Doctoral Dissertation
Academic Year 2025

Adoption of digitalization of climate-smart agricultural services: Case of Tamil Nadu, India

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ABSTRACT OF DOCTORAL DISSERTATION

Agricultural information is central to farmers' decision-making, from sowing to harvesting and selling. Inefficient information dissemination or low access to agricultural information may decrease agricultural productivity, affecting farmers' income. Digitalization of climate-smart agricultural information (DCSA) holds significant potential to enhance resilience in farming communities facing climate change. Advisory services, a part of DCSA, present a high-impact and low-cost and time solution for small-scale farmers in India, especially in Tamil Nadu. Given the scenario of soil diversity, and climate uncertainty, localized digital advisories help optimize crops, manage risks, and improve farm decisions. However, the adoption of advisories remains limited among farmers. The lack of a sufficient number of agriculture extension professionals who can facilitate farmer training poses a key problem. In addition, the public sector, a significant extension service provider, is burdened with providing other non-extension support to farmers, such as subsidies, leaving no time for them to focus on bridging the core extension functions. Understanding the factors influencing farmers' perception is essential to improving adoption rates. The preliminary findings involving interviews with farmers and stakeholders revealed that for equitable adoption of digital advisory services that enhances lives in addition to economic benefits, contextualized digital agricultural information, community-led bottom-up approach, and sustainable institutional support are essential but not adequately incorporated in the institutional design. Therefore, the research was designed to investigate the factors influencing farmers' perception toward the adoption of Digital Climate-Smart Agricultural (DCSA) services. An analytical framework comprising of five constructs and a mediating construct was proposed to assess the key influences on farmers' perception of DCSA and also assess the effectiveness of institutional design in disseminating digital agricultural information. An in-person survey with a well-structured questionnaire covering 64 data points was administered to 200 farmers from four different agro-ecological zones in Tamil Nadu. The farmers were affiliated with three different types of institutional (NGO, private and government) extension support. Exploratory Factor Analysis (EFA) was employed to evaluate the reliability of the constructs and to identify factor loadings. Confirmatory Factor Analysis (CFA) further validated the framework, and Structural Equation Modelling (SEM) was used to examine the relationships between constructs.

Research findings revealed that five key latent variables significantly influence the adoption of DCSA in Tamil Nadu. Awareness and DCSA Adoption (ADA) indicators showed strong factor loadings (0.79–1.19), with specific DCSA tool awareness (ADA3) being most influential. Agricultural Information Seeking Behaviour (AISB) also loaded well (0.64–1.15), where seeking advice from peers or local leaders (AISB5) stood out. Recognition of Climate Change Impact (RCCI) demonstrated high loadings (0.66–1.76), especially for pest management in an environmentally friendly way (RCCI5). Infrastructure Facilities (IF) and Awareness of Government Policies (AGP) presented robust constructs (loadings 0.80–1.23), with availability of seeds and fertilizers near government and private outlets (AGP5) played a significant role. CFA results showed AGP had the most substantial positive influence on Extension Agency Contact (EAC) ($\beta = 1.249$, $p < 0.001$), followed by IF ($\beta = 0.094$, $p < 0.001$), while AISB showed a negative influence ($\beta = -0.180$, $p < 0.001$). EAC strongly influenced Farmers' Perception (FP) ($\beta = 1.206$, $p < 0.001$). Notably, NGOs and private extension agencies are found to be highly effective in strengthening farmer perceptions, with NGOs achieving an R^2 of 15.46% and private agencies 14.73%. Overall, pluralistic extension systems, clear government communication, and targeted digital infrastructure are crucial for accelerating digital advisory adoption among farmers.

This study addresses a critical gap by exploring environmental factors and contextual variables influencing DCSA adoption, offering valuable insights for both academic and practical advancements in climate-smart agriculture. It recommends institutionalizing GO-NGO Partnerships, mainstreaming community-based demonstrations, redesigning and integrating digital platforms into centralized systems among others to ensure effective dissemination of digital agricultural information. This research contributes to existing technology adoption models in agriculture by proposing and validating a new conceptual framework.

Keywords: Climate-smart agriculture, Digitalization, Climate change adaptation, Structural equation modeling, Farmer's perception.

博士論文の要旨

農業情報は、播種から収穫・販売に至るまで、農家の意思決定において中心的な役割を果たしている。しかし、情報普及の非効率性や農業情報へのアクセス制限は、農業生産性を低下させ、農家の所得にも悪影響を及ぼす可能性がある。気候変動に直面する農業コミュニティにおいて、気候スマート農業情報（DCSA）のデジタル化はレジリエンス向上に大きな可能性を秘めているが、その採用は依然限定的である。農家研修を支援できる普及専門家の不足に加え、公的機関が補助金業務などに追われることで、普及活動が後回しになるという課題も存在する。このため、農家の認識に影響を与える要因を理解することが、DCSA 普及促進に不可欠である。

本研究では、農家と関係者への予備調査を基に、地域に即した農業情報、コミュニティ主導のアプローチ、持続可能な制度支援が DCSA 採用促進に重要であることを確認した。これに基づき、農家の認識に影響を与える要因を 7 つの構成概念に整理し、タミル・ナードゥ州の 4 つの農業生態ゾーンに属する 200 人の農家（NGO、民間、政府系普及機関支援）を対象に調査を実施した。探索的因子分析（EFA）と確証的因子分析（CFA）により測定モデルの信頼性・妥当性を検証し、構造方程式モデリング（SEM）を用いて概念間の因果関係を分析した。

分析の結果、ADA、AISB、RCCI、IF、AGP の 5 つの潜在変数が DCSA 採用に有意な影響を及ぼしていることが判明した（因子負荷量 0.64～1.76）。特に、ADA3、AISB5、RCCI5、AGP5 が主要な影響指標であった。SEM 分析では、AGP が Extension Agency Contact（EAC）に対して最も強い正の影響（$\beta=1.249$, $p<0.001$）を持ち、次いで IF（$\beta=0.094$, $p<0.001$）が続いた。一方、AISB は EAC に負の影響（$\beta=-0.180$, $p<0.001$）を示した。EAC は農家の認識（FP）に強い影響（$\beta=1.206$, $p<0.001$）を与えた。NGO および民間普及機関の効果も顕著であり、NGO（$R^2=15.46\%$）、民間機関（$R^2=14.73\%$）が農家認識向上に寄与していた。

本研究は、環境要因と文脈的要素が DCSA 採用に与える影響を明らかにし、地域文脈に即したデジタル情報提供、コミュニティ主導型支援、持続可能な制度設計の必要性を提言した。農家と普及機関の関係性強化と政策情報の効果的伝達が、今後の気候スマート農業推進に向けて重要であることを示した。

キーワード：気候スマート農業、デジタル化、気候変動適応、構造方程式モデリング、農家の認識

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List of associated publications

Journal papers

Suresh, D., Shaw, R., & Masutomi, Y. (2025). Farmers' perspective on digitalization of climate-smart agricultural practices: a comparative study in Tamil Nadu, India. Discover Agriculture, 3(1), 1-21. https://doi.org/10.1007/s44279-025-00176-w

Suresh, D., Zhang, Y., Cao, Y., & Shaw, R. (2024). Climate Change Adaptation Strategies for Grape Cultivation in Yamanashi Prefecture of Japan. Rural and Regional Development, 2(1), 10001. https://doi.org/10.35534/rrd.2024.10001

Suresh, D., Choudhury, A., Zhang, Y., Zhao, Z., & Shaw, R. (2024). The Role of Data-Driven Agritech Startups—The Case of India and Japan. Sustainability, 16(11), 4504. https://doi.org/10.3390/su16114504

Conference Presentations

Suresh, D., (2023, September 23–24). Digital Agricultural Information Dissemination Systems in Tamil Nadu. Oral presentation at the 36th JASAS Annual Conference, Kobe University, Japan.

Suresh, D., (2024, May 9-10). Agricultural Information Dissemination System in Tamil Nadu, India. Oral presentation at the Nexus Forum 2024 in Hong Kong Polytechnic University in Hong Kong.

Suresh, D., (2024, Aug 28-30). The Role of Agri Startups Towards Information Delivery. Oral presentation at the International Conference on Resilient Systems (ICRS) in National university of Singapore.

Suresh, D., (2025, March 13-15). Discussion on Digital Agricultural Information Dissemination Systems in Tamil Nadu, India. Poster presentation at the 16th International Conference on Environmental and Rural Development 2025 in Tokyo University of Agriculture in Tokyo, Japan.

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to my research advisor, Professor Rajib Shaw, for his inspirational guidance, unwavering support, and patient mentorship throughout this journey. His encouragement, exposure to different opportunities like workshops, seminars and insightful advice have been instrumental in shaping my research and personal growth during my doctoral studies.

I am grateful to my co-research advisors, Professor Wanglin Yan, Professor Tomohiro Ichinose, and Professor Sudip Mitra from the Indian Institute of Technology, Guwahati, for their valuable scholarly input and constructive feedback. Their expertise and encouragement have significantly enriched the quality and direction of my research.

I extend my sincere thanks to the M. S. Swaminathan Research Foundation (MSSRF), particularly Dr. Rajkumar, for their invaluable support in facilitating field visits. Their assistance in the field was crucial for my data collection and deepening my understanding of the local context.

I would also like to acknowledge Dr. Masutomi Yuji of the National Institute for Environmental Studies (NIES), Japan, for mentoring me during my time as a research student at NIES. His guidance provided a strong foundation for my research. My heartfelt appreciation and thanks goes to all the farmers who generously participated in this study. Their time, perspectives, and lived experiences added immeasurable value to this research.

I gratefully acknowledge the financial and institutional support provided by the Japan Science and Technology Agency (JST), which made this research possible. I also appreciate the Keio SFC Society and Gakkai for their support in enabling my presentation at an academic conference.

I want to thank all members of the GRIL student lab. It has been a privilege to be part of such a dynamic and collaborative group. I have learned so much from each one of them, and I am grateful for the support, camaraderie, and shared experiences that made this journey both enriching and enjoyable.

On a personal note, I am profoundly grateful to my supportive parents, Dr. Malarvizhi and Mr. Suresh, and my wonderful daughter Aadhya, whose love and encouragement have consistently been a source of strength. Their belief in me has served as a driving force throughout this journey. I am grateful to my companion and life partner, Ragavendran. His unwavering support, motivation, love, and belief in me have been my anchor throughout this journey. This journey would not have been possible without his constant encouragement and kind understanding. I offer my sincere thanks to everyone who has walked this path with me, in big and small ways. Finally, I thank Almighty God for all His blessings upon me and for enabling me in my research pursuits.

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CHAPTER 1: INTRODUCTION

1.1 Research Background

The research delves into improving the climate resilience of small-holder farmers in the context of Indian Agriculture. Agricultural information is central to farmers' decision-making, from sowing to harvesting and selling. Agricultural information dissemination is the process of delivering research-based information to farmers. Inefficient information dissemination or low access to agricultural information may decrease agricultural productivity, affecting farmers' income. Information and Communication Technology (ICT) is vital in disseminating information related to climate-smart agricultural practices, bringing about resilience in agri-food systems. Many studies have validated the effectiveness of ICT and its implication in agricultural information dissemination. However, the advantage of ICT is yet to be reaped to its full benefit in the agricultural sector of the Indian economy.

<u>India's Digital agricultural initiatives</u>:
In recent times, the digital revolution has transformed governance and service delivery in India, by creating digital identities, and secured payments and transactions. The digital ecosystem in finance, healthcare, education, and retail has grown extensively, making the country a leader in citizen-centric digital solutions. A proposal to create a Digital Public Infrastructure (DPI) for agriculture was made in the Union Budget 2023-24, in order to bring a similar transformation in the agricultural sector. This DPI initiative was strengthened more in the Budget 2024-25, with a plan to provide a comprehensive and useful data on farmers consisting of authenticated demographic details, land holdings and crops sown.

