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Digitalization of agricultural extension services: Opportunities and challenges

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Abstract

Agriculture, the backbone of the Indian economy, is undergoing a paradigm shift with the rapid integration of digital technologies, transforming traditional extension services into dynamic, data driven systems. The study explores the digitalization of agricultural extension services in India, highlighting its evolution from conventional approaches to advanced digital ecosystems powered by Artificial Intelligence (AI), Internet of Things (IoT), drones, and mobile-based platforms. Government initiatives such as Digital India, AgriStack, e-NAM, mKisan, and Kisan Sarathi have significantly enhanced farmers' access to real-time information, market linkages, and financial services, thereby improving productivity, transparency, and income levels. The study emphasizes the growing need for digitalization in addressing challenges such as food security, climate variability, and economic sustainability of farmers. It also examines global and national perspectives, including G20 priorities and successful case studies, demonstrating the transformative potential of digital agriculture. Despite its benefits-such as improved accessibility, cost-effective advisory delivery, and real-time decision making-several constraints persist, including digital divide, lack of digital literacy, inadequate infrastructure, and absence of robust data protection frameworks. The findings suggest that a blended approach combining digital and traditional extension methods is essential for inclusive and effective outreach, especially for small and marginal farmers. A notable example is the e-Mausam Krishi Sewa in Haryana, which has shown strong success, with over 376,344 registered users by April 2026, providing localized weather forecasts and agro-advisories that support timely farm decisions and risk reduction. This reflects the growing impact and potential of digital extension services in strengthening climate-resilient and sustainable agriculture.

Keywords: Drones, AgriStack, Digital India, artificial intelligence, internet of things, Kisan Sarathi

Introduction

The Government of India, through its National informatics Centre (NIC), has introduced the District Information System on Agricultural System (Agriculture, Animal husbandry and Fisheries) in 1987, prepared the first IT Blue-Print for Agricultural Sector, through a National Conference on "Informatics for Sustainable Agricultural Development (ISDA)" in May 1995, and in 2005, launched the National-e-Governance Programme in Agriculture (NeGP-A). Digital technologies are critical for increasing productivity in agriculture, making agriculture fair for farmers, ensuring reduction in food loss both at pre/post-harvest stages, and ensuring food safety and security. Agriculture is an Unstructured and Semi structured problem and hence Artificial Intelligence (AI) and ML Applications are having immense applications and use in agriculture.

Artificial intelligence (AI) (Jha *et al.*, 2019) ^[26], precision agriculture (PA), satellites, field sensors robots/drones, cloud computing, blockchain technologies, mobile apps and Internet of Things (IoT) are being increasingly used in agriculture. As the Fourth Industrial Revolution (4IR) has unified data and computer vision, it is crucial to focus on IoT as its subset. The IoT's "Thing" can be animals, people, services, processes, sensors, logical, physical, data and databases. In the age of IoT, data are gathered from millions

of connected gadgets and environmental monitors, microchipped people, humanoids, driverless vehicles and livestock. Ashton invented the IoT in 1999. It is the combination of data from "things" or a group of "things" while using AI (usually machine learning) to draw decisions from big data and the data source position. Thus, to transform PA into smart agriculture, as previously mentioned, only the position of the data was considered. Smart and precision farming makes farmers more informed and productive.

According to Maertens *et al.* (2020) ^[3], before the COVID-19 crisis, extension services mostly employed the "on the field" approaches, such as demonstration plots, group training, and farm visits, all of which implied in-person interaction. However, COVID 19-related physical distancing measures made such approach impossible, thereby necessitated the extension personnel to switch to digital tools for service delivery among farmers. While the pandemic presents many challenges, it also creates opportunities for digital tools to better serve farmers, as well as be adapted to assist public health responses, and prepare for new agricultural needs that arise (FAO, 2020a) ^[18]. Agriculture digitization offers ways to reduce the negative effects of agri-food supply chains and to help farmers receive the financial support and agricultural inputs they need to grow and sell their produce (FAO, 2020b) ^[18]. Digital innovations also

make agriculture more attractive to young people, while productivity increases have also been seen by new collaborative arrangements (Saiz-Rubio & Rovira-Más 2020) [30]. According to Babu, risk and emergencies such as disease outbreaks take a toll on the extension system by directly affecting personnel and farmers functions in the short-term. Such disruptions during the growing season can cut off the flow of information to farmers, resulting in a decrease in crop production, livestock and fish production systems.

Difference between ICT in extension and Digital extension

ICT in extension refers to the use of information and communication technologies (such as SMS, mobile apps, radio, GIS, call centres, expert systems, video conferencing, and internet portals) to support agricultural extension and advisory services. It enables faster, cost-effective, and wider dissemination of agricultural information, improves farmer–extension worker interaction, and enhances decision-making through timely access to weather, market, and production-related data. ICTs also strengthen pluralistic extension systems by integrating public, private, and community actors, thereby improving knowledge sharing and service delivery efficiency (Aker, 2011; Qiang *et al.*, 2012; Mittal & Mehar, 2016) [15, 20, 19].

Digital extension (digital agricultural extension) refers to extension systems that are re-designed around digital platforms, data flows, and interactive services, not just the addition of tools (Vignare, 2013) [5]. It emphasizes two-way communication, real-time advisories, data-driven decision-making, and personalized services using technologies such as artificial intelligence, big data analytics, and IoT. Digital extension transforms traditional extension by enabling scalable, inclusive, and demand-driven services, improving outreach to smallholder farmers, and enhancing resilience in situations like climate change and pandemics (Fabregas *et al.*, 2019; FAO, 2020; Davis & Addom, 2021) [17, 18, 16].

