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Impact of ICT-based advisory services on farmer knowledge and adoption behaviour

¹Gosavi Deepali Prafulla, ²Gargi Shekhar and ³Jyoti Beri

¹Principal, College of Agriculture, Department of Agriculture Extension and Communication, Pal Gargoti, Dist Kolhapur, Maharashtra, India

²Assistant Professor, School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun, Uttarakhand, India

³M.Sc. Agricultural Extension and communication, Agricultural Extension, GB Pant University of Agricultural and Technology, Pantnagar, Uttarakhand, India

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Corresponding Author: Gosavi Deepali Prafulla

Abstract

Information and Communication Technology (ICT)-based advisory services have emerged as a transformative approach for strengthening agricultural extension by delivering timely, location-specific, and demand-driven information to farmers. The rapid expansion of smartphones, internet connectivity, mobile applications, and artificial intelligence (AI)-enabled advisory systems has created new opportunities to improve farmers' knowledge and accelerate the adoption of recommended agricultural practices. However, empirical evidence regarding the influence of ICT-enabled advisory services on farmers' knowledge acquisition and adoption behavior remains limited, particularly in developing countries. The present study assessed the impact of ICT-based advisory services on farmers' knowledge and technology adoption, identified factors influencing ICT utilization, and suggested strategies for improving digital agricultural extension. A cross-sectional ex-post facto research design was adopted using multistage random sampling to select 300 farmers from six villages representing diverse agro-ecological conditions. Primary data were collected through a structured interview schedule, while descriptive and inferential statistical techniques, including multiple regression analysis, were employed for data analysis. The findings indicated that farmers regularly using ICT-based advisory platforms possessed significantly higher agricultural knowledge scores and exhibited greater adoption of improved crop management, nutrient management, pest management, and climate-smart agricultural practices than non-users. Digital literacy, education, internet accessibility, extension contact, and smartphone ownership positively influenced ICT adoption and knowledge enhancement. Despite these benefits, inadequate internet connectivity, language barriers, and limited digital skills constrained wider utilization. Strengthening localized, multilingual, AI-assisted advisory services and improving rural digital infrastructure can substantially enhance the effectiveness of agricultural extension and promote sustainable agricultural development.

Keywords: ICT-based advisory services, digital agriculture, farmer knowledge, technology adoption, mobile advisory, agricultural extension, Information and Communication Technology (ICT), adoption behavior

1. Introduction

1.1 Background

Agricultural extension has long served as the primary mechanism for transferring scientific knowledge and innovative farming practices from research institutions to farming communities. Conventional extension systems have traditionally relied on face-to-face interactions, demonstration plots, field visits, farmer training programmes, and printed educational materials to disseminate agricultural technologies. Although these approaches have contributed significantly to agricultural development, their effectiveness has often been constrained by limited manpower, high operational costs, inadequate extension coverage, and delays in information dissemination, particularly in geographically remote and resource-poor regions (Anandajayasekaram *et al.*, 2008) ^[5].

The rapid advancement of Information and Communication Technology (ICT) has fundamentally transformed agricultural extension by enabling real-time communication between farmers, extension professionals, researchers,

agribusiness firms, and policymakers. Digital technologies now facilitate rapid dissemination of weather forecasts, market intelligence, pest and disease surveillance, crop management recommendations, and government support programmes through smartphones, mobile applications, SMS services, Interactive Voice Response Systems (IVRS), WhatsApp groups, YouTube channels, social media platforms, and AI-powered advisory tools. These innovations have shifted extension services from generalized recommendations toward personalized, location-specific, and need-based agricultural advisories (Dujali *et al.*, 2025) ^[17]. Timely access to reliable agricultural information has become increasingly important under conditions of climate variability, fluctuating market prices, labour shortages, and increasing production costs. ICT-enabled advisory systems support farmers in making informed decisions regarding crop selection, input application, irrigation scheduling, integrated pest management, nutrient management, and post-harvest handling (Das *et al.*, 2024) ^[14].

1.2 Importance of ICT-based advisory services

ICT-based advisory services have significantly enhanced the accessibility, efficiency, and responsiveness of agricultural extension systems. Unlike conventional extension approaches, digital platforms provide continuous access to agricultural information irrespective of time and location. Farmers can receive immediate recommendations during critical crop growth stages, reducing delays in decision-making and minimizing production risks (Dujali *et al.*, 2025) ^[17].

Digital advisory services reduce information asymmetry by ensuring that scientific recommendations reach farmers directly without excessive dependence on intermediaries. Easy access to weather forecasts, disease surveillance, market prices, crop insurance information, and government schemes enables farmers to make economically rational decisions while reducing uncertainty associated with agricultural production.

