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Assessing the Effectiveness of Digital Technologies in Enhancing Climate-Smart Agricultural Practices among Smallholder Farmers in Semi-Arid Regions

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Abstract

Digital technologies are becoming vital tools for helping smallholder farmers manage climate-related challenges, especially in semi-arid regions like Karnataka. This study examines how mobile apps, SMS alerts, and online platforms support climate-smart agricultural (CSA) practices that align with global efforts to achieve Sustainable Development Goals particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action). A survey was conducted with 350 smallholder farmers across three agro-climatic zones. The questionnaire was based on the Unified Theory of Acceptance and Use of Technology (UTAUT), which explores how farmers perceive the usefulness and ease of digital tools, the influence of others on their decisions, and the availability of support systems. Responses were collected using a 5-point Likert scale to measure levels of agreement.

The data was analyzed using statistical methods such as regression and structural equation modeling (SEM). Findings showed that farmers who considered the tools useful and had access to support were more likely to adopt them. These farmers also reported improvements in crop yields, water-use efficiency, and resilience to climate stress key indicators of progress toward sustainable agriculture. The study emphasizes the importance of reliable infrastructure, proper training, and locally relevant content to increase adoption of digital technologies. By identifying key factors that influence usage and linking them to positive farming outcomes, the research provides practical insights for policymakers, agricultural extension workers, and technology developers. These insights can help design better programs that not only support smallholder farmers in climate-affected regions but also contribute meaningfully to global sustainability targets.

Keywords: *Climate-smart agriculture (CSA), Smallholder farmers, Digital technology adoption, Sustainable Development Goals (SDGs), UTAUT), Rural development strategies*

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Background & rationale of the proposed research work

Agriculture remains the backbone of Karnataka's rural economy, with smallholder farmers representing most of the agricultural workforce (Das, P. K. et.al, 2025). Over 75% of Karnataka's cultivable land lies under dryland farming and is highly vulnerable to climate threats, soil degradation, and water scarcity (Bordoloi, P., & Dutta, N, 2025) these impacts are compounded in the Northern, Central and Southern Dry Zones where unseasonal monsoons, and declining groundwater use lead to frequent crop failure and increased farmer distress (Hossain, S. M, 2025).

Many smallholders are facing economic insecurity because of risks they face in the form of climate uncertainty, requiring universal more sophisticated strategies of action and decision-making (Gobikashri, N. et.al, 2025) Collectively, climate-smart agriculture (CSA) provides increasingly sophisticated approaches to enhance productivity, resilience, and sustainability as farming adapts to shifting environmental conditions (Dechamma, N, 2025)This approach to farming provides broad diversity in functioning that integrates new solutions including precision irrigation, drought-resistant crops, and more appropriate soil health management (Aliyar, Q et.al, 2025). But, like any innovative technology and farming practices, and to implement CSA depends on engaged meaningful use of new technologies that happen in a timely way (Lalmuanzuala, B. et.al, 2025). Irrespective of CSA, changing state of mind going forward means advances in adaptation, decision-making, and the use of my resources has to be accompanied by access to appropriate and timely information (Marappan, K et.al, 2025). The importance of meaningful data adoption through digital technologies can have significant implications for farmers (Das, B et.al, 2025).

The introduction of initiatives, both at the federal and state levels, such as Government of Karnataka (GOK) Digital Agriculture Mission, Krishi Bhagya, Bhoomi, m-Kisan and more have been responsible for the introduction of multiple technologies to help farmers over the last two years, which include mobile apps, automated/standardized SMS alerts, social media, air / satellite monitoring technology and onsite sensors (Dash, S. K. et.al, 2025). Still, the above program features, particularly digital technologies (Pouchepparadjou, A et.al, 2025) such as mobile apps and SMS alerts, are often unevenly adopted and brought into play to prevent farming losses in semi-arid zones due to critical constraints like limited connectivity, limited digital literacy, digital equity and localized tech or content (Ranjan Kumar, R., & Rajagopalan, A, 2025)

The proposed research explicitly applies the Unified Theory of Acceptance and Use of Technology (UTAUT) to explore how smallholder farmers perceive and engage with digital tools. As such, the project will identify behavioral motivators and obstacles in the uptake of digital farming technologies as it relates to three agro-climatic zones as defined by the Karnataka Government.

This research is necessary and relevant because:

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- It assesses how digital technologies will impact environmental changes and CSA resulting in higher yields, improved water-use efficiency (WUE), enhanced climate resilience, etc.
- It provides clear and empirical insights on how sociocultural, behavioral, structural and other context-specific factors continue to shape farmers' agricultural digital uptake
- It facilitates the design of interventions that are anchored in relationships between the two regions taken together with those specific to them on the one hand, and global objectives like the Sustainable Development Goals (SDG 2 and SDG 13) on the other.
- It contributes to policy development, agricultural extension approaches, and digital governance frameworks helping to find ways to empower more smallholder farmers in zones that are more sensitive to climate vulnerabilities.