In line with the policies of state governments, these digital initiatives of the central government will include cultivators and tenant farmers and also connect with the relevant Digital Public Infrastructure of the State Governments and Ministries of the Government of India. This is to use data of farmers on livestock, fisheries, soil health, other vocations, family details and schemes and benefits availed by them and thus resulting in innovative farmer-centric digital services in the agriculture sector.

<u>Digital Agriculture Mission:</u>
Further, the government of India approved a Digital Agriculture Mission in September 2024, with an outlay of Rs. 2817 Crore, including the central share of Rs. 1940 Crore. This is considered as an umbrella scheme to support the country's digital agricultural initiatives as proposed in the union budgets 2023-24 and 2024-25. It involves building Digital Public Infrastructure, implementing the Digital General Crop Estimation Survey (DGCES), and taking up other IT initiatives by the Central Government, State Governments, and Academic and Research Institutions. The crux of the Digital Agriculture Mission is DPI for agriculture, aligning with the vision of Viksit Bharat@2047.

1. **AgriStack:** As a collaborative project between the various agencies of the Central and State Governments, AgriStack is being built in a federated structure. It is a farmer-centric DPI which will enable efficient, easier, and faster services and scheme delivery to farmers. It comprises three foundational registries or databases in the agriculture sector, i.e., the Farmers' Registry, Geo-referenced village maps and the Crop Sown Registry, all created and maintained by the State Governments/ Union Territories.

   A digital identity similar to Aadhaar will be given to farmers. This Farmer ID, to be a trusted 'Kisan ki Pehchaan' given under AgriStack, will be linked dynamically to the State's land records, livestock ownership, crops sown, demographic details, family details, schemes and benefits availed etc. The mobile-based ground surveys i.e. Digital Crop Survey to be conducted in each season, will record the crops sown by the farmers.

   The centre and the state governments will be signing a Memorandum of Understanding (MoU) for the creation and implementation of DPI for agriculture. 19 states have so far signed MoUs with the Ministry of Agriculture, Government of India.

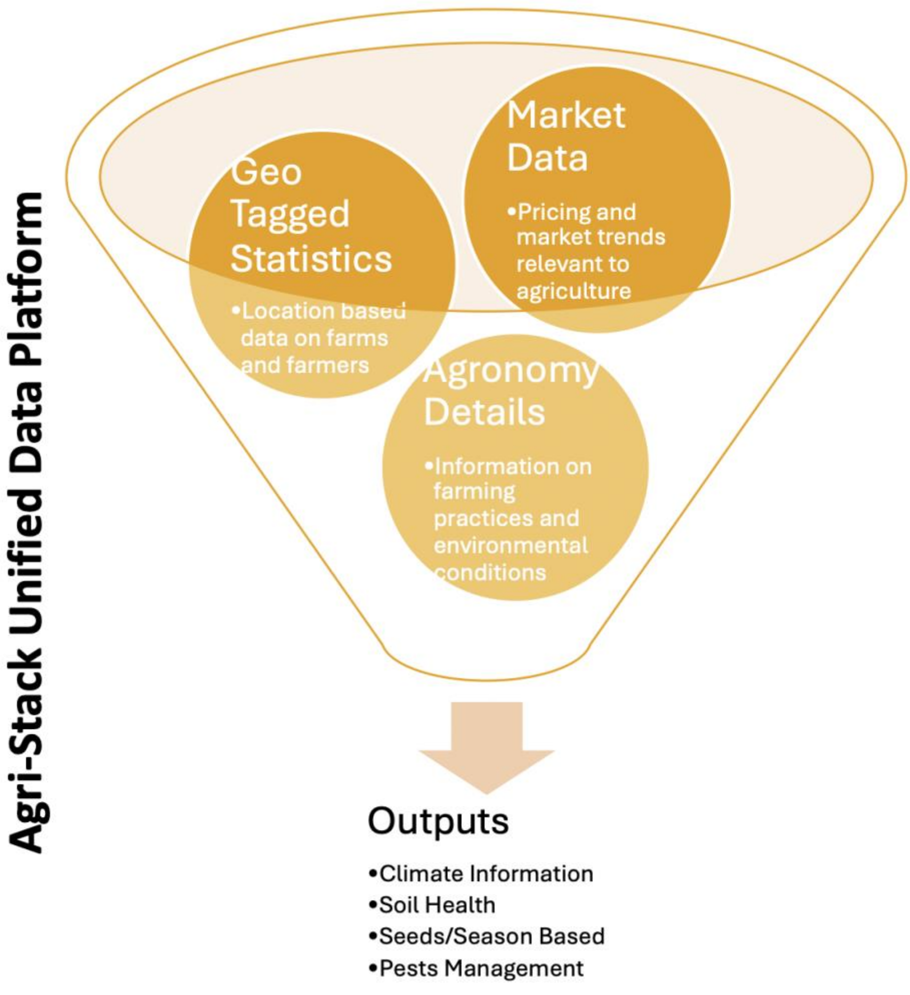


Figure 1: Agristack, unified data platform

On a pilot basis, the basic IT infrastructure for implementing AgriStack has been developed and already tested as follows:

(i) Pilot study have been conducted in one district across each of the six States: Uttar Pradesh (Farrukhabad), Gujarat (Gandhinagar), Maharashtra (Beed), Haryana (Yamuna Nagar), Punjab (Fatehgarh Sahib), and Tamil Nadu (Virudhnagar). The government has targeted to create digital identities for 11 crore farmers over three financial years: Six crore farmers in FY 2024-25, three crore farmers in FY 2025-26, and two crore farmers in FY 2026-27.

(ii) In 2023-24, pilot study on the Digital Crop Survey aimed at the development of the Crop Sown Registry was conducted in 11 States. The actual target is to launch the Digital Crop Survey across the nation within two years, covering 400 districts in FY 2024-25 and all the districts in FY 2025-26.

2. The Krishi Decision Support System: This system intends to provide timely and reliable information to farmers, so as to enable them to make informed decisions. A comprehensive geospatial system to unify remote sensing-based information on Crops, Soil, Weather, water resources, etc. will be created under this system.

3. Soil Profile Mapping: Under this mission, it involves the mapping of soil properties, moisture levels and nutrient content, to empower precision agriculture. It is envisaged to do soil profile maps on a 1:10,000 scale of about 142 million ha of the country's agricultural land. In fact, a detailed soil profile inventory of about 29 million ha has already been completed.

The Digital General Crop Estimation Survey (DGCES)

This is yet another initiative under the Digital Agricultural Mission, to build the country's digital public infrastructure for agriculture. Based on scientifically designed crop-cutting experiments, DGCES will provide yield estimates. This initiative will be very useful in making accurate estimates of agricultural production.

Overall, the Digital Agricultural Mission, with a catalytic effect, will create both direct and indirect employment in the agriculture sector. Moreover, the initiatives such as the digital crop surveys, collection of ground-truthed data for remote sensing, etc., under the Mission, are expected to provide employment opportunities to about 2.5 lakh trained local youth and Krishi Sakhis.

The Mission aims at ensuring the implementation of its various components at the grassroots level, so that the ultimate beneficiaries will be farmers. The Mission aims to make service delivery mechanisms more efficient and transparent for the farmers and the stakeholders in the agriculture sector by using modern digital technologies, such as data analytics, artificial intelligence, and remote sensing and by leveraging trustful data on farmers, farmlands and crops.

The outcome expected of the Mission are:

i) Tedious paperwork can be avoided by the farmers with little or no need to physically visit various offices or service providers. They would be able to digitally identify and authenticate himself/herself to access benefits and services. For instance, they could digitally avail Government schemes and crop loans, connect to agri-input suppliers and buyers of agricultural produce, access personalized advisories in real time, etc.

ii) The reliable data would enable the government agencies to make schemes and services more efficient and transparent, such as paperless MSP-based procurement, crop insurance, and credit card-linked crop loans, and develop systems for the balanced use of fertilizers, etc. Accurate crop production estimation could become possible with the 'digitally captured data on crop-sown area', along with 'Digital General Crop Estimation survey-based yield' and remote-sensing data. Further, crop diversification and evaluation of irrigation needs according to the crop and season could also be facilitated.

iii) The information available on Krishi-DSS would support crop map generation. This would help in identifying crop sown patterns, drought/flood monitoring and technology/model-based yield assessment for settling crop insurance claims by the farmers.

iv) Ultimately, the stakeholders in the agriculture ecosystem will be enabled to establish efficient value chains for agricultural inputs and post-harvest processes through these Digital Public Infrastructure for Agriculture developed under the Mission. It's also likely to develop solutions for customized advisory services to farmers relating to crop planning, crop health, pest and disease management, and irrigation requirements, ensuring that the farmers receive the best possible and timely guidance and services.

In the context of the study area, Tamil Nadu introduced GRAINS (governance and reforms in agriculture using ICT enabled networked systems). The Tamil Nadu government launched a digital platform named GRAINS (Governance and Reforms in Agriculture using ICT enabled Networked Systems) in 2020. It aims at leveraging digital technologies in order to streamline and digitize the agri-value chain. GRAINS is poised to ensure sustainable development of the agricultural sector by collectively shaping the agricultural landscape of Tamil Nadu in the near future.

The various facets of agriculture , from production to marketing are integrated by this initiative to the ease of the farmers. The farmers' decision-making process is enhanced through their access to real-time data on weather, market trends, and crop advisories. This portal has also facilitated seamless access to government schemes and subsidies, thus ensuring efficient resource utilization. The planning and execution of farmer-centric benefit schemes is also made simple in this portal. Easier access to credit, subsidized farm inputs and IT based knowledge transfer through GRAINS is all set to empower the farmers of Tamil Nadu. Though government reports called for GRAINS achieving its success by increasing production and improving farmer livelihoods, challenges remain in ensuring sustainable and inclusive growth within the agricultural sector of Tamil Nadu.

The lack of a sufficient number of agriculture extension professionals who can facilitate training such as digital agricultural services to farmers poses a key problem. In addition, the public sector, a significant extension service provider, is burdened with providing other non-extension support to farmers, such as subsidies, leaving no time for them to focus on bridging the core extension functions. The core concept of digital agricultural information dissemination is tied to improving farmers productivity and income.

1.2 Key Features of the Research

This research presents a comprehensive mixed-methods investigation into the digitalization of climate-smart agricultural (DCSA) information dissemination among small-scale farmers in Tamil Nadu. While previous studies have primarily focused on the impact assessment of DCSA and its economic implications for farmers, this study addresses a critical gap by empirically identifying the factors that facilitate or hinder farmers perception toward DCSA adoption in the context of a developing country.

The significant aspect of the research is that it is case-study-based, mixed-methods research, combining qualitative techniques such as Participatory Rural Appraisal (PRA), focus group discussions (FGDs), and semi-structured interviews with quantitative survey-based data collection across multiple agro-ecological zones. The study investigates mechanisms to deliver essential digital agricultural information equitably and affordably to small-scale farmers, aiming to improve their livelihoods. The DCSA Adoption Framework guides the study and integrates concepts from Diffusion of Innovation theory and institutional context. This framework was validated through comprehensive data analysis involving 64 variables across 200 data sets, using Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modeling (SEM).

Another significant feature of the study is that it provides institutional and regional comparison, investigating reasons behind disparities in access, effectiveness, and barriers faced by farmers. Moreover, it emphasizes the role of strengthening the enabling institutional environment and improving interactions between farmers and extension agency to enhance the dissemination and adoption of DCSA services. Importantly, the research provides academically significant insights and practical recommendations to bridge the digital divide in climate-smart agriculture for smallholder farmers.