Growth of Digital Agriculture in India

Digital agriculture in India has evolved progressively from traditional face-to-face extension systems to ICT-enabled services and, more recently, to integrated digital ecosystems. Earlier, agricultural extension relied heavily on interpersonal communication methods such as demonstrations, trainings, and farm visits, but with the advent of ICT tools like mobile phones, internet platforms, and call centres, information dissemination became faster and more scalable. Over time, this transformation has expanded into data-driven and platform-based approaches, enabling real-time advisory services and improved farmer outreach (Aker, 2011; Mittal & Mehar, 2016; Fabregas *et al.*, 2019) [15, 19, 17].

Government initiatives have played a central role in accelerating this transition. Programmes such as Digital India Programme and National e-Governance Plan in Agriculture (NeGP-A) have strengthened digital infrastructure, promoted e-governance, and enhanced service delivery mechanisms in agriculture. These initiatives aim to provide farmers with timely access to information, inputs, credit, insurance, and markets through digital platforms, thereby improving transparency, efficiency, and inclusiveness in the agricultural sector (Government of India, 2015; World Bank, 2017) [25, 31].

Institutional support has further enabled this digital transformation. The National Informatics Centre has been instrumental in developing and maintaining the digital backbone for agricultural data systems, supporting integration across departments, and enabling platforms for real-time data sharing and decision-making. Such institutional frameworks are essential for ensuring interoperability, scalability, and reliability of digital agriculture services (FAO, 2020) [18].

The emergence of digital platforms like AgriStack and eNAM (National Agriculture Market) has significantly improved market access and service delivery. These platforms integrate farmers, markets, and service providers, enabling transparent price discovery, reducing transaction costs, and facilitating efficient supply chains. They also provide access to advisory services, financial products, and input markets, thereby enhancing farmers' participation in digital value chains (PIB, 2021; Chand, 2016) [29, 22].

In recent years, there has been a clear shift toward advanced technologies such as artificial intelligence (AI), machine learning, big data analytics, and Internet of Things (IoT) in agriculture. These technologies enable real-time decision support, predictive analytics, and personalized advisories based on weather, soil, and crop data. AI-based systems and digital decision-support tools are helping farmers optimize input use, manage risks, and improve productivity, marking a transition toward smart and precision agriculture (Jha *et al.*, 2019; Saiz-Rubio & Rovira-Más, 2020; FAO, 2022) [26, 30, 35].

Digital Agriculture in India

According to the Press Information Bureau, about 95.15% of Indian villages are now covered with 3G/4G connectivity, reflecting significant progress in rural digital infrastructure. India has also witnessed rapid growth in internet users, increasing from 251 million in 2014 to around 954 million in 2024, indicating a massive expansion in digital access across the country. This growth has been a key enabler for digital agriculture and extension services (Press Information Bureau 2024) [34].

Growth in Rural Internet Users

Out of the total internet subscribers, nearly ~398 million users are from rural areas, showing a substantial contribution of rural India to the digital ecosystem. This shift highlights the increasing penetration of digital technologies in agriculture and rural livelihoods, enabling farmers to access information, markets, and advisory services more effectively (Telecom Regulatory Authority of India 2024) [33].

Rural Digital Access and Usage (NSSO & FAS Data)

Data from the National Sample Survey Office (2025) [32] indicates that around 83% of rural households have internet access, reflecting improved infrastructure and affordability. Similarly, studies by the Foundation for Agrarian Studies show that about 96% of households use some form of ICT device, such as mobile phones. However, despite high access, only around 50% of adults effectively use the internet, pointing to a significant digital literacy gap. This highlights the need for capacity-building and digital skill development to fully realize the benefits of digital agriculture (National Sample Survey Office 2025) [32].

Major Digital Platforms & Initiatives in Indian Agriculture

Kisan Suvidha App (Launched: 21 March 2016)

Launched by the Government of India under the leadership of Narendra Modi, the Kisan Suvidha Mobile App is designed to provide farmers with timely and relevant agricultural information. It offers weather updates (current and 5-day forecasts), mandi-wise market prices, plant protection advisories (pest and disease management), and expert agro-advisories. The app also provides details of input dealers dealing in seeds, fertilizers, and pesticides, along with a direct link to the Kisan Call Centre. By delivering real-time information, it significantly reduces farmers' dependency on middlemen and improves decision-making.

Pusa Krishi App (Launched: March 2016)

The Pusa Krishi App was launched by the Ministry of Agriculture and Farmers Welfare in collaboration with the Indian Council of Agricultural Research. It provides comprehensive information on ICAR-developed crop varieties, resource conservation technologies, improved farm machinery, and scientific agricultural practices. The app also offers weather-based crop management advisories, helping farmers make informed decisions. It plays a crucial role in bridging the "lab to land" gap and promotes the adoption of innovative and research-based agricultural technologies.

e-NAM (National Agriculture Market) (Launched: 14 April 2016): e-NAM is a pan-India electronic trading portal that integrates APMC mandis to create a unified national agricultural market. It enables transparent price discovery, inter-state trade, digital payments, and quality testing of produce. By connecting buyers and sellers across markets, e-NAM reduces the role of intermediaries and enhances farmers' access to better prices and wider markets, thereby improving income opportunities.

m-Kisan Portal (Launched: 2013)

The m-Kisan Portal is an SMS-based advisory system that delivers crop advisories, weather alerts, and government scheme information directly to farmers' mobile phones in local languages. It is particularly important for farmers who do not use smartphones, ensuring last-mile connectivity and inclusiveness. By leveraging simple mobile technology, it has strengthened communication between extension services and farmers.