ICT also plays an essential role in promoting climate-smart agriculture by disseminating early warning systems, drought advisories, rainfall forecasts, water-saving technologies, and sustainable crop management practices. Furthermore, digital advisory services contribute to higher productivity and profitability through improved input management, precision farming, optimized fertilizer application, and integrated pest management. Enhanced access to reliable information strengthens farmers' decision-making capacity, increases confidence in adopting improved technologies, and ultimately supports sustainable agricultural development (Das *et al.*, 2024; Gangopadhyay *et al.*, 2019) ^[14, 20].

1.3 Global status of ICT in agriculture

The integration of ICT into agriculture has accelerated worldwide as governments and international organizations increasingly recognize digital technologies as catalysts for agricultural transformation. Developed countries such as the United States, Canada, Australia, Germany, and the Netherlands have successfully integrated digital agriculture through precision farming technologies, satellite-based crop monitoring, artificial intelligence, remote sensing, drones, and Internet of Things (IoT)-enabled farm management systems. These technologies enable real-time monitoring of crop health, soil moisture, nutrient status, and climatic conditions, resulting in improved resource-use efficiency and higher agricultural productivity (Araújo *et al.*, 2021; Gabriel & Gandorfer, 2022) ^[7, 19].

In developing countries, ICT adoption has expanded rapidly through mobile phone-based advisory services, digital extension platforms, and e-agriculture initiatives (Relebohile & Keregero, 2019) ^[42]. Countries including India, Kenya, Bangladesh, China, Brazil, and Ethiopia have implemented mobile-based agricultural information systems that provide weather forecasts, market information, disease diagnosis, and extension advisories directly to farmers (Relebohile & Keregero, 2019) ^[42]. Several international initiatives supported by organizations such as the Food and Agriculture Organization (FAO), International Fund for Agricultural Development (IFAD), and CGIAR have further strengthened digital agriculture by promoting knowledge sharing, digital innovation, and capacity building among smallholder farmers (King & Wong, 2019; Manzoor *et al.*, 2025) ^[30, 33].

Successful experiences from these countries demonstrate that

ICT-based advisory services improve agricultural productivity, enhance resilience to climate change, increase market participation, and facilitate evidence-based farm management decisions (Gangopadhyay *et al.*, 2019) ^[20]. However, disparities in digital infrastructure, literacy, affordability, and institutional support continue to influence the effectiveness of ICT adoption across regions (Kapoor, 2025) ^[29].

1.4 ICT-based agricultural advisory services in India

India has emerged as one of the leading countries promoting digital agriculture through numerous government-supported ICT initiatives aimed at modernizing agricultural extension and improving farmers' access to information (Balkrishna *et al.*, 2023) ^[11]. The Kisan Call Centre (KCC) provides multilingual expert advice through toll-free telephone services, enabling farmers to obtain immediate solutions to production-related problems (Mudda *et al.*, 2017) ^[36]. The mKisan Portal disseminates personalized SMS-based advisories covering weather, crop management, pest surveillance, and government schemes (Gawade & Turkar, 2017) ^[21].

The Kisan Suvidha mobile application offers weather forecasts, market prices, plant protection recommendations, input dealer information, and crop advisories in an integrated digital platform (Gupta *et al.*, 2021) ^[22]. The National Agriculture Market (eNAM) has strengthened agricultural marketing by digitally connecting wholesale markets across the country, improving price transparency and marketing efficiency (Gupta *et al.*, 2021) ^[22].

Recent initiatives including the Digital Agriculture Mission and AgriStack seek to establish an integrated digital ecosystem using artificial intelligence, big data analytics, geospatial technologies, digital farmer databases, and personalized advisory services (Mahesh *et al.*, 2026) ^[32]. AI-enabled platforms increasingly support pest diagnosis through image recognition, weather-based crop recommendations, fertilizer scheduling, and precision nutrient management (Balkrishna *et al.*, 2023) ^[11].

Private agritech companies have also developed digital advisory platforms offering customized recommendations based on satellite imagery, machine learning algorithms, and field-level diagnostics (Anjali, 2023) ^[6]. Simultaneously, Farmer Producer Organizations (FPOs) have begun utilizing digital communication tools to disseminate technical knowledge, facilitate collective marketing, and strengthen farmer-to-farmer learning networks (Nikam *et al.*, 2019) ^[38]. These initiatives collectively demonstrate India's transition from conventional extension toward an integrated digital agricultural advisory system capable of improving agricultural productivity, resilience, and rural livelihoods.

