrient levels, and animal health. This technology enables precision farming, which can lead to more efficient use of resources and reduced input costs. Companies like CropIn utilize IoT in India to integrate smart farming solutions that help in monitoring farm conditions and advising farmers accordingly [35]. Blockchain: Blockchain technology can revolutionize agricultural supply chains by increasing transparency and traceability. It ensures that all parties in the supply chain, from farmers to consumers, have access to the same information, potentially reducing fraud and increasing the efficiency of operations. This technology can also play a crucial role in securing land records and ensuring fair transactions for farmers [36].

Robotics: The use of drones and robotic technology for tasks such as planting, harvesting, and spraying pesticides can significantly reduce labor costs and improve precision. The deployment of drones for spraying pesticides, for example, is not only more efficient but also helps in reducing the exposure of workers to harmful chemicals [37]. To harness the full potential of ICT in agricultural extension services, India needs robust policy frameworks that can facilitate the integration and adoption of these technologies. The following recommendations can guide policy formulation: Enhancing Digital Infrastructure: Building reliable and widespread digital infrastructure is critical. This includes not only improving internet connectivity across rural areas but also ensuring electricity access, which is a prerequisite for digital technology usage. Fostering Public-Private Partnerships (PPPs): Encouraging partnerships between the government and private sector can accelerate technology transfer and innovation. Private companies can bring in expertise, innovation, and investment, while public institutions can provide scalability and sustainability. Developing Human Capital: There is a dire need for training and capacity building not only for farmers but also for agricultural extension officers. Programs designed to enhance digital literacy and technical know-how among these groups are essential. Regulatory Reforms: Updating regulations to keep pace with technological advancements is necessary. This includes creating standards and guidelines for new technologies such as drones, AI, and IoT in agriculture. Incentivizing Technology Adoption: The government can encourage technology uptake through subsidies, grants, and tax breaks for farmers who invest in advanced technologies. While there has been significant progress in understanding the impact of ICT on agriculture, several research gaps remain that provide opportunities for further study: Longitudinal Impact Studies: There is a need for long-term studies that can assess the sustained impact of ICT interventions on agricultural productivity and socio-economic conditions of farmers. Interdisciplinary Research: Combining insights from information technology, agricultural science, economics, and sociology can provide a more holistic understanding of the challenges and opportunities presented by ICT in agriculture. User-Centric Design Research: More studies are required to understand the usability and accessibility of ICT tools among different farmer groups, including women and the elderly, to design more inclusive technologies. Impact on Sustainability: Researching the environmental impact of ICT tools in agriculture, including their role in promoting sustainable practices, is crucial as India moves towards more eco-friendly farming practices.

## 8. CONCLUSION

The integration of Information and Communication Technology (ICT) into agricultural extension programs in India represents a transformative shift towards more efficient, inclusive, and sustainable farming practices. Through the utilization of e-learning platforms, mobile applications, and advanced data management systems, ICT has significantly enhanced the reach and effectiveness of agricultural education and communication. However, challenges such as infrastructural limitations, economic barriers, cultural resistance, and policy gaps need to be systematically addressed to fully harness the potential of these technologies. Future perspectives are promising, with emerging technologies like AI, IoT, and blockchain poised to further revolutionize the agricultural landscape. Ensuring robust digital infrastructure, fostering public-private partnerships, and updating regulatory frameworks are crucial steps forward. Continued research into the long-term impacts and accessibility of ICT tools will also be vital. Ultimately, strategic integration of ICT in agricultural extensions holds the key to achieving sustainable agricultural growth and enhanced food security in India.

## 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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