AgriStack (Launched: 2024 under Digital Agriculture Mission)

AgriStack is an advanced digital initiative aimed at building a comprehensive farmer-centric digital ecosystem. It involves the creation of a unique Farmer ID by integrating data such as Aadhaar, land records, and bank details. This enables efficient delivery of services like Direct Benefit Transfer (DBT), crop insurance, credit access, subsidies, and AI-based advisory services. AgriStack supports data-driven farming and improves the efficiency, transparency, and targeting of agricultural policies.

PM-KISAN (Pradhan Mantri Kisan Samman Nidhi) (Launched: 24 February 2019): PM-KISAN is a flagship income support scheme of the Government of India that

provides ₹6,000 per year to eligible farmers, distributed in three equal installments of ₹2,000 each. The amount is transferred directly to farmers' bank accounts through the Direct Benefit Transfer (DBT) system and is linked with Aadhaar for transparency and accountability. The scheme aims to supplement farmers' income and support their agricultural and household needs.

e-Choupal

Integration of market and extension services. The e-Choupal initiative, launched by ITC Limited, is recognized as one of the earliest and most impactful digital interventions in agricultural extension and market linkage. It functions as a rural internet kiosk operated by a trained farmer, known as a sanchalak, who provides access to a web-based platform delivering information on weather forecasts, crop advisory, input prices, and mandi rates. At the same time, it serves as a procurement hub, allowing ITC to buy produce directly from farmers, bypassing intermediaries and offering better prices.

FarmStack

Data interoperability in agricultural advisories. FarmStack is an open-source data exchange protocol developed to enable secure and interoperable sharing of agricultural data among various stakeholders. Built as part of a broader effort to establish a unified digital ecosystem for agriculture, it addresses the challenge of data silos by creating a framework that allows different systems government databases, private apps, research platforms, farmer profiles to communicate and share information seamlessly. The platform ensures that farmers receive more accurate, personalized, and timely advisories by integrating data from land records, satellite imagery, market trends, and weather systems. For example, a farmer using a soil testing service through one app can have that information automatically integrated with a government fertilizer subsidy program or a private crop advisory platform.

PGDAEM (Post Graduate Diploma in Agricultural Extension Management) MOOCs is an online capacity-building programme offered by the National Institute of Agricultural Extension Management (MANAGE) for extension functionaries such as officials of State Agriculture Departments, Krishi Vigyan Kendras (KVKs), NGOs, and other stakeholders. It aims to strengthen their professional competencies in agricultural extension through structured modules on extension management, communication strategies, agribusiness development, ICT applications, and climate-resilient agriculture. Delivered through a flexible MOOC platform, the programme includes video lectures, reading materials, case studies, and assessments, enabling in-service professionals to upgrade their knowledge and skills without disrupting their field responsibilities (MoA&FW).

DAESI (Diploma in Agricultural Extension Services for Input Dealers) MOOCs is another digital initiative of the National Institute of Agricultural Extension Management (MANAGE), specifically designed for agri-input dealers who act as key intermediaries between research institutions and farmers. The programme focuses on enhancing their technical and advisory capabilities by providing scientific knowledge on crop production, pest and disease management, soil health, nutrient management, and safe use of agricultural inputs. Through the MOOC mode, DAESI

offers self-paced learning with multimedia content, quizzes, and certification, helping input dealers deliver accurate and reliable farm advisory services, thereby contributing to improved agricultural productivity and sustainability at the grassroots level (MoA&FW).

KVK's implemented by Indian Council of Agricultural Research. These are Knowledge Network to digitally connect Krishi Vigyan Kendras across the country for real-time knowledge sharing and dissemination. This network facilitates faster transfer of technologies, best practices, success stories, and location-specific advisories from research institutions to extension personnel and farmers. It strengthens coordination among KVKs, enhances capacity building, and ensures that farmers in remote villages receive timely, relevant, and reliable agricultural information through digital platforms.

Management Information Systems implemented by Indian Council of Agricultural Research to systematically collect, store, and manage agricultural data related to research, extension, and field-level activities. MIS enables efficient monitoring, reporting, and evaluation of various programmes, including KVK performance, training programmes, and technology dissemination. It improves decision-making by providing accurate and timely information to administrators and policymakers, thereby enhancing transparency and accountability in agricultural extension systems (ICAR).

Decision Support Systems promoted by Indian Council of Agricultural Research to assist farmers, extension workers, and policymakers in making informed agricultural decisions based on scientific data and predictive models. DSS integrates data on weather, soil, crops, and market trends to generate advisories on crop planning, irrigation scheduling, pest management, and risk mitigation. These systems enhance precision in farming decisions and contribute to increased productivity and sustainability in agriculture (ICAR).

Expert Systems developed by Indian Council of Agricultural Research as intelligent digital tools that replicate the knowledge of agricultural experts to provide problem-solving support to farmers. These systems offer diagnosis and recommendations on crop diseases, pest infestations, nutrient deficiencies, and farm management practices through user-friendly interfaces. By delivering expert-level advice directly to farmers, even in remote areas, ES helps bridge the gap between scientific research and field-level application.

Incubators for Agri-tech Sector in India

Agri UDAAN is a structured accelerator programme aimed at scaling agri-startups through mentorship, investor linkage, and business incubation support. It plays a crucial role in strengthening the agri-startup ecosystem by enabling entrepreneurs to refine business models and access funding opportunities. Studies have shown that such accelerator programmes significantly improve startup performance, innovation capacity, and market linkage in agriculture, thereby contributing to the growth of agripreneurship and rural development (Mukherjee A, *et al.* 2026) ^[10].