1.3 Research objectives

The primary objective of the study is to gain comprehensive understanding on digitalization of climate smart agriculture (DCSA) and specific research gaps. This was followed by framework development to assess the key influences on farmers' perception of DCSA in the study area. The objectives are as follows:

i. To **understand the digitalization of climate-smart agricultural information systems** in Tamil Nadu, by examining the evolution of agricultural extension, weather, and market information services, and analyzing the current digital agricultural information systems and services available.

ii. To **evaluate farmers' access and utilization of digital climate-smart agricultural information** in Tamil Nadu, by investigating the extent of service reach, farmers' perceptions of service effectiveness, barriers faced, and regional differences in digital information usage.

iii. To **develop a framework to bridge the digital information dissemination gap for climate-smart agriculture**, by identifying the evidence of farmers' demand for digital services, analyzing factors shaping farmers' perception and institutional effectiveness, and recommending specific actions for enhancing effective dissemination.

1.4 Research Methodology and Tools

To establish a comprehensive understanding of factors shaping farmers' perceptions and institutional effectiveness regarding Digitalization of Climate-Smart Agriculture (DCSA), a multi-phase methodology was employed. Initially, the literature review guided the development of a conceptual framework on the digitalization of climate-smart agricultural practices. This was followed by a reconnaissance survey that was conducted using a Participatory Rural Appraisal (PRA) approach, incorporating focus group discussions (FGDs) and semi-structured interviews with 50 farmers across two locations: Chengalpattu district in Tamil Nadu and Embalam village in Puducherry. Snowball sampling, a non-probability technique, facilitated the recruitment of participants, ensuring deeper insights. Data collection spanned from February 7-21, 2023, in Puducherry, and January 18-30, 2024, in Chengalpattu. About 60% of farmers were from Chengalpattu and 40% from Puducherry.

The PRA tools included four FGDs (two at each site), attended by approximately 12 farmers per session. A standardized checklist guided the discussions, focusing on five technology attribute dimensions of the Diffusion of Innovation (DOI) theory. Topics included farmers' awareness of climate change impacts, their information needs, sources and accessibility of information, and perceptions of digitalization in agriculture. Open-ended questions encouraged a natural dialogue, helping uncover drivers and barriers to DCSA service access. Key qualitative insights from the FGDs led to the identification of perception items based on technology attributes, later tabulated and used for analysis.

Following this, a semi-structured survey was conducted with the same 50 farmers, using a questionnaire developed around the technology adoption dimensions of DOI theory. The survey captured farmers' demographic characteristics, DCSA adoption rates, and perceptions toward digital agricultural information services. Innovators, early adopters, early majority, and late majority were classified as "Adopters," while non-adopters were categorized as "Laggards" under the DOI framework. Responses from both the FGDs and surveys were grouped using the Diffusion of Innovation framework, which allowed for the categorization of adoption behavior and identification of key influencing factors shaping farmers’ perception toward better DCSA adoption. In addition to farmer interviews, stakeholder interviews with 12 specialists (government officers, agricultural scientists, agricultural domain specialists in technology firms, and NGO representatives) were conducted to supplement the data. Insights from both farmers and specialists informed the development of an analytical framework comprising five constructs and a mediating construct involving 64 variables to assess key influences on farmers' perception of DCSA and institutional effectiveness. The five constructs were: awareness of DCSA and adoption, recognition of climate change impact, awareness of government policies, infrastructure facilities, and agricultural information seeking behaviour. The mediating variable was identified as extension agency contact. A questionnaire was constructed based on this information.

For the main study, an in-person survey was conducted with 200 farmers from four distinct agro-ecological zones(Pudukottai, Tanjavur, Kancheepuram, and Chengalpattu) in Tamil Nadu, each affiliated with different types of institutional extension support: NGO, private, and government sectors. It was also ensured that selected study areas represented different DCSA adoption rates: very high, high, medium, and low. The data analysis process was structured in multiple phases. Exploratory Factor Analysis (EFA) was first employed using SPSS 26.0 to test the reliability of the constructs and explore underlying factor structures. Regression analysis was performed separately for each of the four study areas to further investigate localized patterns in farmer responses. Following EFA, Confirmatory Factor Analysis (CFA) was carried out using AMOS 26.0 to validate the factor structure and ensure model fitness. Finally, Structural Equation Modelling (SEM) was utilized to examine the interrelationships between constructs and to test the overall theoretical framework statistically. This robust analytical approach helped in providing a holistic understanding of the factors influencing DCSA perceptions and adoption among farmers across varying institutional and agro-ecological contexts. Thus, the methodology combined participatory qualitative techniques with quantitative analysis, ensuring that the findings were grounded in field realities while being statistically validated.

The below figure 2 connects the research objectives to the corresponding thesis chapters and outline the specific the methods used.

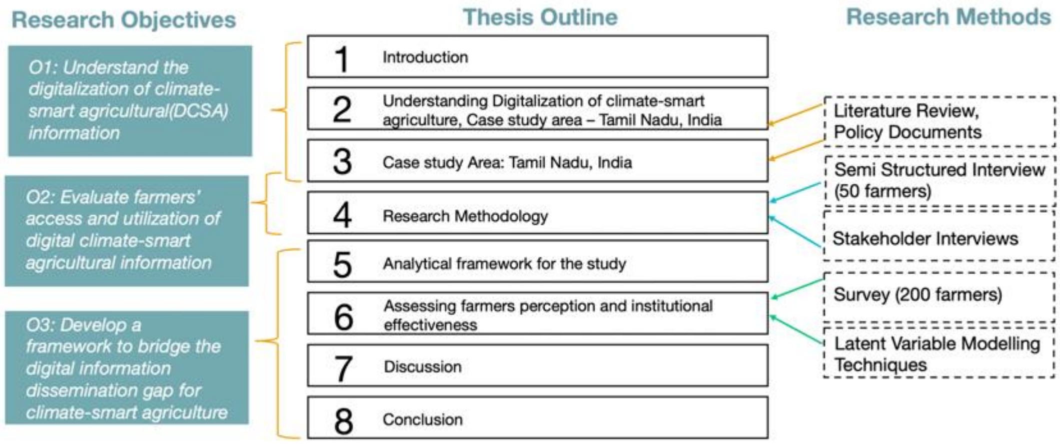


Figure 2: Linking Research Objectives with Thesis Structure and Methodology for Studying Digital Climate-Smart Agriculture in Tamil Nadu

1.5 Academic Significance of the Study

The study investigates the environmental factors and contextual elements that influences farmers' adoption of Digitalization of Climate-Smart Agriculture (DCSA) practices. It recognizes that adopting technology varies widely, depending on the diverse agro-ecological zones and institutional extension approaches. By examining how these contextual factors shape farmers' perceptions and adoption behaviors, the research provides important theoretical and practical insights that enhance both academic understanding and field application of digital climate-smart agricultural innovations.

A significant contribution of this research is its advocacy for contextualizing digital agricultural information, steering clear of one-size-fits-all models. The study emphasizes the necessity of community-driven, bottom-up strategies that involve farmers as active partners in the innovation process. Additionally, it stresses the importance of sustainable institutional support, focusing on enhancing the farmer-extension agency relationship and ensuring more effective communication of pertinent agricultural and climate policies to grassroots communities.

This research advances current agricultural technology adoption models by introducing and empirically confirming a new conceptual framework. The framework combines elements from the Diffusion of Innovation theory with specific contextual variables. The study offers a structured and empirically grounded framework to examine how various factors shape farmers' perceptions and how institutional configurations affect the dissemination of digital climate-smart agriculture (DCSA) information. The contributions are fourfold:

- Bridge farmers' behavioural factors with institutional support mechanisms
- Empirical validation of institutional effectiveness across different regions
- Reframing the Digital Divide through Institutional Mediation
- Local context adaptation

- Policy and design implications

  Utilizing statistical methods including Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modelling (SEM), the study presents a validated model that can be adapted, tested, and refined by future researchers in various regions and technology platforms. The study has made a contribution to the interdisciplinary field of agricultural innovation research by connecting digital transformation, climate resilience, and rural development within an empirical framework. It leads the way for scholarly inquiries in the future to enhance the development of more targeted, inclusive, and accessible agricultural extension strategies that align with the needs of diverse farming communities, especially in the context of climate challenges.

  Finally, the below figure 3 illustrates the sequential research steps taken conducted from literature review to data analysis to explore farmers' perceptions and effectiveness of institutional roles in the dissemination and adoption of digital climate-smart agricultural information.

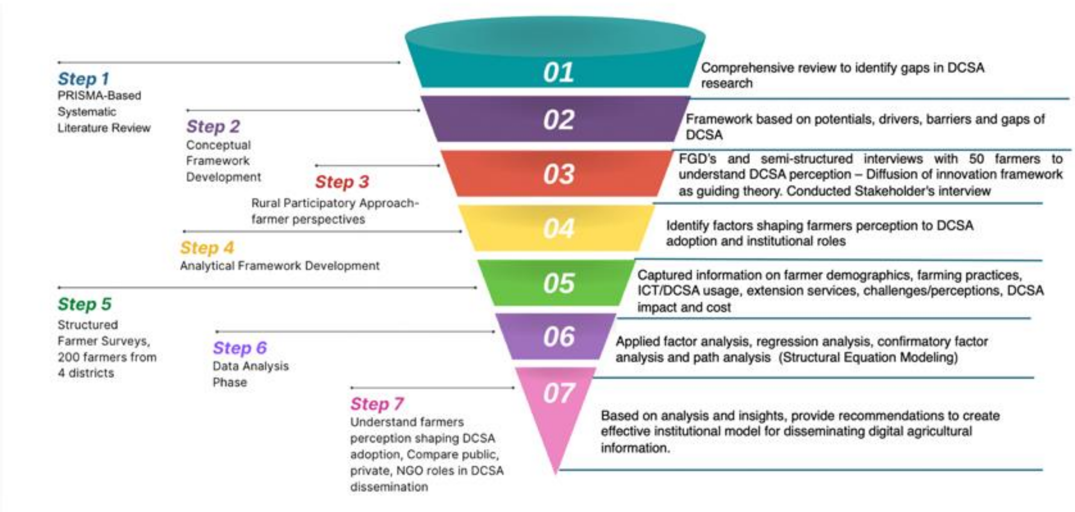


Figure 3: Stepwise Research Design for Investigating Digital Climate-Smart Agriculture (DCSA) Adoption in Tamil Nadu

CHAPTER 2: UNDERSTANDING DIGITALIZATION OF CLIMATE-SMART AGRICULTURE

2.1 Introduction

Technological innovation plays a vital role in transforming every other economic sector. Amongst various sectors, agriculture has not kept pace with innovation and is the least digitized sector. The growing demand for technological innovation in the agricultural sector is due to a multi-faceted problem, such as the rapidly growing global population, impacts of climate change, labour shortages, evolving consumer demand, food waste, farm efficiency and profitability, opaque supply chains, distribution inefficiencies, food safety, and traceability, restrictions in the utilization of natural resources, and increasing health problems. It is anticipated that agrifood tech could be a solution to addressing many of these problems.

Agricultural technology has been consistently evolving since time immemorial. The initial focus for deploying technology, such as using machinery and tools in agriculture, was to increase productivity. However, with time passing, the type of technology (IoT, sensors, robotics, and data analytics) and the context for using it for agriculture have evolved, for instance, to improve economic efficiency. Recently, the definition of agritech emphasizes environmental sustainability and climate-resilient solutions. Agriculture 4.0 was framed as analogous to Industry 4.0, which signifies digital agricultural transformation. With the onset of Information and communication technology, agricultural technology(agritech) started encompassing precision agriculture and data-driven decision-making. AgriTech could be defined in today's agricultural context (Agriculture 4.0) as the use of data-driven smart technologies, analytical methods, drones, robotics, the Internet of Things (IoT), vertical farms, artificial intelligence (AI), and solar energy for enhancing farming practices, operations, and decision-making to achieve the agricultural field's economic efficiency and environmental sustainability in multiple forms and ways. It is strongly associated with the use of AI applications.