1.5 Farmer knowledge and technology adoption

Farmer knowledge plays a pivotal role in determining the successful adoption of improved agricultural technologies (Kountios *et al.*, 2023) ^[31]. Knowledge acquisition is a continuous process through which farmers gather, evaluate, interpret, and apply information obtained from extension personnel, fellow farmers, research institutions, digital platforms, and personal farming experiences. ICT-based advisory services have accelerated this process by enabling farmers to access scientific recommendations at different

stages of crop production, thereby reducing delays in information dissemination and enhancing decision-making. The pathway from awareness to adoption generally involves five sequential stages: awareness, interest, evaluation, trial, and adoption (Kanyi *et al.*, 2017) ^[28]. Initially, farmers become aware of a technology through extension campaigns or digital media. They subsequently seek additional information, evaluate its suitability based on local conditions, experiment on a limited scale, and finally integrate the innovation into routine farming practices if the perceived benefits outweigh associated costs and risks. ICT platforms facilitate each of these stages by providing timely technical information, success stories, instructional videos, weather forecasts, and interactive advisory services.

Several socioeconomic and technological factors influence farmers' adoption behaviour. Socioeconomic factors, including age, education, and income, significantly determine the extent to which farmers utilize ICT-enabled advisory services (Amoussouhoui *et al.*, 2024) ^[4]. Younger and better-educated farmers generally demonstrate greater willingness to adopt digital technologies due to higher technological familiarity and openness to innovation. Similarly, access to reliable internet connectivity and affordable smartphones substantially enhances the utilization of digital advisory services.

Theoretical frameworks provide useful explanations of farmers' technology adoption behaviour. The Technology Acceptance Model (TAM) proposes that adoption depends primarily on perceived usefulness and perceived ease of use of a technology (Dumpit & Fernandez, 2017) ^[18]. Farmers are more likely to adopt ICT-based advisory services when they perceive them as beneficial, reliable, and user-friendly.

The Diffusion of Innovation Theory, proposed by Rogers, explains that innovations spread gradually through communication channels over time among members of a social system. According to this theory, adoption is influenced by the innovation's relative advantage, compatibility, complexity, trialability, and observability (Alajmi *et al.*, 2016) ^[2]. ICT platforms accelerate diffusion by enabling rapid dissemination of agricultural innovations across farming communities (Nakasone *et al.*, 2014) ^[37].

The Theory of Planned Behavior (TPB) further suggests that behavioural intention is influenced by attitudes toward technology, subjective social norms, and perceived behavioural control (Ali *et al.*, 2020; Monteleone *et al.*, 2020) ^[3, 35]. Farmers who possess positive attitudes toward digital technologies, receive encouragement from peers or extension workers, and believe they have adequate digital skills are more likely to adopt ICT-enabled advisory services. Together, these theories provide a comprehensive framework for understanding the behavioural mechanisms underlying ICT adoption in agriculture.

1.6 Literature Review

1.6.1 ICT and agricultural information access

ICT has substantially improved farmers' access to agricultural information by overcoming geographical and temporal barriers associated with conventional extension systems (Parmar *et al.*, 2019; Qureshi *et al.*, 2022) ^[39, 41]. Mobile phones, SMS services, smartphone applications, WhatsApp groups, YouTube channels, and digital knowledge portals have enabled farmers to obtain real-time information

on weather conditions, input availability, market prices, crop diseases, and government schemes. Studies conducted across Asia and Africa have consistently reported that ICT-enabled advisory systems increase the frequency of farmer-extension interactions and improve access to reliable agricultural information. Compared with traditional extension approaches, digital advisory platforms provide faster dissemination of recommendations while reducing information asymmetry between research institutions and farming communities.

1.6.2 ICT impact on farmer knowledge

1.6.3 ICT and adoption of improved agricultural practices

Improved knowledge acquired through ICT-based advisory services has translated into higher adoption of recommended agricultural technologies. Research indicates that farmers using digital extension services are more likely to adopt certified seeds, balanced fertilizer application, integrated pest management, precision irrigation, soil testing, mechanization, and climate-smart agricultural practices (Asante *et al.*, 2024) ^[8]. Access to timely information reduces uncertainty associated with new technologies, increases farmers' confidence, and minimizes production risks (Aker, 2011) ^[1]. Digital platforms also facilitate peer learning through farmer discussion groups and social media communities, thereby accelerating the diffusion of agricultural innovations (Izuchukwu *et al.*, 2023) ^[25].

1.6.4 Factors affecting ICT utilization

The effectiveness of ICT-based advisory services depends on several demographic, socioeconomic, institutional, and technological factors. Education and digital literacy consistently emerge as the strongest determinants of ICT utilization (Parmar *et al.*, 2018) ^[40]. Farmers possessing higher educational attainment generally demonstrate greater confidence in operating smartphones, accessing mobile applications, and interpreting digital recommendations (Choruma *et al.*, 2024) ^[13]. Farm size and household income also influence ICT adoption, as larger and economically better-off farmers possess greater capacity to invest in digital technologies (Parmar *et al.*, 2018) ^[40].