Centre for Innovation Incubation and Entrepreneurship (CIIE) represents a leading incubation model in India that supports agri-tech startups through structured mentoring,

funding access, and ecosystem networking. Research on agribusiness incubation highlights that such institutional incubators play a vital role in transforming innovative ideas into scalable enterprises by providing technical guidance, infrastructure, and financial support. These incubation platforms contribute significantly to strengthening entrepreneurial ecosystems in agriculture and enhancing innovation-driven growth (Kadirvel G, *et al.* 2025) ^[9].

a-IDEA (Association for Innovation Development of Entrepreneurship in Agriculture) functions as a specialized agri-business incubator under ICAR, focusing on nurturing startups through innovation support, capacity building, and commercialization of research outputs. Evidence from research studies indicates that incubation centres like a-IDEA significantly contribute to developing successful agri-startups by offering technical expertise, business incubation services, and funding opportunities. These institutions help bridge the gap between agricultural research and entrepreneurship, thereby promoting sustainable agribusiness development (Srinivas K, *et al.* 2019) ^[8].

Agri-Clinics and Agri-Business Centres (ACABC) Scheme is a flagship initiative promoting self-employment among agricultural graduates by establishing agri-ventures that deliver extension and advisory services to farmers. Research studies reveal that the scheme plays a significant role in enhancing agripreneurship, improving technology transfer, and generating rural employment. It strengthens the extension system by creating a cadre of trained agripreneurs who act as service providers and knowledge intermediaries between research institutions and farmers (Afroz S, *et al.* 2022) ^[7].

m-Farms (Ghana) and iCow (Kenya): African success stories in e-extension mFarms and iCow are leading examples of successful digital agricultural extension platforms developed to address the needs of smallholder farmers in sub-Saharan Africa. mFarms, developed by Esoko in Ghana, is a mobile and web-based system that connects farmers with buyers, suppliers, and extension agents. It allows farmers to access input prices, weather alerts, market trends, and expert advice via SMS and smartphone apps. By enabling coordination among actors in the value chain, mFarms enhances transparency and strengthens the bargaining power of smallholders. As of 2021, mFarms had supported over 250,000 farmers across 80 districts. Impact assessments conducted by the Ghana Ministry of Food and Agriculture showed that farmers using mFarms achieved a 15–25% increase in yield and improved access to inputs and financial services. The platform also supports digital profiling of farmers, enabling targeted delivery of extension and subsidy programs.

iCow, launched in Kenya, started as a mobile voice and SMS platform to support dairy farmers with breeding calendars, feeding schedules, and veterinary advice. It quickly expanded to include crop advisories and climate-smart practices. Farmers register by texting specific codes and receive personalized messages based on their farming profile. As of 2022, iCow had more than 400,000 registered users and had recorded a 40% increase in dairy productivity among consistent users. The service also includes a farmer helpline and a learning platform called "Ask iCow," where farmers can pose questions and get responses from experts.

Web Portals and Knowledge Repositories

Web-based platforms have become central to modern agricultural extension by providing centralized, 24/7 access to information, expert guidance, and government schemes. These digital portals serve as knowledge repositories where farmers, extension workers, and agricultural students can find reliable and updated information on crops, soil health, pest control, weather conditions, and market prices. The Farmer Portal is a comprehensive service that offers region specific advisories based on location, landholding size, and cropping patterns. It integrates data from agricultural research institutes, meteorological departments, and government agencies to provide customized content. Agri-Info is another robust platform that delivers detailed knowledge on more than 150 crops and their management practices. It provides multimedia resources such as images, charts, and videos, aiding both literate and semi-literate users. Users can search for specific issues like nutrient deficiency symptoms, pest identification, and fertilizer recommendations. As of 2022, Agri-Info had registered over 1.2 million visits annually from rural users accessing content in multiple Indian languages. Kisan Call Center (KCC) remains a widely accessed hybrid model, where queries are received through toll-free numbers and resolved by trained agricultural experts and subject matter specialists. Operational across all states, KCC receives more than 15,000 calls per day, with over 65% of the inquiries related to crop protection, irrigation, and market-related queries. This service bridges the digital divide by allowing farmers who lack internet connectivity to access real-time advice using basic phones.

Bhuvan Hailstorm App

Through this mobile app, the data of damage caused to the farm due to hailstorm is recorded along with photographs and geographical location, which simplifies the process of giving insurance to the farmer by assessing the loss due to hailstorm. Data analytics of smart agriculture is used by this mobile.

Agri-Market Mobile App

This app can be used by farmers on their mobile devices. To know the market price of the crops within 50 km. This app automatically captures the location of the person using the mobile and informs the farmer about the Global Positioning System (GPS) and price of the markets within 50 km.

Fasal Salah

It is an informative Mobile app which is designed to help farmers by providing real time personalized crop advisory based on current and forecast weather which includes Temperature, Humidity, Wind Speed and Direction, Rainfall for next 10 days at taluk and village level.

Krishi Insecticide and Fungicide Calculator

National Centre for Integrated Pest Management Research, New Delhi has developed insecticide and fungicide app on web and mobile platform for 12 major crops, viz. Rice, Cotton, Cabbage, Cauliflower, Brinjal, Arhar, Groundnut, Tomato, Soybean, Gram, Chilli, Okra. The main objective of these apps is to assist researchers, agricultural extension workers and farmers in the selection and use of pesticides with labels, judicious pesticide selection for the management of pests and diseases.

Farm mech App

The App is related to decision support for selection of suitable farm machineries for five major crops of Tamil Nadu. It also has dynamic Networking of 2,250 Custom hiring service operators in Android platform.