2.2 Literature Review

A semi-systematic literature review was employed to review the state-of-the-art literature on digital agricultural technologies for climate-smart agriculture. Scopus was the central database used to screen and collect literature for the review. The figure 4 elucidates the steps involved in identifying and screening and includes selected articles for the study. The steps are described below:

a. In the Scopus database, a search was conducted using (ALL=(CSA)) or ALL= ("climate-smart agriculture"), which resulted in 16,921 articles.
b. A further search was conducted to find articles related to digital agriculture, agritech, or agricultural technology, which resulted in 2125 articles.

c. In the given scenario, the goal was to identify articles related to the potential, challenges, and impact of digital agricultural technologies for CSA. Therefore, the search involving keywords such as potentials, challenges, and impact resulted in 2072 articles.
d. Further, to narrow down the scope of research, other filtering criteria were used to exclude articles published before 2013, articles in non-English language, not open access, and articles from less relevant disciplines. The abstracts were skimmed and scanned. Based on their relevance to the research topic and objective and highly cited articles, 32 articles were finally included, as mentioned in the citations for the review scope.

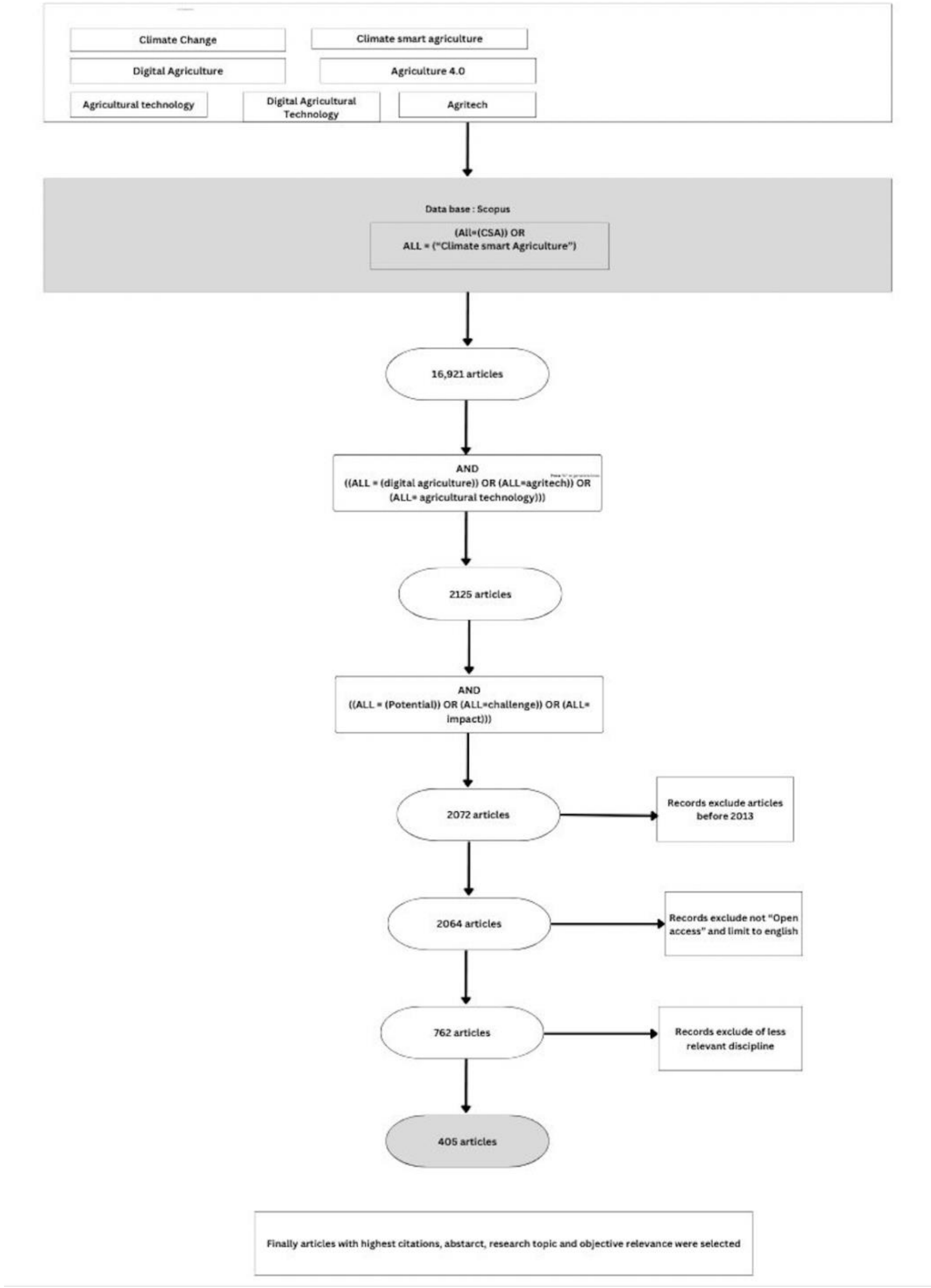


Figure 4: PRISMA framework-based systematic literature review

Research directions

After identifying the relevant literature, the research was synthesized into four critical dimensions or directions for successfully implementing digital agriculture technologies to improve climate smartness, as mentioned below:

1. Context of Digitalization in agricultural practices
2. Barriers (institutional, informational, economic, environmental, political, technological) & Drivers
3. Importance of Farmer-led innovative & collaborative arrangements, institutional support, and prioritizing local knowledge & influencing farmers' perception of DCSA
4. Gap: Digital Divide and Inequality.

The table 1 below lists key literature reviewed on the interplay between climate smart agriculture and digital advisory services.

Table 1: Summary of Key Literature on Digital Agriculture and Climate-Smart Agricultural
Practices

Reference	Studied Aspect	Methodology	Key Finding
(Asante et al., 123 C.E.)	Relationship between digital advisory services and climate smart agricultural practices	Case study (Ghana)	Determining the specific determinants of the impact of DAS on CSA technology adoption among both users and non-users. need for broader country-specific studies
(Quarshie et al., 2023)	Farmers engagement with DCSA	Participatory learning approach (Ghana)	Promote DCSA and increase capacity building to overcome problems related to accessibility, availability, digital divide, reliability, institutional support
(da Silveira et al., 2023)	Strategies to overcome the barriers of agriculture 4.0	Literature review, case study (Brazil)	Lack of infrastructure as the significant barrier
(Zhao et al., 2023)	Recent advancements, challenges and future directions of CSA	Literature review	Improving agricultural information security, quality of information and weather index based insurance.

(Hisano, 2022)	Discourse on CSA global perspective	Literature review	Climate crises framed as a new opportunity without fundamental transformation of agrifood systems
(Konfo et al., 2024)	Recent climate-smart innovation in agriculture	Comprehensive review	Need for interdisciplinary collaboration, regulatory foresight, commitment to ethical and responsible innovation
(Balasundram et al., 2023)	Crucial role of digital agriculture for climate change and food security	review	Lack of empirical evidence on effectiveness of digital agricultural technology esp in developing nations context. To operationalize sustainable and equitable way of benefit sharing with farmers
(Klerkx et al., 2019)	Social science aspects of digital agriculture relation to farm production systems, value chains and food systems	Exploratory literature review	Future research agenda to be on conceptualizations on "digital agriculture" socio-cyber-physical-ecological systems, policy process, digitally enabled agricultural transition pathways, global geography of digital agriculture development
(Ingram et al., 2022)	Existing and emerging issues relevant to digitalization in agricultural production	Participatory methodology	Priority research questions under themes themes: data governance, data management, enabling use of data and technologies, understanding benefits and uptake of data and technologies, optimizing data and technologies for performance, impacts of digital agriculture, new collaborative arrangement.
(Mühl & de Oliveira, 2022)	Core agriculture 4.0 research themes	Bibliometric analysis	Need for responsible development of digital solutions for agriculture. To comprehend if the social, environmental, and economic impacts of these solutions are positive or negative.

(Steinke et al., 2021)	Inform future investments into agricultural information services	Review	Rather than pushing a certain digital technology , identify and act on communication challenges. Focus on strong user centeredness and problem-orientation. Beyond design, enabling institutions needed.
(van Wijk et al., 2020)	CSA assessment tools widely focusses on only biophysical and mostly ignores socio-economic aspects	Review	Indicator development for sustainable assessments, house hold level analysis to identify drivers od adoption, system specification quantification of greenhouse gas emission
(Li et al., 2022)	CSA focus on environmental sciences, and agricultural economic management	Bibliometric study	For sustainable promotion of CSA, future research on trade-off and synergy of 3 pillars of CSA, investment , finance and evaluation criteria of CSA
(Akudugu et al., 2023)	Factors influencing farmers in technology adoption	Case study (Ghana)	Farmers willingly adopt technology if it impacts their welfare through timely resolution of problems that confront them. Policy to promote positive technology adoption behaviors should have consideration for efficiency, effectiveness, relevance, sustainability and impact. It must also consider farmers age, gender, education, house hold size, farm size, credit access, savings, farm investment.
(Rotz et al., 2019)	Key trends observed at the nexus of agricultural production, technology and labor	Participatory workshop and literature review (North America context)	Ways policies should support digitalization for marginalized farmers. Technology as ways not to deepen labor and spatial marginalization.

(Khatri-Chhetri et al., 2016)	Assess farmers preferences and willingness to pay for selected CSA practices and technologies	Empirical analysis (Rajasthan, India)	Farmers preference to technologies and their willingness to pay are influenced by cost of implementation. Potential for using participatory CSA prioritization approach to provide information on climate change adaptation planning at the local level.
(Dinesh et al., 2018)	Lessons drawn from science policy engagement efforts	Case study analysis	Emphasize on the importance of engagement (participatory and demand-driven research processes), evidence(building scientific credibility while adopting an opportunistic and flexible approach), and outreach (effective communication capacity building)
(Andrieu et al., 2017)	How to achieve CSA outcomes at a scale through the CSA prioritization framework	Case study (Mali)	Enabling institutional environment with linkages of national and regional realities, needs and challenges. To be led through local stakeholders especially in CSA planning stage, research scientist to monitor the process.
(Ahikiriza et al., 2022)	Effect of farmer knowledge and awareness in their intention to use DCSA. Identify factors that influence farmers intention emphasis on farmer knowledge	Structural equation modeling	Farmer intention was shaped by self-efficacy, facilitating conditions, and performance expectancy even before being exposed to DCSA app. User friendliness and promotional activities targeting specific users were the key.
(Amoak et al., 2023)	Role of information sources in climate resilience. Given the plurality of	Quantitative comparative analysis	Primary source was massmedia and external sources (TV, radio, etc) in Malawai while in Ghana interpersonal sources helped and external sources decreased.

	information sources it is challenging.		Relevance of climate information happen to be place-specific; some sources may impede resilience building if contextual factors are sidelined. Context specific policies regard to heterogeneity of agarian communities.
(Finger et al., 2019)	Potential environmental benefits of precision farming. Investigate and assess developments of precision farming from farmer and policy makers perspective	Economic framework	Improvements in technical infrastructure and the legal framework can expand accessibility but also help in bringing societal benefits to farmers.
(Da Silveira et al., 2023)	Validate the barriers that hinder development of agriculture 4.0 from farmers perception	Empirical study (southern brazil)	Lack of infrastructure, lack of solutions accessible to farmers, need to foster R&D, and innovative business models, age group risk, and lack of efficacy in the data on the rural environment were identified to be the key barriers.
(Bryant & Higgins, 2021)	How to make the uncertainties in terms of making smart farming more workable at the farm-level.	Stakeholder interview	Securitise resource uncertainty regarding adoption of technology, and emphasize the importance for adoption of comparatively simpler technologies in the initial stage compared to complex smart farming technology
(Ibrahim et al., 2021)	Large gap between potential yield and actual yield, because of factors such as sub-optimal crop management especially in rice	Comprehensive review	Digital platforms such as decision support tool has the enormous scope of improving the productivity, profitability, and sustainability in agronomic practices.

	cultivation. Less focus on environmental and social sustainability as against economic sustainability (yield, and profit)		
(Carbonell, 2016)	Power asymmetry between farmers and large agribusiness	Review	Digital agricultural data should be provided as a common good and should be funded and developed by public organizations
(Kenny & Regan, 2021)	Factors that influence farmers engagement with smartphones and explored the support required by farmers to successfully use smartphone for agricultural information	Focus group discussion (Ireland)	Emphasize importance to understanding barriers and enablers of farmers engagement. Factors such as poor internet availability, lack of comfort with emerging technologies, technology trust issues, perceived lack of sufficient benefits deterred adoption. Perceived support network (farm advisors, family members and peers) was key.
(Chapman et al., 2022)	Forefront issues in the food value chain with a focus on technology	Comprehensive review	Agriculture 4.0 is not just about technology. it represents a holistic transformation, integrating digital innovation with shifting social values to build resilient, health-oriented, and sustainable food systems.