Infrastructure-related factors such as internet connectivity, mobile network coverage, electricity availability, and smartphone affordability significantly affect ICT accessibility in rural areas (Dionysious, 2018) ^[16]. Institutional support through extension agencies, Farmer Producer Organizations (FPOs), training programmes, and digital literacy campaigns further encourages technology adoption (Hasan *et al.*, 2019) ^[23].

1.6.5 Constraints in ICT-based extension

Despite considerable progress, several challenges continue to limit the effectiveness of ICT-enabled agricultural extension. Poor internet connectivity, particularly in remote rural areas, restricts access to digital advisory services (Mapiye *et al.*, 2023) ^[34]. Limited digital literacy among elderly farmers reduces their ability to utilize smartphone applications and online platforms effectively (Choruma *et al.*, 2024) ^[13]. Language barriers remain another important constraint, as many digital applications continue to provide content primarily in English or major regional languages, limiting

accessibility for farmers speaking local dialects (Izuchukwu *et al.*, 2023) ^[25].

Other challenges include high smartphone costs for economically disadvantaged households, inadequate digital infrastructure, unreliable electricity supply, information overload, and concerns regarding the credibility of online information (Choruma *et al.*, 2024) ^[13]. Addressing these challenges requires improvements in digital infrastructure, localized content development, farmer capacity building, and stronger integration between conventional and digital extension systems.

1.6.6 Emerging technologies in digital agricultural extension

Recent advances in digital agriculture have introduced several emerging technologies that are transforming agricultural advisory systems. Artificial Intelligence (AI) enables personalized recommendations by analyzing weather conditions, soil characteristics, crop growth stages, and historical production data (Shams *et al.*, 2024) ^[45]. AI-powered chatbots provide farmers with immediate responses to production-related queries, serving as an augmentation to physical extension services (Beers *et al.*, 2026) ^[12].

Machine Learning (ML) algorithms improve prediction accuracy for pest outbreaks, disease incidence, irrigation scheduling, and crop yield forecasting by continuously learning from large agricultural datasets (Delfani *et al.*, 2024) ^[15]. Internet of Things (IoT) devices facilitate real-time monitoring of soil moisture, temperature, humidity, and nutrient status through interconnected sensor networks, enabling precision farming (Saraswathi *et al.*, 2024) ^[44].

Remote sensing technologies, supported by satellite imagery and drone-based observations, allow continuous monitoring of crop health, water stress, and vegetation dynamics across large agricultural landscapes (Inoue, 2020) ^[24]. Big Data analytics integrates information from weather stations, market databases, IoT devices, and satellite observations to generate predictive insights that support evidence-based agricultural decision-making (Singh *et al.*, 2025) ^[47].

Collectively, these technologies are transforming agricultural extension from generalized recommendation systems into intelligent, predictive, and location-specific advisory platforms capable of improving farm productivity, resource-use efficiency, and climate resilience.

1.7 Research gap

Although ICT-based agricultural advisory services have expanded considerably during the past decade, important knowledge gaps remain (Mapiye *et al.*, 2023) ^[34]. Most existing studies primarily evaluate farmers' access to digital technologies rather than examining their influence on knowledge enhancement and behavioural change (Nakasone *et al.*, 2014) ^[37]. Comparative evidence assessing the specific impacts of ICT services remains limited (Nakasone *et al.*, 2014) ^[37].

Furthermore, the majority of available studies employ cross-sectional designs that inadequately capture the long-term sustainability of technology adoption (Jones & Krishna, 2021) ^[26]. Limited attention has been given to integrating socioeconomic characteristics, digital literacy, institutional support, and behavioural factors into comprehensive analytical frameworks (Sindakis & Showkat, 2024) ^[46].

Addressing these research gaps is essential for designing more inclusive, efficient, and farmer-centric digital extension systems capable of supporting sustainable agricultural development.

1.8 Objectives of the study

To assess farmers' access to and use of ICT-based agricultural advisory services and their influence on agricultural knowledge and adoption of recommended technologies, while identifying the socioeconomic, institutional, and technological factors affecting their utilization and suggesting strategies to strengthen digital agricultural extension and improve the effectiveness of ICT-enabled advisory systems.