Apart from this, many apps have also been developed by various government organizations, private companies, which use smart agricultural techniques to reach accurate information at the right time to the farmers like Solapur Pomegranate, Cane Advisor, Animal Nutrition, Agriculture Video Advice App etc. Understanding the importance of mobile app, Indian Council of Agricultural Research has also created a special mobile app gallery where detailed information and downloading link of 355 agriculture mobile apps are available.

E-learning platforms and MOOCs Web-based learning platforms and Massive Open Online Courses (MOOCs) have emerged as significant tools for agricultural knowledge dissemination. Platforms such as AgMOOCs, Coursera, and EdX provide tailored courses focusing on agricultural extension education, soil health management, pest control, and sustainable farming practices. Studies have shown that e-learning platforms enhance knowledge retention rates by approximately 30-40% compared to traditional learning methods.

Use of podcasts, webinars, and YouTube channels Newer digital media tools such as podcasts, webinars, and YouTube channels are becoming valuable resources for disseminating agricultural knowledge. Platforms such as The Climate Corporation's YouTube channel and the Future of Agriculture podcast provide in depth discussions on farming innovations and best practices. Research shows that video-based learning enhances knowledge retention by 35-45% due to visual learning components.

Language and literacy barriers represent significant obstacles to the widespread adoption of digital agricultural technologies. Many digital platforms and advisory services are developed in dominant languages, neglecting local dialects and culturally relevant content. Research indicates that approximately 40% of farmers struggle to use digital platforms due to language limitations. Studies also highlight the role of literacy in influencing the effectiveness of digital tools.

Public-Private Partnerships for scaling innovations Public-private partnerships (PPPs) are increasingly recognized as effective mechanisms for scaling digital innovations in agriculture. Collaborations between governments, technology companies, research institutions, and civil society organizations can enhance the availability of affordable, high-quality advisory services. Studies show that PPPs improve the scalability of digital platforms by approximately 45%, particularly when stakeholders share resources and expertise.

Technologies Used in Digital Extension

1. Artificial Intelligence (AI)

Artificial Intelligence refers to the use of algorithms and machine learning models to analyze agricultural data and support decision-making. It performs key functions such as crop disease and pest detection through image-based diagnosis, yield prediction and crop planning, smart irrigation scheduling, and providing personalized advisory to

farmers. In agricultural extension, AI is used in chatbots and decision-support tools to deliver real-time recommendations based on weather, soil, and crop data. Importance: AI improves the accuracy, speed, and scalability of extension services, enabling farmers to make data-driven decisions and enhancing productivity.

2. Internet of Things (IoT)

IoT involves interconnected devices and sensors that collect real-time data from farms. Its key components include soil moisture sensors, weather sensors (temperature and humidity), livestock tracking devices, and smart irrigation systems. Applications of IoT include real-time monitoring of crop and soil conditions, automated irrigation and fertigation, and livestock health tracking. Importance: IoT enables precision agriculture, improves farm management, and reduces wastage of resources such as water and fertilizers, thereby increasing efficiency and sustainability.

3. Remote Sensing & GIS

Remote sensing uses satellite or drone imagery, while Geographic Information Systems (GIS) analyze spatial data for agricultural planning and monitoring. Key functions include crop health monitoring using vegetation indices (such as NDVI), soil moisture assessment, land-use mapping, and weather or drought forecasting. Applications involve early detection of crop stress and diseases, area-specific recommendations, and disaster management such as flood and drought monitoring. Importance: These technologies support location-specific decision-making, improve resource management, and enhance the ability to respond to climatic risks.

4. Mobile-Based Advisory

Mobile technology is one of the most widely used tools in digital extension. It includes features such as SMS services, mobile applications, IVR (voice-based systems), multilingual advisories, and real-time weather and market information. Applications include dissemination of agricultural advisories, farmer feedback and query resolution, and access to government schemes, markets, and inputs. Importance: Mobile-based advisory ensures wide outreach, inclusiveness, and last-mile connectivity, especially for small and marginal farmers.

5. Big Data Analytics

Big Data refers to large volumes of structured and unstructured agricultural data collected from multiple sources such as IoT sensors, satellite imagery, weather data, market information, and farmer databases. Its applications include predictive analytics for yield estimation and pest outbreaks, risk assessment, and supply chain optimization. Importance: Big Data analytics converts raw data into actionable insights, improves policy planning, enhances extension delivery, and supports evidence-based decision-making in agriculture.

6. Blockchain (Traceability)

Blockchain is a distributed digital ledger technology that ensures secure, transparent, and tamper-proof record-keeping. Its key features include decentralization, transparency, and immutability (data cannot be altered). Applications in agriculture include food traceability (farm-to-

fork tracking), supply chain transparency, and smart contracts for transactions. Importance: Blockchain builds trust among farmers, traders, and consumers, reduces fraud, enhances transparency, and improves food safety and quality assurance.