2.2.1 Climate-smart Agriculture

Climate-smart agriculture is rooted in three pillars: sustainability, adaptation, and mitigation. In addition to the three pillars, the other targeted benefits of employing CSA include the farmers' economic well-being, recognition of the pivotal role of lawmakers, institutions, and communities in facilitating the adoption process, advocacy of gender equality, resilience-oriented strategies, etc. (Konfo et al., 2024)

In terms of adaptation on improving the existing CSA assessment tools, a more comprehensive understanding of the factors that facilitate the adoption of CSA must be developed by undertaking household surveys (van Wijk et al., 2020). A special focus needs to be given to risk monitoring. Significantly, theoretical, and empirical research is currently happening in silos which need to be combined for better results. Also, quantifying and analyzing the disasters in different climate change scenarios with respect to the applicable adaptation options needs to be simulated and documented, which will help minimize the impact of such climate change on small land-holding farmers in case of the occurrence of future events. This sort of exercise is more important relative to the existing tools that can quantify or assess crop yield and livestock productivity, which are considerably less important to small land-holding farmers. Because of the scope for broad access to open data, improvement in the quantification of agricultural production has become easily possible. On the other hand, the essential information farmers need to produce agricultural produce, such as information on crop rotation, land management, and intercropping, is missing.

CSA research is increasing in trend, and research areas are increasingly focusing on environmental sciences and agricultural economics management. The frequently researched topics within this are conservation agriculture, CSA practices, smallholder farmers, and regions such as South Asia and sub-Saharan Africa primarily impacted by climate change. The critical aspect of the CSA research is the promotion of the adoption of technology to cope with climate change. This implies the growing need to study the factors that influence CSA practices, which will give insight into supporting the promotion and adoption of CSA technology. The evolution of CSA research could be discussed in three stages: the first stage of understanding the CSA focused on the year of the inception of the concept in 2010; the second stage focused on essential elements and strategic direction of CSA (2013-2015), and the third stage focuses on emission reduction, influencing factors and CSA practices (2016 onwards). The three crucial aspects to be focused on for the future CSA research direction are the case studies approach, fundraising mechanism, and CSA evaluation criteria (Li et al., 2022).

2.2.2 Digitalization in Agriculture

Digitalization in Agriculture refers to the employing of digital technological advancements such as blockchain, cyber-physical systems, robotics & autonomous systems, cloud-fog-edge computing, and generative adversarial networks (GAN) in agriculture and allied activities. (Sharma et al., 2022) These technologies offer promising benefits in terms of sustainability development goals, especially of food security. They have proven to improve food production, safety & quality through innovative technologies. However, the prerequisite for scalability is the promotion of such technologies by the regional government bodies through initiatives to encourage Science, Technology, Engineering, and Mathematics (STEM) learning to equip the local workforce (Musa & Basir, 2021 and Singh & Singh, 2020).

The role of digital agriculture, especially of technologies such as IoT and its application in precision agriculture and smart greenhouses, has proven to have incomparable advantages in terms of sustainability when compared to other potential risks. But there lies the problem because reaping benefits from such advanced technology may not be the same between developed nations and developing nations where resource is constrained along with the digital divide (Maraveas et al., 2022).

The analysis of international organizations' policy documents reveals that agricultural digitalization is envisioned to maximize food output. This implies that improving food production directly translates to improving food security. Lajoie-O'malley et al., 2020 emphasizes the importance of studying the environmental impacts of digital agriculture and also to analyze its impact at the intersection of regulatory, cultural and provisioning ecosystems, in the context of the future of different food systems. This is anticipated to result in responsible research innovation in digital agriculture.

The digital revolution in agriculture is characterized by climate-smart agriculture, the Internet of Things, artificial intelligence, remote sensing, and site-specific management. Different studies have identified themes related to digitalization in agriculture. Five themes characterize the field of social sciences, namely: 1) change in farmer identity, the sophistication of farm work, 2) introduction and adaptation of digital technology on farms, 3) economics and management of digitized agricultural production systems, 4) ownership, privacy, ethics, 5) agricultural knowledge and innovation (Mühl & de Oliveira, 2022).

The different dimensions of digitalization in agriculture are categorized broadly as external (economic, government, sustainability), mixed (cooperation, infrastructure, and technological), and internal (change, people, knowledge, and skills). The most supportive factors are those that are often overlooked and are internal in nature, which becomes the critical barrier toward successful digitalization (Alves et al., 2022). Earlier studies on farmers' technology adoption have been primarily oriented toward studying demographics, farm characteristics (farm size, land use, ownership, labor availability), operator characteristics (education, age, computer use, farming experience), interaction of farmers (various information sources, other farmers, extensions), and some even on institutional access (subsidies, laws, and regulations). (Shang et al., 2021) Few studies have focused on technology attributes (relative advantage, complexity, compatibility, trialability, observability) and psychological factors (attitude, subjective norm, perceived behavioral control) regarding farmers' technology adoption (Shang et al., 2021) (Ingram et al., 2022). This is true even for the case of studies related to the digitalization of climate-smart agricultural practices or services with more emphasis on socio-economic factors that have been studied (Asante et al., 123 C.E.)(Akudugu et al., 2023)(Tanti et al., 2022).

2.2.3 Digitalization of climate-smart Agricultural Practices

The future of climate-smart innovation is towards digital transformation in precision agriculture, 3D printing, robotics and automation, traceability and blockchain, and augmented and virtual reality technologies. Digital platforms, data analytics, blockchain technology, and artificial intelligence are synonymous with improving supply chain and market access for producers by addressing the challenges of transparency, trust, and traceability (Konfo et al., 2024).

Few studies have anticipated that the digitalization of climate-smart agricultural practices has the potential to reduce the information symmetry that exists in farmers' perceptions and practices of climate-smart technologies. Given the erratic climate change scenario in recent times, the entire agricultural value chain is vulnerable to climate change impacts, which are shaping farmers' information needs and information-seeking behavior. Digitalization of agricultural advisory services seems to be the need of the hour for farmers. Such information is being disseminated to the farmers through different mediums such as TV, radio, computer, smartphone, and the internet (Asante et al., 123 C.E.).

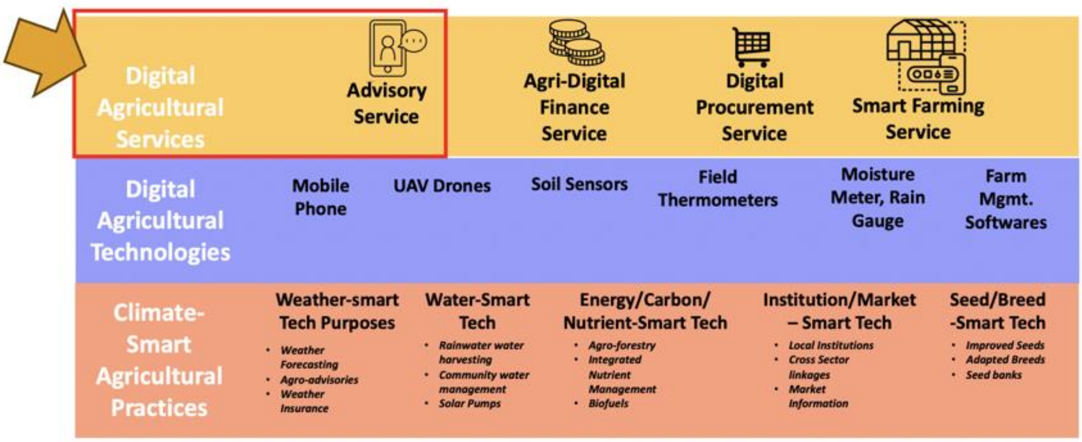
Mobile phones or smartphones are an effective measure for farmers to become climate smart. Notably, the advantages offered by these knowledge delivery or agricultural advisory services through mobile phones to small land-holding farmers are equivalent to the merits provided by precision technologies to large land-holding farmers (Rao, 2018).

Simple devices such as Television, radio, and feature phones were most sought after in introducing climate smartness to farmers. Other relevant climate-smart tools, such as Unmanned Aerial Vehicle, soil sensors, field thermometers, moisture meters, smartphone applications, farm management software, and rain gauges, were used minimally or sometimes not at all because of low awareness, the complexity involved in utilization, unavailability, and inaccessibility, etc. in the context of developing nations or their resource-constrained scenario. Importantly, in the context of developing nations and considering the capacity of farmers, mobile phones catering to agronomic advisory services seem to have enormous potential (Quarshie et al., 2023).

Digitalization of climate-smart agricultural services (DCSA) refers to leveraging digital technologies in the agricultural sector through digital agricultural services and the nexus of climate-smart agricultural practices. Climate-smart agricultural practices are broadly categorized under weather-smart tech, water-smart tech, energy/carbon/nutrient-smart tech, institution/market-smart tech, and seed/breed-smart tech, whereas digital agricultural services are categorized into advisory purpose, agri-digital finance services, digital procurement services, smart farming services, and agri e-commerce (Quarshie et al., 2023). The digital transformational tools in agriculture referred to in various climate adaptation studies range from low-tech solutions such as agronomic advisory disseminating services to high-tech solutions such as smart farming services (big data analytics, soil and moisture sensors, satellites, etc.). Precision agriculture or smart farming services are more relevant in the context of more advanced nations (Quarshie et al., 2023). These set of digital agricultural technologies bridge the set of climate smart agricultural practices to digital agricultural services. The various digital agricultural services are: advisory service, agri-digital finance service, digital procurement service and smart farming service. Considering the rapid penetration of mobile phone devices in the context of developing countries, the advisory services, as highlighted in Figure 4, are focused in the current study. The rationale and relevancy behind choosing to study advisory services broadly in the Indian context and study areas which is Tamil Nadu will be explained further in chapter 3.

Advisory services refers to any organization in the public or private sectors (NGOs, farmer organizations, private firms, etc.) that facilitates farmers' and other rural actors' access to knowledge, information and technologies, and their interactions with other actors; and assists them to develop their own technical, organizational and management skills and practices, so as to improve their livelihoods and well-being. (FAO, 2017) Therefore DCSA referred to in the study is elaborated as the digital agricultural services such as advisory purpose, agri-digital finance services, digital procurement services, and agri-e-commerce in the context of receiving climate-smart agricultural information such as weather, water, energy/carbon/nutrient, institution/market, and seed/breed-smart tech leveraging mobile phone-based applications and other digital agricultural technologies.