The proposed project strives to leverage the evidence to identify the work between actual technology use and access to technology, all informed by digital technology to crystallize the relationship, as well as the long-term climate management significance, between local farmers and the emergence of new farming technologies to contribute to systemically equitable agricultural practices.

Research Objectives

1. To assess the adoption and usage patterns of digital technologies supporting climate-smart agricultural practices among smallholder farmers in Karnataka's semi-arid agro-climatic zones.
2. To evaluate farmers' behavioral intentions and perceptions toward digital tools using the Unified Theory of Acceptance and Use of Technology (UTAUT) framework.
3. To analyze the impact of digital technologies on agricultural outcomes such as crop productivity, water use efficiency, and resilience to climate variability.
4. To develop a conceptual model integrating UTAUT constructs with climate-smart agricultural outcomes, tailored to the socio-economic and ecological context of smallholder farmers in Karnataka.

Methodology

1. *Research Design*

This study adopts a **cross-sectional survey design** using a structured questionnaire to collect quantifiable data from smallholder farmers. The aim is to statistically analyze adoption patterns, behavioral intentions, and the impact of digital technologies on climate-smart agricultural outcomes.

2. *Study Area*

The research will be conducted in Karnataka's **semi-arid agro-climatic zones**, specifically:

- **Northern Dry Zone:** Vijayapura, Bagalkot
- **Central Dry Zone**: Chitradurga, Tumakuru
- **Southern Dry Zone**: Mandya, Mysuru

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These zones are selected due to their high exposure to climate stress and relevance to dryland farming systems.

3. *Population and Sampling*

- **Target Population**: Smallholder farmers (owning less than 2 hectares of land) actively engaged in agriculture.
- **Sampling Technique: Stratified random sampling** to ensure representation across zones and demographic categories (age, education, farm size).
- **Sample Size**: Approximately **350 respondents**, calculated using Cochran's formula for adequate statistical power and generalizability.

4**. *Data Collection Instrument***

- A **structured questionnaire** will be developed based on the **UTAUT model**, covering:
  - **Performance Expectancy**
  - **Effort Expectancy**
  - **Social Influence**
  - **Facilitating Conditions**
  - **Behavioral Intention**
  - **Actual Usage**
  - **Agricultural Outcomes** (e.g., yield, water efficiency, resilience)
- Responses will be measured using a **5-point Likert scale** (Strongly Disagree to Strongly Agree).

5. ***Data Analysis Techniques***

Each objective will be addressed using appropriate statistical tools:

Objective	Statistical Techniques
1. Adoption & Usage Patterns	Descriptive statistics (mean, frequency, percentage), cross-tabulation
2. UTAUT-Based Perceptions	Exploratory Factor Analysis (EFA), reliability analysis (Cronbach's alpha), multiple regression
3. Impact on Agricultural Outcomes	linear regression
4. Conceptual Model Development	Confirmatory Factor Analysis (CFA), Structural Equation Modeling (SEM)

- **Software Tools**: SPSS, Smart PLS will be used for data entry, cleaning, and analysis.

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6. ***Validity and Reliability***

- **Pilot Testing**: The questionnaire will be pre-tested with 30 farmers to ensure clarity and reliability.
- **Reliability Analysis**: Cronbach's alpha will be used to test internal consistency of UTAUT constructs.
- **Construct Validity**: Factor analysis will confirm the dimensionality of the model.

Significance of the Study

This research holds critical significance for advancing sustainable agriculture and digital inclusion among smallholder farmers in Karnataka's semi-arid zones. As climate variability intensifies and resource constraints deepen, the need for adaptive, technology-driven solutions becomes more urgent (Kashyap, G. R.et.al, 2025). The study addresses this need by evaluating how digital technologies such as mobile apps, SMS advisories, and online platforms can enhance climate-smart agricultural (CSA) practices.

Key Contributions

- Empowering Smallholder Farmers: By identifying behavioral and infrastructural factors that influence technology adoption, the study empowers farmers to make informed decisions, improve productivity, and build resilience against climate stress.
- Bridging the Digital Divide: The research highlights barriers such as poor connectivity, limited digital literacy, and lack of localized content offering actionable insights to bridge the gap between innovation and grassroots implementation.
- Policy and Program Design: Findings from the study can inform policymakers, agricultural extension workers, and technology developers in designing region-specific interventions that are inclusive, scalable, and contextually relevant.
- Advancing Sustainable Development Goals (SDGs**)**: The study directly contributes to SDG 2 (Zero Hunger) and SDG 13 (Climate Action) by promoting sustainable farming practices and enhancing climate resilience through digital tools.

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