Strengths of Digitalization in Agricultural Extension

- a) **Accessibility:** Digitalization in agricultural extension significantly enhances accessibility by providing information anytime and anywhere through mobile applications, SMS services, and web portals. It helps bridge the rural-urban information gap by reaching farmers in remote and underserved regions. Importantly, it ensures inclusion of smallholders, women farmers, and marginalized groups. The availability of multi-language content further strengthens its effectiveness in a diverse country like India, enabling better understanding and adoption of technologies.
- b) **Timeliness:** Digital platforms enable the real-time dissemination of critical agricultural information, allowing farmers to make prompt decisions. Farmers can receive weather forecasts, pest and disease alerts, and market price updates instantly. This reduces crop losses through early warning systems and improves farm management. For example, weather alerts provided by the India Meteorological Department are integrated into various digital platforms, helping farmers respond quickly to changing climatic conditions.
- c) **Cost-effectiveness:** Digital extension reduces the dependency on frequent physical visits by extension workers, thereby saving time, travel, and operational costs for both farmers and service providers. It enables mass communication at a very low cost through SMS, mobile apps, and IVR systems. A single digital advisory can reach thousands of farmers simultaneously, making it a highly efficient and economical approach to agricultural extension.
- d) **Personalization:** Digital technologies enable location-specific and crop-specific advisories, improving the relevance and effectiveness of extension services. Tools such as Artificial Intelligence (AI), Big Data analytics, GIS, and remote sensing help tailor recommendations based on soil health, weather conditions, and crop growth stage. For instance, advisories provided by the Indian Council of Agricultural Research are often customized according to different agro-climatic zones, ensuring better adoption and outcomes.
- e) **Transparency:** Digitalization enhances transparency by providing farmers with accurate and real-time information on market prices, government schemes, and subsidies. Platforms like e-NAM (National Agriculture Market) improve price discovery and reduce the role of intermediaries, thereby minimizing exploitation. It also strengthens systems like Direct Benefit Transfer (DBT), ensuring that financial benefits reach farmers directly, which builds trust between farmers and institutions.
- f) **Scalability:** One of the major strengths of digital extension is its scalability, as digital platforms can serve millions of farmers simultaneously without significant additional infrastructure. It allows easy expansion of services across regions and supports large-scale initiatives such as the Digital Agriculture Mission and

AgriStack. These platforms also enable the integration of multiple services—including advisory, credit, insurance, and market access—into a single unified system, improving overall efficiency and reach.

Opportunities of Digitalization in Agricultural Extension

- a) **Precision Agriculture:** Precision agriculture refers to the use of advanced technologies such as Artificial Intelligence (AI), Internet of Things (IoT), sensors, drones, and GPS for site-specific farm management. It enables efficient use of inputs like water, fertilizers, and pesticides, leading to increased productivity at reduced cost. Real-time monitoring of crops and soil conditions allows farmers to make informed decisions. Startups like DeHaat and Arya.ag provide data-driven advisory and supply chain services. Sensor-based irrigation systems further optimize water use, supporting the principle of “more crop per drop”, thereby improving water-use efficiency.
- b) **Climate-Smart Agriculture:** Digital technologies play a crucial role in climate-smart agriculture by helping farmers adapt to climate variability and risks. They provide weather-based advisories, early warning systems for pests and diseases, and climate-resilient crop planning support. For example, mobile-based agro-advisories delivered through mKisan Portal provide timely alerts, while systems like Krishi Decision Support System (KDSS) offer insights on crop conditions, weather, and drought situations. These tools enhance farmers’ resilience and reduce vulnerability to climate shocks.
- c) **Youth Engagement:** Digital agriculture is increasingly attracting educated rural youth by creating new employment and entrepreneurship opportunities. It opens avenues in agri-tech startups, drone operations, data analysis, and digital advisory services. India has over 2800 agri-tech startups, contributing significantly to innovation and job creation. Additionally, village-level entrepreneurs are being engaged in activities like crop surveys and data collection under initiatives such as AgriStack, promoting rural entrepreneurship and skill development.
- d) **Women Empowerment:** Digital tools are enhancing women’s participation in agriculture by improving their access to information, resources, and markets. Through mobile-based advisory services, women farmers can access knowledge on crop management, government schemes, credit facilities, and market opportunities. They are also increasingly participating in Farmer Producer Organizations (FPOs). Initiatives supported by AgriStack have enabled large-scale registration of women farmers, strengthening inclusiveness and promoting gender empowerment in agriculture.
- e) **Market Linkages:** Digital platforms have significantly improved market linkages by connecting farmers directly with buyers, reducing dependency on intermediaries. These platforms ensure better price discovery, transparent transactions, and wider market access. For instance, e-NAM (National Agriculture Market) enables online trading of agricultural commodities across markets. Integration with digital systems further provides real-time price information,

helping farmers make better marketing decisions.

- f) **Data-Driven Policy Making:** Digital agriculture enables the use of big data and farmer databases for improved governance and policy formulation. It supports targeted subsidy delivery, evidence-based policymaking, and real-time monitoring of agricultural activities. Platforms like AgriStack integrate farmer ID, land records, crop data, and bank details, allowing policymakers to design efficient and targeted interventions, thereby improving overall system effectiveness.

Way Forward / Recommendations

1. **Capacity Building of Farmers:** One of the biggest challenges in digital agriculture is the lack of digital literacy among farmers, particularly small and marginal farmers. To address this, it is essential to organize training programmes, workshops, and digital literacy campaigns at the village level. Approaches such as Farmer Field Schools (FFS) integrated with digital tools and demonstration-based learning (e.g., training on how to use mobile applications like Kisan Suvidha App) can significantly improve adoption. Institutions like Krishi Vigyan Kendras and extension agencies should play a key role in providing hands-on training. For example, under the Digital India Programme, initiatives such as Pradhan Mantri Gramin Digital Saksharta Abhiyan (PMGDISHA) have trained rural households in basic digital skills. **Why important:** Without adequate capacity building, even advanced technologies remain underutilized.
2. **Strengthening Digital Infrastructure:** Digital agriculture relies heavily on robust infrastructure, including reliable internet connectivity, electricity, and access to digital devices. Key actions include expanding broadband connectivity in rural areas, strengthening initiatives such as BharatNet, ensuring affordable smartphones and data services, and improving power supply in remote villages. Strengthening these components is essential to ensure uninterrupted access to digital advisory services and platforms.
3. **Development of Local Language Content:** India’s linguistic diversity presents a major challenge for digital extension, as language barriers can limit the effectiveness of information dissemination. To overcome this, content should be provided in regional languages and local dialects, and technologies such as voice-based advisory systems and IVR (Interactive Voice Response) should be promoted. The use of AI-powered chatbots in local languages can further enhance accessibility. For example, the mKisan Portal delivers SMS advisories in regional languages, and apps like Pusa Krishi App offer multilingual support. **Why important:** Farmers better understand, trust, and adopt information delivered in their native language.
4. **Integration of AI & Real-Time Data:** The future of agricultural extension lies in data-driven and intelligent advisory systems. Integrating Artificial Intelligence (AI) can support pest and disease detection, yield prediction, and personalized advisories. The use of real-time weather data and satellite imagery further enhances decision-making. Platforms like AgriStack enable the