Figure 5: Digitalization services of Climate Smart agricultural practices



Source: Authors own adapted from (Quarshie et al., 2023)

Research studies have pointed to the benefits and effectiveness of climate-smart agriculture and the digital agricultural revolution toward offering new strategies for climate change adaptation. (Khatri-Chhetri et al., 2016) (Arvanitis & Symeonaki, 2020) Digital agricultural services influence small-scale farmers' short-term responses to long-term climate change adaptation and mitigation measures, enhancing farmers' climate resilience. (Ferdinand et al., 2021a, 2021b) The state of Tamil Nadu, India, is being exposed to climate change vulnerability due to the increase in the frequency of erratic weather patterns, rising temperatures, floods, and water scarcity. Integrating digital tools in agriculture or DCSA has been widely recognized as an important strategy for adapting to the impacts of climate change in agriculture.(TNAU climate change, 2024; Varadan & Kumar, 2015)

2.2.4 Drivers

Digital agriculture technologies (DATs) and digital advisory services (DAS) are considered powerful drivers for the advancement of agriculture and CSA. Agriculture 4.0 technologies, such as the internet of things (IoT), machine learning, unmanned aerial vehicles (UAVs), big data analytics, robotics, and artificial intelligence, can benefit all stages and processes of the agricultural production chain. These technologies are expected to increase efficiency in food productivity and provide social and environmental benefits. Towards providing the addressing the information asymmetry and delivering climate smart informations to the farmer community, Digital agriculture technologies play a vital role. DAT leads to the wider adoption of CSA since by providing the critical information, promoting state holder communications, fostering social capital and improving learning opportunities. The technologies like the TV, radios and mobile phone have been widely accepted to facilitate the access to digital agro services, digital finance services and the digital procurement services. The example of mobile money wallets which makes it possible to make or receive payments, access credit and loans overcoming the financial technological barrier. There has been rising optimism and confidence in farmer community on the ability of DATs in increasing the productivity, farmer income and climate resilience multiplying the environmental benefits. The rising incidences of drought stress, pest and diseases outbreak drives the farmers towards DAT and CSA for increased resilience. Another steps towards the DATs adoption is the membership in farmer based organisations which help in bringing down the cost and increasing the accessibility towards CSA while facilitating the adoption of new technologies.

In the agriculture environment, digitalisation has a very transformative potential due to which it is expected to revolutionize productive processes, value chains and food systems. The optimisation capabilities offered by the digitalisation are across agricultural production, addresing the socital concerns such as traceability, animal welfare, environmental impact and also further the learning and knowledge exchange between stakeholders. The variety of data such as weather, behaviour, location, consumption, energy use, prices, phytosanitary status) collected through multiple sensors through the sensor such as achines, drones and satellites enables the accurate decision making.

There is a large body of social science literature and increasing attention at scientific conferences and in policy circles, driven by the recognition of the social, economic, and institutional dimensions of digital agriculture. Key motives for adopting technologies like robotic milking include improving quality of life, offering a more flexible workday, and reducing physical labor. Certain technologies such as data analytics, data marketplace, block chain are proven to be effective in improving the supply chain efficiency which further improves the supply chain efficiency and market access for producers to make effective decisions.

Many innovations in the field of CSA such as climate resilient crops varieties, agroforestry, vertical farming and regenerative agriculture which helps with results such as improved productivity, increasing resilience, improving soil health and diversifying farmer income. On the other hand the precision farming techniques such as remote sensing, precision irrigation and variable rate technology leads to maximizing the resource efficiency, minimizing the waste emission thereby providing a more positive environmental impact. Towards the overall sustainability and resilience, emerging fields of artificial intelligence and digital twins enhance the data driven decision making ability at a farm level through prediction of climate shifts, and resource optimization.

To ensure accelerating the progress towards global goals the science-policy engagement is crucial through allowing the scientific findings find their way to the decision making processes amongst the stakeholders such as governments, private sector, NGOs and international development partners. Production of demand driven research, effective engagement in policy processes, building science backed credibility, strategic communications and capacity building are few key principles in the effective management. Few measures such as capacity building, deep engagement with users, allocation of resources to research and including few external processes of the next users will further strengthen the adoption. Adding to the research acceptance would be through the scientific credibility of research, institute and researchers themselves and also the other participatory processes.

Co-learning processes facilitate knowledge exchange, co-production, and adaptation of research products to user needs. Tackling power and influence, being mindful of gender differences, and employing strategies like stakeholder mapping are important for successful engagement. Investing in and monitoring capacity enhancement for next users and research partners strengthens their ability to articulate demand and translate knowledge into action. Mainstreaming higher-level goals like poverty reduction, gender equity, and food security helps focus on development outcomes. Creating mechanisms for internal learning allows researchers to review strategies and seize opportunities. Strategic and active communication with diverse audiences is considered important for sharing research findings and increasing impact. The lower per-unit cost of dissemination for digital communication allows for reaching more farmers and mitigating geographic bias. Two-way communication via mobile phones enables tailoring advisory content to individual farmers' diverse needs.

The necessity of farmer to farmer exchange of experiences and integration of the different knowledge cultures alongside the crowdsourcing of farmers information needs through the digital advisory platform would help to increase the research acceptance through the digital tools. For the purpose of speeding up the research and detection of the pest and disease outbreak, the agricultural citizen science which is supported by digital communication facilitates on-farm experimentation and observations. The remote sensing digital services has enabled monitoring and analyses of data which provides auditable metrics for performance which is further integrated into the advisory applications allowing continuous panel data collection. In order to maintain the quality on the advisory services effectiveness, it is necessary to keep the feedback loop closed by crowdsourcing user evaluation within the digital services. During the pandemic of COVID, the farmers awareness of the pandemic and its impact led to increased acceptance and adoption of the digital services such as e-extension, e-market information, e-payment and e-market information.

In the African context, it has been observed that climate resilience has been improved with increased accessibility, timeliness and reliability of climate information. The ability to access investment capital in forms like initial endowments, off-farm income, or land raises the adoption rates of precision farming. Precision farming is also considered profitable investment in the areas with high spatial variability of field conditions primarily due to the economic benefits of the variable rate technologies. The precision farming outcome is resultant of the key drivers such as higher education levels and the presence of agribusiness infrastructure such as internet services, data platforms and associated advisory services. PF technologies have the potential to increase farmers' income, improve crop quality, and decrease negative environmental effects simultaneously. Policy incentives, such as taxes on inputs (e.g., fertilizer, pesticides) or subsidies for environmental stewardship technologies, can encourage PF adoption by internalizing external costs and promoting efficiency. Additionally, cheaper PF technologies and mobile phone-based services can play a vital role in promoting widespread benefits in developing countries.

CSA drives the primary objective to improve the agricultural productivity and to transform the agricultural production and food systems by shifting towards data based decision making. Amongst the involved stakeholders, the Meso scalar actors such as economists and farm advisors are key in the adoption journey of smart farming technologies. The basis of CSA to make this transformation is its ability to allow the farmers to process information which is sourced across multiple sensors and contextualised for their decision making thereby leading to reduction in the uncertainity in the implementation process. The younger genration have shown more inclination towards this adoption of CSA compared to their previous generation. Also in addressing the current challenges, the collaboration between public and private extension roles is important.

2.2.5 Barriers

Towards the development of Agriculture 4.0 and CSA technologies, there are key barriers across economic, political, technological, social and environmental dimensions. These barriers have caused multiple bottlenecks in the implementation journey. In the economic dimension, high cost associated with skilled labor, operation components and facility maintenance makes the solutions inaccessible to small and medium sixed farmers. On the technological dimension, it includes the technological complexity, lack of infrastructure such as rural connectivity, incompatibility between components and also concerns such as reliability issues with data privacy and cyber security. Political dimension is on the limited availability and accessibility of technologies and the lack of political procedures. Elaborating on the social barriers, the prominent ones being age group risks, lack of digital skills and asymmetry of information. Environmental obstacles include issues with system behaviors and climatic influence, ineffective data on rural environments, and worries about sustainable energy sources and regulations. The obstacles such as inaccessibility and lack of availability of DATs, low digital literacy and the inadequate extension assistance hinder adoption of the digital services. The sociocultural norms leads to gender restrictions to specifically women using the digital tool.

The digital agriculture and CSA technologies implementation journeys faces significant hurdles. Issues such as lack of transparency and clarity on data ownership, privacy, trust and liability in commercial settings leads to farmers reluctance and dissatisfaction in the implementation journey. The current licenses arrangements with the digital services, results in lower confidence and acceptance amongst the farmers towards higher risk and vulnerabilities. There are possibilities for displacement of certain sections of the farming workforce due to the lack of required digital skills. Additionally concerns also includes inequitable distribution of the risks and benefits amongst the farming community and any adverse socio economic reactions which could result from the interaction with the digital services. The existence of digital divide in terms of access and capabilities in the usage of internet furthers the barriers in the technical and infrastructure perspective. In the region such as Poland, the usage of digital tools is perceived as individualistic and eroding traditional common knowledge. The high initial investment costs for digital agriculture systems, equipment, and software, along with a learning curve and the need for significant training, make it expensive and difficult for small-scale farmers to adopt these technologies. In the need to leverage data for these digital services, there is also a gap in expectations from the relevancy and accurate of the data and its interpretation within the farmer community, also the required skills to make the charges to the data to be further analysed is still largely missing in the community. The operational costs of these high technology services such as subscription services runs into thousands of dollars causing a economic barrier. There are certain studies which also highlights the farmer's reservations on the environmental performance of precision farming and its tendency to benefit a section of the community and marginalizing the smaller ones.

For digital agro-advisory services, common shortcomings include a lack of feedback mechanisms and mismatches with farmers' information needs, technological capabilities, habits, and timing of information delivery, as well as insufficient trust in information sources. Many such services have been discontinued after initial funding because they failed to engage policymakers or develop viable business models. Often the root cause is that the new services are put together based on flawed assumptions of user needs. In addition, factors such as lack of digital infrastructure in rural areas, poor electricity, gap in digital skills and non availability of content based on local language. Social and political complexities surrounding migrant labor management can also make automation attractive to farmers, sidestepping issues of worker safety and security. Rural areas often experience lower levels of education and skills, which disempower agricultural workers and hinder their capacity to adopt new technologies.

Barriers such as limited access to critical and relevant climate information, often due to a lack of timely access, unawareness of available information, complicated television programming, and sporadic extension service visits. Illiteracy and language barriers further hinder access and understanding. Adding to the hurdles in the adopting the Agriculture 4.0 and digital services is the rising costs associated with the digital technologies and related poor infrastructure. Costs are mostly due to the limited internet access and lack of electricity. Furthermore many farmers have not been able to maintain the farm records in the required formats which would enable them to leverage the associated digital services. In the context of precision farming, there is a significant upfront cost associated with the infrastructure and learnings for the setups and maintenance of these complex systems. Also the precision farming is seen as the one which could lead to more gaps and discrimination amongst the farming community on the person’s ability to invest and leverage these for efficiency and results.

Adding to the barriers list is the unwillingness amongst the farmers community to change their traditional practices to the newly developed innovations. The progress associated with smart farming requires a fundamental mind shift in decision making from traditional experiential decision making to data driven processes. Any recent negative experiences such as compatibility or access issues within the farmers community with these technologies would further widen the gap towards adoption. The nature of uncertainity with these digital and technological transformations makes it lack the required control over direction and outcomes rising the barrier to adoption.

2.2.6 Digital divide issues

A significant challenge to the equitable adoption of CSA technologies and digital services is the digital divide, particularly affecting smallholder farmers and certain demographics. Capital-intensive technologies, robust infrastructure, and specialized expertise are vital for Digital agriculture. But, these may lessen the scope for smallholder farmers which may ultimately make them lose possession of their autonomy and local knowledge. Access to digital resources, including the internet, still remains limited in many developing regions. Digitalization services available to smallholders are often subsidized. Basic technologies like SMS, Interactive Voice Response (IVR), and radio are primarily leveraged by development-oriented NGOs and private-sector projects. Low digital literacy rates, inadequate digital competencies, and restricted access to advanced digital resources frequently limit their participation in these services , which tends to diminish over a period of time. Class structures, gender constraints, resource endowment, and formal education levels further exacerbate the present digital divide. For instance, socio-cultural norms such as restricting women's ability to make or receive phone calls at certain times, can impose gendered limitations, thus hindering their engagement with digital advisory services. Overall, the current state of digital agriculture among smallholders glaringly contrasts with the rhetoric of widespread digitalization and transformation. This highlights a significant gap between envisioned potential and lived realities.