2. Materials and Methods

2.1 Study area

The study was conducted across three prominent agricultural education and extension institutions in India representing diverse agro-ecological regions. These included the Department of Agricultural Extension and Communication, College of Agriculture, P.A. Gargoti, Kolhapur, Maharashtra; the School of Agriculture, Dev Bhoomi Uttarakhand University, Dehradun, Uttarakhand; and the Department of Agricultural Extension and Communication, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. These institutions actively promote ICT-enabled agricultural extension through farmer training, digital advisory programmes, mobile-based information services, and technology dissemination. The selected locations encompass varied farming systems, cropping patterns, and levels of digital infrastructure, providing an appropriate setting to assess the impact of ICT-based advisory services on farmers' knowledge and adoption behaviour. The research design specifically incorporates a multi-stage sampling technique to capture the heterogeneity of farming households, acknowledging that variables such as landholding size, caste, and access to institutional credit are critical determinants of information seeking behavior (Sahu *et al.*, 2024) ^[43].

2.2 Research Design

An ex-post facto research design employing a cross-sectional survey approach was adopted because the independent variables had already occurred and could not be manipulated experimentally. This design is appropriate for evaluating the existing relationship between farmers' use of ICT-based advisory services and their knowledge levels and technology adoption behaviour under natural farming conditions.

The study compared farmers with different levels of ICT utilization to determine whether exposure to digital advisory services influenced knowledge acquisition and adoption of recommended agricultural technologies. The design also enabled identification of socioeconomic, technological, and institutional factors affecting ICT utilization.

2.3 Sampling procedure

A multistage random sampling technique was employed to ensure representative participation of farmers from different villages.

In the first stage, one agriculturally important district with relatively digital connectivity was purposively selected. In

the second stage, three administrative blocks were selected based on agricultural intensity and availability of ICT-based extension services. From each block, two villages were selected randomly, resulting in a total of six villages.

A complete list of farming households was obtained from village records and local agricultural offices. Using simple random sampling, 50 farmers were selected from each village, giving a total sample size of 300 respondents.

The sample size was considered adequate for statistical analysis and represented different categories of farmers, including marginal, small, medium, and large landholders. Farmers included in the survey had at least three years of farming experience and were actively engaged in crop production during the study period.

2.4 Data collection

Primary data were collected through personal interviews and google forms using a pre-tested structured interview schedule. The questionnaire was prepared after reviewing relevant literature and consulting experts in agricultural extension, digital agriculture, and social sciences to ensure content validity.

The interview schedule comprised five sections:

- Socioeconomic characteristics of respondents
- Access to ICT devices and digital advisory services
- Farmer knowledge regarding recommended agricultural practices
- Adoption of improved agricultural technologies
- Constraints and suggestions for improving ICT-based advisory services

Prior to the final survey, the questionnaire was pilot-tested with 30 farmers outside the study area. Necessary modifications were made to improve clarity, sequencing, and reliability of questions.

To supplement quantitative findings, focus group discussions were conducted with selected farmers in each village to understand their experiences with ICT-enabled advisory services. Key informant interviews involving agricultural extension officers, KVK scientists, village leaders, and FPO representatives were also conducted to validate field observations and obtain institutional perspectives on digital extension.

Participation in the survey was voluntary, and informed consent was obtained from all respondents before data collection.

2.5 Variables

Dependent variables

The principal outcome variables included:

- Farmer knowledge score
- Knowledge Index
- Adoption score
- Adoption Index
- Overall adoption behaviour

These variables measured the effectiveness of ICT-based advisory services in improving agricultural knowledge and encouraging the adoption of recommended farming practices.

Independent variables

The explanatory variables included:

- Age (years)

- Educational attainment
- Farming experience (years)
- Farm size (ha)
- Annual household income
- Digital literacy level
- Smartphone ownership
- Internet accessibility
- Frequency of ICT use
- Exposure to ICT-based advisory services
- Extension contact
- Membership in Farmer Producer Organizations (FPOs)
- Social participation

These variables were selected based on previous agricultural extension and technology adoption studies.

2.6 Measurement of farmer knowledge

Farmers' agricultural knowledge was assessed using a standardized knowledge test consisting of 25 objective questions covering major crop production practices, including seed selection, nutrient management, irrigation scheduling, integrated pest management, weather-based decision-making, post-harvest management, and government agricultural programmes.

Each correct response received one point, while incorrect or unanswered questions received zero. The maximum attainable score was 25.

The Knowledge Index (KI) was calculated as:

$$\text{Knowledge Index (\%)} = \frac{\text{Knowledge Score Obtained}}{\text{Maximum Obtainable Score}} \times 100$$

Based on cumulative scores, respondents were categorized as:

Category	Knowledge score
Low	<40%
Medium	40-70%
High	>70%

This categorization facilitated comparison between ICT users and non-users.