creation of comprehensive farmer databases and analytics. For example, AI-based tools can detect crop diseases through image recognition, while weather-based advisory systems provide real-time alerts to farmers, improving productivity and reducing risks.

5. **Strengthening Extension Personnel Skills:** Extension workers act as a crucial bridge between technology and farmers, and their skills must evolve with digital advancements. Key actions include training extension personnel in digital tools and platforms, data interpretation, use of AI, and mobile-based advisory systems. Promoting e-extension services and virtual advisory platforms can further enhance outreach. Collaboration with agri-tech startups and the private sector should also be encouraged to ensure exposure to innovative solutions and improve service delivery efficiency.

Table 1: Role of ICT in transforming agricultural practices

Aspect of Agriculture	ICT Applications	Examples	Impact
Crop Management	Remote sensing, GIS, weather forecasting apps	Smart Fertilizer Management Tools, Krishi Apps	Improved decision-making in sowing, irrigation, and pest control
Soil Management	Soil sensors, nutrient mapping, and fertility analysis	Soil Health Card Portal, Digital Soil Maps	Enhanced soil health monitoring, precision application of fertilizers
Irrigation	IoT-based automated irrigation systems, mobile apps	Drip-Irrigation Systems, mKRISHI Aqua	Efficient water usage, reduced wastage, and optimized crop water requirements
Market Access	e-NAM, digital marketing platforms, and mobile applications	e-Choupal, AgriBazaar	Improved access to market information, price transparency, and reduced exploitation
Livestock Management	RFID, health tracking apps, and breeding data analytics	NDDB Dairy Dashboard, CattleTracs	Enhanced productivity through health monitoring and better breeding practices
Pest and Disease Control	AI-based pest identification tools, SMS-based advisories	Plantix App, Pest Prediction Models	Reduced crop loss through timely detection and actionable guidance
Weather Forecasting	Weather apps, SMS alerts, and cloud platforms	AccuWeather for Farmers, Skymet Agriculture	Minimizing risks from extreme weather events and optimizing field operations
Extension Services	Digital kiosks, m learning platforms, video conferencing	Digital Green, eSagu	Increased outreach and real time knowledge dissemination
Financial Services	Mobile banking, digital wallets, and credit platforms	Kisan Credit Card, M PESA in Kenya	Improved access to credit and insurance services for smallholder farmers
Supply Chain Management	Blockchain, ERP systems, and tracking tools	AgriChain, AgriDigital	Enhanced traceability, reduced food loss, and streamlined logistics
Farmer Education	Online courses, SMS-based learning, and video tutorials	ICAR's e-Learning Portal, YouTube Agri Ed Videos	Enhanced skill development and knowledge transfer

Table 2: Challenges of Digital Agriculture

Challenge	Description	Impact on farmers	Citations
Digital Divide	Lack of internet access and reliable electricity in rural areas	Limited access to digital tools, inability to utilize data-intensive applications	Mehta <i>et al.</i> (2023)
Digital Literacy & Skill Gap	Farmers lack skills to operate digital tools; complex interfaces	Underutilization of technology, skepticism, reliance on intermediaries	Yuan <i>et al.</i> (2025)
High Initial Investment	Cost of hardware (sensors, drones) and software subscriptions	Unaffordable for small & marginal farmers, low ROI perception	Fabregas <i>et al.</i> (2019) ^[17]
Data Fragmentation & Quality	Inconsistent data formats, lack of reliable real-time data	Difficulty in comprehensive analysis, inaccurate advisories	Kramarz and Runowski (2025)
Policy & Regulatory Gaps	Evolving policy framework, coordination issues among stakeholders	Hindered innovation, slow adoption, lack of clear guidelines	Lajoie O'Malley <i>et al.</i> (2020)
Appropriate Mechanization Integration	Digital solutions sometimes developed in isolation from ground realities of farm machinery needs	Disconnect between digital tools and practical farm operations, underutilization of both	Romera <i>et al.</i> (2024)

References

1. Madaswamy M. Digitalization of agriculture in India: Application of IoT, robotics and informatics to establish farm extension 4.0. *Journal of Informatics and Innovative Technologies*. 2020;4(2):23-32.

2. Jarial S. Internet of Things application in Indian agriculture, challenges and effect on the extension advisory services—a review. *Journal of Agribusiness in Developing and Emerging Economies*. 2023;13(4):505-519.

3. Maertens A, Michelson H, Nourani V. How do farmers learn from extension services? Evidence from Malawi. *American Journal of Agricultural Economics*. 2021;103(2):569-595.

4. Olagunju O, Adetarami O, Koledoye GF, Olumoyegun AT, Nabara IS. Digitization of agricultural extension system for effective management of emergency in Nigeria. *Journal of Agricultural Extension*. 2021;25(4).

5. Vignare K. Options and strategies for information and communication technologies within agricultural extension and advisory services. East Lansing (MI): Michigan State University; 2013.