In the context of digital agriculture, the digital divide is a critical issue with the potential to reinforce existing economic, spatial, and social inequalities within the agricultural sector. There is a significant disparity in access to and capabilities for using digital technologies, particularly among small-scale farmers and in developing countries. Larger commercial farms and suppliers are often the beneficiaries of digitalization rather than the individual farmers. This leads to perceptions that the technology primarily serves the interests of agri-businesses and government agencies. The uneven distribution of value extracted from big data is ironic because the farmers, who are often the data contributors, enjoy only a limited share of this value. In fact, policies and research have been criticized for not effectively addressing the deepening digital divide, specifically in the context of farming systems with slow technological development or farmers lacking digital literacy and infrastructure. Access to technology does not equate to the capability to derive benefits is a well known fact, with the disempowered farmers struggling to independently exploit the potential of big data. The inequalities in the agricultural sector is further exacerbated by this digital divide, resulting n in the risk of locking out some groups or further benefiting those who are already privileged.

The digital revolution in agriculture, though promising, still highlights and potentially deepens existing divides. Unequal geographic access to information and communication technologies (ICT) leading to uneven socio-economic development outcomes is a major tension. The use of mobile phones for agricultural information can aggravate information asymmetries between traders and farmers, wealthier and poorer farmers, or men and women, when the access to phones and other ICTs is not equal among them. These inequities are exacerbated by the pre-existing infrastructure access issues (e.g., poor broadband internet) combined with a lack of comfort, trust, or perceived utility of new technologies. The agricultural digitalization and automation will reinforce social, economic, and racial inequities in labor, skills development, and rural spatiality, mirroring existing social divides, which is a concern to be addressed. Employment opportunities in digital technologies are increasingly accessed by privileged populations. This raises questions of equity for those without the necessary skills. For instance, the "digital divide" in rural Australia is described as a "double jeopardy of remoteness and social exclusion". The gentrification of some rural areas driven partly by agricultural industries, relies on cheap, often migrant, labor, creating stark contrasts with nearby impoverished communities. This suggests that even though some rural areas experience an influx of tech-savvy populations, the benefits are not equitably distributed and potentially marginalizes migrant workers further.

The lack of high-speed internet access is crucial for farmers to fully utilize PF technologies. But it is often unavailable in many remote regions, even in wealthy nations, becoming a primary issue of concern. Lack of electricity, still more limiting the access to digital tools exacerbates the infrastructural gap. Furthermore, with high illiteracy rates being a negative socioeconomic marker, illiteracy and significant knowledge gaps are major determinants for the non-adoption of PF. The educational disparities create a lack of basic digital literacy among farmers, thus hindering their ability to engage with and benefit from new technologies. This divide is further widened particularly among infrequent users, by the unfamiliarity of smartphone-based applications and the perceived effort required to learn them. These issues can be addressed by prioritizing improvements in education and information distribution. It can enhance farmers' capacity to leverage digital tools for agricultural development, especially in developing countries.

A significant concern highlighted in the sources is the "big data divide". It refers to the unequal access to and control over data. Farmers, typically lacking the necessary tools or context for analysis, are often not granted access to their own data. Corporations only are primarily benefiting from the data collected. Farmers are explicitly aware of the secrecy surrounding how their data is used. A high percentage of them fear government access or commodity market speculation without their consent. Most of the farmers believe they own their data with a vast majority unaware of what companies intend to do with it. A power asymmetry is created between farmers and large agribusinesses. With the amassing of large quantities of previously proprietary data, these companies gain a privileged position with unique insights into farming practices . Concentration of expert and informational power in the hands of a few further compounds this issue. Legal tactics like copyright claims are employed by agribusinesses to prevent farmers from accessing or modifying software on their own tractors. The focus of big data collection in "big agriculture" is exclusively on inputs and production, completely neglecting externalities and vulnerabilities like the effects of pesticides or mono cropping risks. Crucial research on broader agricultural impacts is ethically hindered. Current big data tools primarily designed by and for large agribusinesses, operating in industrial agriculture are unsuitable for smaller, non-industrial farms. Technology Use Agreements (TUAs) signed by farmers, mostly on compulsion, restrict their autonomy and dictate many aspects of their operations. Thus the technology's potential is limited by the concentration of big data analytics in the hands of a few agribusinesses , primarily serving only corporate interests.

2.3 Future research areas

To enhance the understanding and promote more effective implementation of CSA technologies and digital services, future research should focus on several key areas. More evidence-based studies are required to focus on the barriers of agriculture 4.0 in the agricultural production chain. Beyond the level of just awareness, studies can specifically investigate the adoption rate of various DATs and DAS, utilizing trans disciplinary approaches. Researches should further delve into how DATs influence farmers' adaptive capacity or vulnerability to climate and non-climatic stressors, both immediately and in the long term. It will help to understand if they contribute to maladaptation.

The extent to which DATs can complement 'non-digitalized CSA practices' to achieve the triple-win benefits (adaptation, productivity, GHG emission mitigation) is also a crucial matter to be explored. The dynamic relationships between DAS use and CSA adoption over time (beyond cross-sectional data limitations) could also be additionally addressed by future studies. There is also scope for examining the impact of DAS use on the intensity of CSA technology adoption, and analyzing the cost and revenue implications for DAS users versus non-users. The future development of CSA should also prioritize using advanced internet technology, so as to ensure agricultural information security, including improvements in remote sensing, IOT systems (adaptability, efficiency, security), and AI applications (data collection, analysis, deep learning). Improving cropping patterns and management techniques, enhancing "internet + weather" services, and developing agricultural weather index-based insurance are the other areas where further emphasis is required.

Current limitations can be addressed and full potential can be realized, if future research in digital agriculture and CSA focuses on the following key areas:

<u>Understanding Adoption and Adaptation:</u>

1. The diversity of farm types, farming styles, and producer characteristics in the adoption and adaptation of digital agriculture technologies, assessing the distribution of benefits and risks among different actors need to be investigated.

2. Adaptation and learning dynamics post-adoption and the co-evolutionary processes between digital technologies and their embedded contexts should be explored.

3. The day-to-day experiences of implementing digital technologies on farms and whether practices and outcomes match expectations should be examined.

Socio-Economic and Ethical Dimensions:

1. Power dynamics, data ownership, privacy, and ethics in digitalizing agricultural production systems and value chains should be deeply analyzed.
2. The societal role of farms and the reflection of epistemological choices made in data selection, connection, and interpretation should be investigated.

3. The preconditions for trust among stakeholders in data-sharing networks should be understood and codes of conduct regarding private and societal goals need to be scrutinized.

4. The possibilities of how Responsible Research and Innovation (RRI) principles can help actors manage the 'unknowns' and 'unseens' related to digital agriculture should be explored.

5. The impacts of digitalization on farmer identity, skills, and farm work, including the performativity of 'Smart Farming' concepts and the influence of social media on farmer autonomy need to be addressed.

6. The economic viability of digital agriculture technologies and business models, including cheap strategies for small and medium-sized farmers should be researched.

Agricultural Knowledge and Innovation Systems (AKIS):

1. Concepts like 'digiware', 'Digital Agricultural Innovation Systems', and 'digi-grasping' should be developed further for the better understanding of digitalizing AKIS.

2. The possibilities of collaboration between traditional and non-traditional players in agri-food, and the role of new AKIS actors in local and global innovation dynamics should be studied.

3. There is a need to investigate how digitalization changes the functioning of agricultural R&D and find out whether virtual models, digital twins, or big data can replace field experimentation.

4. The emergence of new forms of digital learning and innovation spaces, such as Digital Innovation Hubs and Data Cooperatives should be explored.

5. New roles, functions, and identities of agricultural researchers and advisors in data management, sense-making, and application, and how unlearning/reskilling processes are managed should be analyzed.

Policy and Governance:

1. More research on digital agricultural policy-making processes, including how data feeds into real-time policy and the distributive effects of algorithm-informed policies should be conducted.

2. It is necessary to examine how policymakers counteract negative impacts like power concentration and cyber-attacks.

3. The nature of policy instruments framed or restricted by technologies, such as subsidies linked to remote monitoring should be investigated.

Global Geography and Interdisciplinarity:

1. Critical social science studies should be extended to developing and emerging countries in order to understand how digital agricultural technologies travel, translate, and are reconfigured in diverse contexts.

2. The role of global technology providers, local firms, and public-private partnerships in technology generation and diffusion should be assessed.

3. Interdisciplinary and trans disciplinary research to integrate technological, social, economic, and ethical aspects, developing robust frameworks and methodologies should be increased.

4. The binary nature of analytical frames, focusing on integrating process and data-driven approaches and exploring digital opportunities for smaller farms and alternative agro ecological systems should be tackled.

The existing knowledge gaps can be bridged and equitable development can be ensured by prioritizing research in several critical areas. It is imperative to refine the design principles for science-policy engagement efforts in specific contexts and also to gain a deeper understanding about the role of scientific evidence in policy-making. This also includes the need for more systematic empirical assessments to understand the mechanisms of co-evolution between policy-demand and scientific capability which would lead to desired development outcomes. Future initiatives must emphasize building local capacities to continuously analyze changing user requirements, develop services, and generate new content in the context of digital services. The viability of digital communication elements as integral parts of regional extension systems should be tested by researchers and policymakers. This is to ensure that they are effectively integrated into existing farmer-advisor relationships on a large scale. Furthermore, research is needed to design and employ appropriate algorithms to translate large datasets from digital applications into actionable insights for researchers and policymakers. The social justice implications of agricultural digitalization is another crucial area that needs to be addressed, with a focus on shifting the trajectory of digitalization to support food production and marginalized agricultural laborers. More empirical research on the impact of digital agricultural technologies on marginalized and racialized labor and rural communities is required, particularly to investigate how some actors benefit while others are disadvantaged. The implications of shifts in power dynamics (e.g., related to agricultural data) for marginalized groups like racialized and migrant farm workers could be understood through specific research. As digitalization evolves, it is essential to examine how economic dynamics in rural communities might impact agricultural labor, particularly concerning the gentrification of certain areas and their reliance on, or displacement of, migrant labor. Similarly, the study about the influence of racial tensions on farmers' decisions to displace migrant labor for automation and the subsequent impact on small rural communities is important. Some of the key policy areas requiring further research and discussion include establishing pathways to agriculture and farming for immigrants and migrant workers, encompassing residency, resources for starting farms, and training; providing support for marginalized forms of farming, including land repatriation and labor programming that integrates labor with automation (e.g., collective automation); and developing capacity and skill-building support in rural areas for vulnerable populations to acquire digital agricultural technology skills and to foster rural spaces where immigrant workers feel comfortable residing. Finally, as achieving "win-win-win" outcomes is paramount, future research must pay greater attention to the trade-off and synergy of its three pillars (food security, adaptation, mitigation), more broadly within the realm of CSA. Fundraising being a significant bottleneck, the industrial investment, finance, and evaluation criteria of CSA are urgent, current research directions. The establishment of scientific evaluation criteria for CSA to promote its healthy and effective development is of utmost importance.

Future research should focus on increasing the understanding and implementation of CSA technologies and digital services. More studies on the role of specific information sources in climate resilience and clarification regarding the media that best supports resilience building against changing climates are very much necessary. Contextual factors such as off-farm incomes, water security, distance to paved roads, and market access correlate with farmers' perceptions of climate change resilience. Hence this has to be investigated by the researchers. A multi-pronged approach is suggested to clarify the distinction between weather and climate for farmers and thereby, ensure a clear understanding of survey questions. Qualitative approaches are needed in the future to explain contextual factors contributing to climate resilience. The current adoption rates, especially for applicative tools, being moderate and underutilized, it is crucial to assess the full potential of PF. Private and public support can be better quantified and justified through additional research into the environmental effects of PF. Data confidentiality and ownership at both national and international levels can be addressed by proper developments in the legal framework. This includes an in depth study of public-private partnerships and data standards so as to enable privacy-protected research and also to ensure data security. Finally, future studies should analyze the distributional effects of

PF, especially concerning potential concentrations in the agri-food sector and unequal benefit distribution along the value chain.