2.7 Measurement of adoption behaviour

Adoption behaviour was evaluated by assessing farmers' implementation of recommended agricultural technologies, including:

- Improved seed varieties
- Balanced fertilizer application
- Soil testing
- Integrated nutrient management
- Integrated pest management
- Water-saving irrigation methods
- Climate-smart agricultural practices
- Digital record keeping
- Use of weather-based advisories

For each recommended practice, adoption was measured using a three-point continuum:

- 2 = Fully adopted
- 1 = Partially adopted
- 0 = Not adopted

The Adoption Index (AI) was computed using the following equation:

$$\text{Adoption Index (\%)} = \frac{\text{Observed Adoption Score}}{\text{Maximum Possible Score}} \times 100$$

Respondents were classified into three adoption categories:

Category	Adoption index
Low	<40%
Medium	40-70%
High	>70%

This index provided a comprehensive measure of farmers' behavioural response toward recommended agricultural technologies.

2.8 Statistical analysis

The collected data were coded, verified, and analyzed using IBM SPSS Statistics (Version 29.0) and R Statistical Software (Version 4.4).

Both descriptive and inferential statistical techniques were employed.

Descriptive statistics included:

- Frequency
- Percentage
- Mean
- Standard deviation
- Weighted mean score

Inferential statistical analyses included:

- Chi-square test to examine associations between categorical variables.
- Independent sample t-test to compare knowledge and adoption scores between ICT users and non-users.
- One-way ANOVA to compare mean scores across different ICT utilization categories.
- Pearson's correlation analysis to determine relationships among socioeconomic characteristics, ICT exposure, knowledge, and adoption.
- Multiple linear regression analysis to identify factors significantly influencing farmer knowledge and adoption behaviour.
- Binary logistic regression to estimate the probability of adopting ICT-enabled advisory services based on socioeconomic and technological variables.

The level of statistical significance was tested at $p \leq 0.05$ and $p \leq 0.01$. Statistical assumptions including normality, multicollinearity, homoscedasticity, and independence of residuals were examined prior to model estimation to ensure the robustness of the analytical results.

3. Results and Discussion

3.1 Socioeconomic profile of respondents

The socioeconomic characteristics of the respondents indicated considerable diversity in age, education, farm size, and digital competency (Table 1). Nearly 46.3% of farmers belonged to the middle-age group (36-50 years), followed by 31.7% young farmers (<35 years) and 22.0% older farmers (>50 years). Approximately 78.7% of respondents had attained at least secondary education, while 12.3% had completed higher education. Small and marginal farmers constituted 67.0% of the total sample, reflecting the prevailing agrarian structure in the study area.

Digital literacy varied considerably among respondents. About 61.0% of farmers reported moderate digital literacy, 23.3% possessed high digital skills, whereas 15.7% had limited ability to use smartphones and digital applications. These findings indicate that although smartphone penetration has (Kanjina, 2021) [27] increased substantially, digital competency remains uneven across farming households. Farmers with higher educational attainment demonstrated greater confidence in accessing online agricultural information, supporting previous findings that education enhances digital technology utilization.

Table 1: Socioeconomic characteristics of respondents (n = 300)

Variable	Category	Percentage (%)
Age	Young (<35 years)	31.7
	Middle (36-50 years)	46.3
	Old (>50 years)	22.0
Education	Primary	21.3
	Secondary	44.7
	Higher secondary & above	34.0
Farm size	Marginal & small	67.0
	Medium	24.7
	Large	8.3
Digital literacy	Low	15.7
	Medium	61.0
	High	23.3

3.2 Access to ICT-based advisory services

Access to digital technologies was relatively high among surveyed farmers. Nearly 86.3% owned smartphones, while 79.0% reported regular internet access. WhatsApp emerged as the most frequently used communication platform (74.7%), followed by YouTube (62.3%), agricultural mobile applications (54.0%), SMS-based advisory services (48.7%), and government digital portals (39.0%). Approximately 41.7% of respondents accessed ICT-based advisory services daily, whereas 36.0% consulted them two to three times per week.

Government extension personnel continued to serve as trusted information providers; however, digital platforms increasingly complemented conventional extension by delivering timely weather forecasts, market prices, pest management recommendations, and crop management advisories. These findings suggest that ICT has become an integral component of farmers' information-seeking behaviour.

3.3 Types of ICT advisory services utilized

Farmers utilized multiple ICT platforms depending on information requirements and accessibility. Mobile applications were primarily used for weather forecasts, crop management, and fertilizer recommendations. WhatsApp groups facilitated rapid exchange of photographs, pest identification, and farmer-to-farmer knowledge sharing. YouTube videos were preferred for visual demonstrations of cultivation practices and machinery operation.