6. Fuentes-Peñailillo F, Gutter K, Vega R, Silva GC. Transformative technologies in digital agriculture:

- Leveraging Internet of Things, remote sensing, and artificial intelligence for smart crop management. *Journal of Sensor and Actuator Networks*. 2024;13(4):39.
7. Afroz S, Singh R, Nain MS, Mishra JR. Determinants for agripreneurship development under Agriclincs and Agribusiness Centers (ACABC) scheme. *Indian Journal of Agricultural Sciences*. 2022;92(2):258-262. doi:10.56093/ijas.v92i2.122248.
 8. Srinivas K, Kumar R, Gerard M. Fostering entrepreneurship in agriculture through incubation centres in National Agricultural Research & Education System (NARES). Policy Brief No. 5. Hyderabad: NAARM; 2019.
 9. Kadirvel G, Marak TB, Gangmei DL, Kalita H. Agribusiness incubation in India: Current status and strategic directions. *Journal of Scientific Research and Reports*. 2025;31(11):421-437. doi:10.9734/jsrr/2025/v31i113678.
 10. Mukherjee A, *et al.* Assessing the effectiveness of AGRI UDAAN accelerator program on agri-startups in India: An integrated PCA and machine learning approach. *Frontiers in Sustainable Food Systems*. 2026;10. doi:10.3389/fsufs.2026.1705691.
 11. Ministry of Agriculture & Farmers Welfare, Government of India. MANAGE. <https://www.manage.gov.in>
 12. Ministry of Agriculture & Farmers Welfare, Government of India. DAESI MOOCs Programme. <https://www.manage.gov.in>
 13. Indian Council of Agricultural Research. Krishi Vigyan Kendra (KVK) Portal and Knowledge Network. <https://kvk.icar.gov.in>
 14. Indian Council of Agricultural Research. Agricultural Extension Management through MIS. <https://icar.org.in>
 15. Aker JC. Dial "A" for agriculture: Using information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*. 2011;42(6):631-647.
 16. Davis K, Addom BK. Digital agricultural extension: Global experiences and future directions. *Journal of Agricultural Education and Extension*. 2021;27(2):123-140.
 17. Fabregas R, Kremer M, Schilbach F. Realizing the potential of digital development: The case of agricultural advice. *Science*. 2019;366(6471).
 18. Food and Agriculture Organization. Digital technologies in agriculture and rural areas: Status report. Rome: Food and Agriculture Organization; 2020.
 19. Mittal S, Mehar M. Socio-economic factors affecting adoption of modern information and communication technology by farmers in India: Analysis using multivariate probit model. *Journal of Agricultural Education and Extension*. 2016;22(2):199-212.
 20. Qiang CZ, Kuek SC, Dymond A, Esselaar S. Mobile applications for agriculture and rural development. Washington (DC): World Bank; 2012.
 21. Vignare K. Review of distance education and e-learning in agricultural extension. *Journal of Agricultural Education and Extension*. 2013;19(3):309-327.
 22. Chand R. e-NAM: A pan-India electronic trading portal for agricultural commodities. *Economic and Political Weekly*. 2016;51(28):15-18.
 23. Food and Agriculture Organization. Digital technologies in agriculture and rural areas: Status report. Rome: Food and Agriculture Organization; 2020.
 24. Food and Agriculture Organization. The future of digital agriculture. Rome: Food and Agriculture Organization; 2022.
 25. Government of India. Digital India Programme: Transforming India into a digitally empowered society and knowledge economy. New Delhi: Government of India; 2015.
 26. Jha K, Doshi A, Patel P, Shah M. A comprehensive review on automation in agriculture using artificial intelligence. *Artificial Intelligence in Agriculture*. 2019;2:1-12.
 27. Ministry of Electronics and Information Technology. National Informatics Centre and e-governance initiatives in India. New Delhi: Government of India; 2018.
 28. Mittal S, Mehar M. Socio-economic factors affecting adoption of modern ICT by farmers in India. *Journal of Agricultural Education and Extension*. 2016;22(2):199-212.
 29. Press Information Bureau. AgriStack: Creating a unified digital agriculture ecosystem in India. New Delhi: Government of India; 2021.
 30. Saiz-Rubio V, Rovira-Más F. From smart farming towards Agriculture 5.0: A review. *Agronomy*. 2020;10(6):1-21.
 31. World Bank. ICT in agriculture: Connecting smallholders to knowledge, networks, and institutions. Washington (DC): World Bank; 2017.
 32. National Sample Survey Office. Household Social Consumption: Education and Digital Access Survey. New Delhi: Government of India; 2025.
 33. Telecom Regulatory Authority of India. The Indian Telecom Services Performance Indicators Report. New Delhi: Telecom Regulatory Authority of India; 2024.
 34. Press Information Bureau. Expansion of digital connectivity in rural India. New Delhi: Government of India; 2024.
 35. Food and Agriculture Organization. The future of digital agriculture: Trends, challenges and opportunities. Rome: Food and Agriculture Organization of the United Nations; 2022.
 36. World Bank. ICT in agriculture: Connecting smallholders to knowledge, networks, and institutions. Updated ed. Washington (DC): World Bank; 2019.
 37. Ministry of Agriculture & Farmers Welfare. Digital Agriculture Mission documents. New Delhi: Government of India; 2023-2024.
 38. Indian Council of Agricultural Research. Reports on ICT in agricultural extension. New Delhi: Indian Council of Agricultural Research.
 39. NITI Aayog. India Digital Ecosystem for Agriculture (IDEA): Framework for agriculture. New Delhi: Government of India; 2021.