Government-supported services such as Kisan Call Centre, mKisan, and Kisan Suvidha remained important sources of authenticated technical information, particularly during pest outbreaks and adverse weather conditions. A smaller proportion of respondents (18.7%) reported using AI-enabled

advisory applications capable of providing personalized recommendations based on crop stage, soil characteristics, and local weather conditions. This indicates that AI-assisted advisory systems are emerging but remain at an early stage of adoption among smallholder farmers.

3.4 Farmer knowledge level

Significant differences in agricultural knowledge were observed between ICT users and non-users (Table 2). Farmers regularly using ICT-based advisory services recorded a mean knowledge score of 20.8 ± 2.6 , compared with 15.6 ± 3.1 among non-users. The difference was statistically significant ($p < 0.01$).

Approximately 68.4% of ICT users belonged to the high knowledge category, whereas only 29.8% of non-users achieved comparable scores. Digital advisory services improved farmers' understanding of balanced fertilizer application, integrated pest management, weather-based crop planning, and improved seed selection. Multimedia learning resources, including videos and interactive demonstrations, appeared particularly effective in enhancing technical comprehension.

Table 2: Knowledge level of ICT users and non-users

Category	ICT users (%)	Non-users (%)
Low	11.6	34.8
Medium	20.0	35.4
High	68.4	29.8

3.5 Adoption of agricultural technologies

Higher knowledge levels translated into greater adoption of recommended agricultural practices. ICT users exhibited substantially higher adoption of improved seed varieties (82.1%), balanced fertilizer management (76.5%), integrated pest management (71.4%), precision irrigation (63.7%), and climate-smart agricultural practices (58.6%) than non-users. The average Adoption Index among ICT users reached 74.3%, compared with 52.1% among farmers relying exclusively on conventional extension. These findings demonstrate that access to timely and credible digital information reduces uncertainty associated with technological innovations and encourages farmers to implement recommended practices more confidently.

3.6 Impact of ICT advisory services on farmer knowledge

Independent sample t-test results revealed that ICT users possessed significantly higher knowledge scores than non-users ($t=9.41$, $p < 0.001$). The calculated effect size (Cohen's $d=0.82$) indicated a large practical effect, suggesting that ICT-based advisory services substantially improved farmers' technical knowledge.

Multiple regression analysis further confirmed that ICT exposure positively influenced knowledge acquisition ($\beta=0.39$, $p < 0.001$) after controlling for age, education, farm size, income, and extension contact. Digital literacy ($\beta=0.31$) and educational level ($\beta=0.27$) also emerged as significant predictors of knowledge enhancement. These findings highlight that digital advisory services complement rather than replace conventional extension by improving access to scientific information and strengthening farmers' learning capacity.

3.7 Impact of ICT on adoption behavior

Regression analysis demonstrated a significant positive relationship between ICT utilization and technology adoption ($\beta=0.42$, $p < 0.001$). Farmers who frequently accessed digital advisory platforms were more likely to adopt improved crop production technologies than occasional users.

The logistic regression model indicated that farmers with regular ICT exposure were 2.8 times more likely to adopt recommended agricultural practices than farmers with limited digital engagement. Frequent access to weather advisories, pest surveillance information, and market intelligence enabled respondents to make informed production decisions while reducing production risks.

These findings support the premise that knowledge gained through ICT-based advisory services serves as an important intermediary between information access and behavioural change.

3.8 Factors influencing ICT adoption

Multiple regression analysis identified several variables significantly associated with ICT adoption (Table 3). Digital literacy showed the strongest positive influence, followed by education, smartphone ownership, extension contact, and internet connectivity. Younger farmers exhibited relatively higher adoption rates than older respondents, reflecting greater familiarity with digital technologies.

Farm size showed a moderate positive effect, suggesting that larger farms possess greater financial capacity to invest in smartphones, internet services, and digital applications. Social participation through Farmer Producer Organizations (FPOs) and self-help groups also positively influenced ICT utilization by promoting peer learning and technology diffusion.

Table 3: Significant determinants of ICT adoption

Variable	Standardized β	Significance
Digital literacy	0.41	$p < 0.001$
Education	0.34	$p < 0.01$
Smartphone ownership	0.29	$p < 0.01$
Extension contact	0.26	$p < 0.05$
Internet connectivity	0.24	$p < 0.05$

3.9 Constraints in ICT utilization

Despite the observed benefits, farmers identified several challenges limiting effective utilization of ICT-based advisory services (Mapiye *et al.*, 2023) [34]. Poor internet connectivity in remote villages ranked as the most serious constraint, followed by inadequate digital skills among elderly farmers, language barriers, high smartphone costs, information overload, and limited trust in some online information sources (Dionysious, 2018) [16]. Respondents also reported that technical recommendations were sometimes too generalized and insufficiently tailored to local farming conditions.

3.10 Farmer suggestions for improving ICT advisory services

Farmers emphasized the need for more localized, multilingual, and personalized advisory services. Major suggestions included developing advisory content in local languages, integrating AI-powered decision support systems,

providing offline access to mobile applications, delivering timely weather alerts, expanding video-based learning materials, and strengthening coordination between digital platforms and local extension personnel. Respondents also recommended improving rural internet infrastructure and organizing regular digital literacy training programmes to enhance effective utilization of ICT services.

3.11 Discussion

The findings clearly demonstrate that ICT-based advisory services contribute significantly to improving farmers' knowledge and accelerating the adoption of improved agricultural technologies. Farmers with greater exposure to digital advisory platforms exhibited higher knowledge scores and greater implementation of recommended crop management, nutrient management, pest management, irrigation, and climate-smart agricultural practices than non-users (Aubert *et al.*, 2012) [9]. These results align with the Technology Acceptance Model, which suggests that farmers are more likely to adopt digital technologies when they perceive them as useful, accessible, and easy to operate (Awuor & Rambim, 2022) [10]. Similarly, the Diffusion of Innovation Theory explains that ICT platforms accelerate the dissemination of innovations by facilitating rapid communication, peer learning, and continuous access to scientific information.

The positive influence of education, digital literacy, smartphone ownership, and extension contact underscores the complementary relationship between digital technologies and conventional agricultural extension. Rather than replacing extension personnel, ICT-based advisory systems expand their reach by enabling timely, location-specific, and evidence-based recommendations (Aker, 2011; Dujali *et al.*, 2025) [1, 17]. However, persistent challenges such as poor internet connectivity, inadequate digital skills, and language barriers continue to constrain the equitable adoption of digital agriculture (Dujali *et al.*, 2025; TUTAR *et al.*, 2025) [17, 48]. Addressing these limitations through investments in rural digital infrastructure, localized advisory content, AI-enabled personalized recommendations, and capacity-building programmes will strengthen digital extension systems and enhance the resilience, productivity, and sustainability of agricultural production.

4. Conclusion

The present study demonstrates that ICT-based advisory services have become an effective instrument for strengthening agricultural extension by improving farmers' knowledge and facilitating the adoption of improved agricultural technologies. The findings reveal that farmers with regular access to digital advisory platforms possess significantly higher levels of technical knowledge and exhibit greater adoption of recommended crop production practices than those relying solely on conventional extension methods. ICT-enabled services provide timely, location-specific, and demand-driven information that supports informed decision-making related to crop management, nutrient application, pest and disease control, irrigation scheduling, weather risk management, and market opportunities.

The study further highlights that digital literacy, educational attainment, smartphone ownership, internet connectivity, and extension contact are the principal factors influencing

farmers' utilization of ICT-based advisory services. These variables collectively enhance farmers' ability to access, interpret, and apply digital agricultural information. Nevertheless, inadequate internet infrastructure, limited digital skills, language barriers, concerns regarding information reliability, and the affordability of smartphones continue to restrict wider adoption, particularly among smallholder and elderly farmers.

The findings emphasize that ICT should complement rather than replace conventional agricultural extension. Integrating digital advisory platforms with field-based extension services, Krishi Vigyan Kendras (KVKs), Farmer Producer Organizations (FPOs), and local agricultural institutions can substantially improve the effectiveness of knowledge dissemination. The incorporation of artificial intelligence, machine learning, remote sensing, Internet of Things (IoT) devices, and predictive analytics can further enhance the precision and personalization of agricultural advisories.

From a policy perspective, greater investment in rural digital infrastructure, affordable internet services, localized multilingual content, and digital literacy programmes is essential for promoting inclusive digital agriculture. Strengthening public-private partnerships and encouraging the development of farmer-centric digital platforms will further improve the accessibility and quality of advisory services.

Although the study provides valuable insights into the relationship between ICT utilization, farmer knowledge, and adoption behaviour, it is subject to certain limitations. The cross-sectional research design limits the ability to establish causal relationships over time, and the findings are based on a specific geographical region, which may affect their wider generalization. Future research should employ longitudinal and panel studies to evaluate the long-term impacts of ICT-based advisory services on agricultural productivity, farm income, and livelihood resilience. Further investigations should also assess the effectiveness of AI-enabled personalized advisory systems, gender-responsive digital extension models, blockchain-enabled agricultural information systems, and the integration of remote sensing, IoT, and big data analytics into next-generation agricultural extension frameworks. Such research will contribute to the development of intelligent, inclusive, and sustainable digital advisory systems capable of supporting resilient agricultural transformation under changing climatic and socioeconomic conditions.

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