Research in the future should broaden its focus to understand the uncertainties experienced by meso-scalar actors as well their implications for smart farming implementation. More research is required to scale up and scale out agronomic options to enhance the productivity and sustainability of irrigated rice-based cropping systems. Investigations should extend to include the impact of these technologies on smallholder livelihoods beyond economic outcomes alone. The development and evaluation of alternative agronomic options that consider economic, environmental, and social dimensions to encourage smallholder farmer adoption is dependent on good research. In-depth investigation into the ethics, power dynamics, and potential consequences surrounding the use of big data in agriculture and food production is very important. It is necessary to examine the role of research and public policy to ensure a more equitable use of big data in agriculture. The potential misuse of agricultural data can be addressed by proper legal reforms. It is important to ensure that there is a systematic collection of big data on industrial agriculture externalities, while ensuring this data is anonymized and made publicly accessible. The significance of GMO food labeling is highlighted in order to facilitate data collection on potential health effects and environmental disturbances. Finally, the necessity of publicly funded research and development of open-source big data analytic tools that operate independently of corporate control is emphasized. A critical role has to be played by public structures such as government agencies, universities, NGOs, and international organizations like the United Nations to support parallel research and development for innovative solutions that benefit a diverse range of farmers and agricultural models globally.

The data resolution in digital advisory services is a key aspect to ensuring the effectiveness of the service provided. The data resolution in advisory services can be improved through a combination of advanced data collection technologies. The technologies related to bringing data resolution into advisory services involve deploying tools like Internet of Things (IoT) sensors in the field that capture granular information on soil moisture, pH, temperature, and nutrients, allowing for tailored advice on irrigation and fertilizer application. Also, mobile soil testing services equipped with portable scanners and machine learning capabilities have the potential to reduce the cost and time required for soil analysis.

Some examples of technology involved in this scope include: Unmanned Aerial Vehicles (UAVs), or drones, which capture high-resolution remote sensing images that provide insights into monitoring plant health, soil conditions, and nutrient levels. These images can be converted into Geographic Information System (GIS) maps to help identify problem areas and guide interventions. Smartphone-based computer vision tools detect crop pests and diseases through image recognition, offering immediate and targeted recommendations. (Adla et al., 2022)

A dynamic content development process is required to convert the rich extracted data into actionable insights. It begins in requirement gathering phase with farmers that digital tools reflect the real needs of farmers, including women and low-literacy users. Expert validation will follow this step involving agronomists or agricultural research institutions. This validation helps converting data into localized advisory messages. The localization process should reflect not only farm location and crop types but also consider input usage and farming practices. Advisory content will then be formatted for diverse delivery formats such as SMS, voice messages, videos, graphics, or interactive chatbots. In counties with many languages and diverse people it will be translated into local languages. These services are especially valuable for real-time, day-to-day decisions such as fertilizer planning, sowing schedules, irrigation management, and pest control; guided by dynamic data on weather forecasts, soil status, and crop suitability. (Data-Driven Advisory Services for Climate-Smart Smallholder Agriculture, 2022)

To summarize, different dimensions involved in examining the barriers, potentials, and impact of adopting digitalization of climate-smart agricultural services has provided a conceptual framework as in Figure 6.

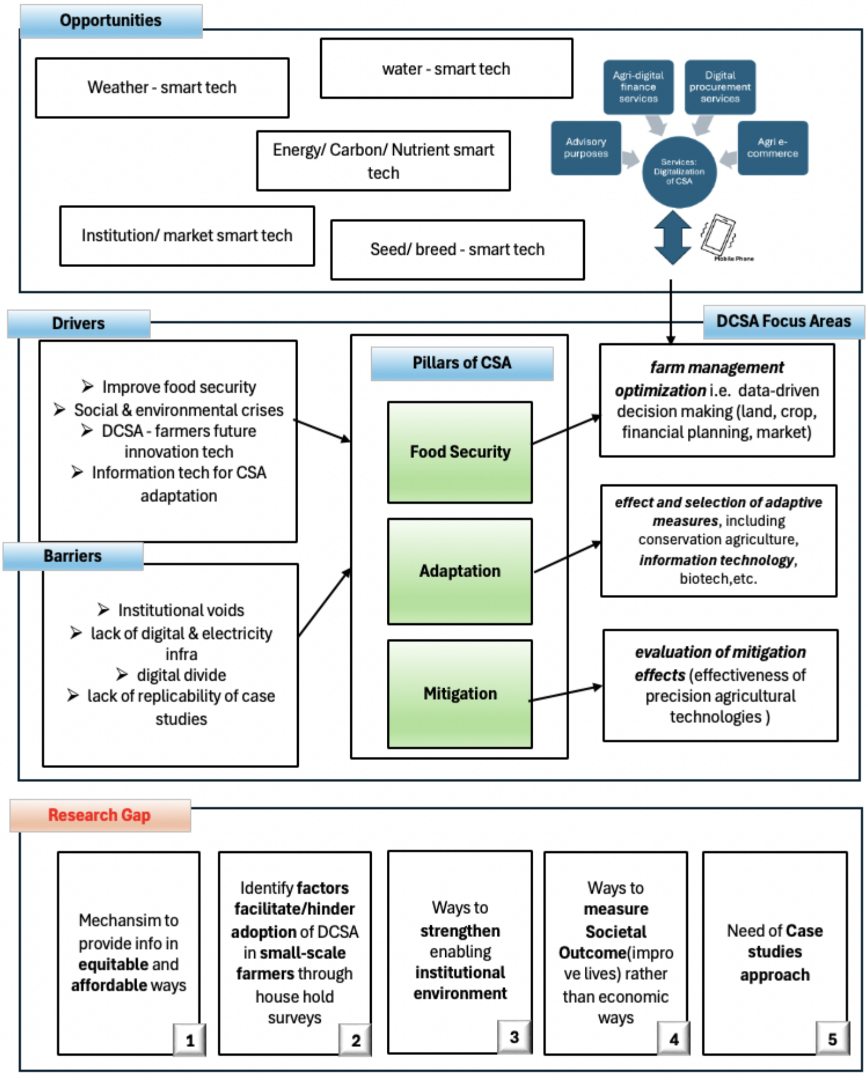


Figure 6 : Conceptual Framework on DCSA

2.4 Promoting Digitalization of Climate-Smart Agricultural Practices: An Approach to reduce digital divide and increase equitable Access

As discussed in the previous section, the adoption of DCSA has suffered because of many barriers. A few important ones are mismatches between farmers' needs or requirements and the services offered, an insufficient feedback mechanism, limited access to technology and capabilities regarding the same, and mistrust about such sources (Steinke et al., 2021). Implementing the digitalization of climate-smart agricultural practices is entirely feasible, as envisioned through leveraging different agricultural technologies, integrated agricultural systems approaches, and current data science potential. The key to achieving this is promoting institutional support of public and private institutions (Rao, 2018). Two crucial lessons highlighted in the study regarding prioritization of investments for CSA are maximizing the different facets of agricultural production in the face of climate change, and to enable an institutional environment that can synchronize with national and regional targets, challenges, and needs. Secondly, successful implementation of the CSA project happens when local stakeholders are engaged in the planning process. (Andrieu et al., 2017)

Institutional voids are crucial factors that obstruct farmers from receiving the disseminated agricultural information, thereby remaining unaware of new technologies and lack of access to credit, land, and infrastructure. Institutional voids refer to the absence or flaws in formal or informal institutions. These institutions are expected to be facilitators of mechanisms such as governance structure, contract enforcement, and property rights that are essential enablers for the effective adoption of digital agricultural technologies. Because of institutional voids, farmers resort to other substitute mechanisms such as networking, trust, and social connections with fellow farmers. The different innovative mechanisms that farmers tend to pursue to combat institutional voids are Social entrepreneurship, frugal entrepreneurship, bricolage, which refers to relying on his own intuition and experience in overcoming the problem, and Ingenieuring, which means rather than targeting to solve the problem through practical experience, starting to employ abstract concepts. (Akudugu et al., 2023)

Other reasons for underutilizing DCSA practices are mismatches in farmer user requirements and service providers' perspectives on what is important, a need for more understanding of application usage, the unavailability of services, and less contextualized, demand-specific, and localized information. Notably, many efforts need to be made to promote the farmers' perception and belief in the scientific credibility of DCSA. For the best outcome, services targeting DCSA practices must be built on farmers' requirements and in consultation with them. The service provider, who can be public or private or public-private, must explore ways to sustain the momentum with government cooperation and institutional support. The other critical dimensions to be considered as value propositions for increased DCSA adoption behaviors during policy interventions are effectiveness, relevance, sustainability, efficiency, and impact (Akudugu et al., 2023).

Responsible research and innovation that can guide the agricultural digital transformation by understanding the barriers and enablers of digitalization of agricultural advisory services and, importantly, the need to co-design the service with farmers by understanding his/her needs and values will be vital. (Kenny & Regan, 2021) Therefore, user-centeredness and problem-solving, which are the basis of digital design and enable institutional support, form the backbone of designing and promoting DCSA (Steinke et al., 2021).

When discussing the digitalization of climate-smart agricultural practices, it becomes essential to understand the nuances of terminologies such as digitization, digitalization, and digital transformation in the digital landscape, irrespective of the business domain. While digitization refers to the conversion of information from analog to digital, the digitalization process refers to using digital technologies to improve processes and operations, and digital transformation denotes a comprehensive way of looking at business strategies and operations through the digital lens and application of digital technologies. Digitalization or datafication in agriculture refers to the digitization of quantifiable agricultural data with regard to agricultural assets and production. This helps to monitor, track, analyze, and optimize processes.(Jouanjean, 2019) The different dimensions of digital transformation in modern agriculture are broadly classified under government, infrastructure, economics, technology, sustainability, cooperation, change and people, and knowledge and skills.

Research studies confirm that increased digitalization is proportional to increased productivity through agile ways compared to least digitalized sectors such as agriculture.(Alves et al., 2022) Digitalization in agriculture poses multi-fold challenges. The primary challenge farmers face in embracing digitalization is the digital divide and inequality issue surrounding mainstreaming the idea of digitalization and CSA. The focus is also more on economic sustainability and less on environmental and social sustainability (Gras & Cá, n.d.,Carbonell, 2016,Stock & Gardezi, 2021, Hisano, 2022,Balasundram et al., 2023). The underlying challenges in the digitalization of agriculture stems from the involvement of large agribusiness corporations, which often prioritize expanding their market opportunities over addressing core issues or driving meaningful and sustainable transformation within the agribusiness value chain. This dynamic can reinforce farmers' dependence on external technologies and platforms. Additionally, many digital agriculture algorithms are primarily designed for monocropping systems, making them less adaptable to diverse or traditional farming practices. As a result, these technologies can limit farmers' autonomy, hinder the integration of local knowledge, and undermine efforts to empower and institutionalize local agri-food actors and grassroots initiatives.

The review and field study analysis highlighted several barriers and drivers to the digitalization of climate-smart agricultural practices. The main themes drawn from them could be broadly classified under governance and policy, education and awareness, affordability, and technology accessibility. Following this and by relating the findings, a framework is conceptualized to summarize the study's main results.

2.4.1 Governance and Policy

The low adoption of DCSA can be mainly attributed to the digital divide and a lack of user-centric design. This is primarily because DCSA services and products are built using a top-down rather than bottom-up approach. Also, very few cases mostly lack systematic feedback from farmers. Even when a farmer gives feedback, the service provider fails to incorporate such changes into the service or product. It will be crucial to devise farmer-led innovative and collaborative arrangements that could be facilitated through crowdsourcing farmers’ requirements and iterative evaluation.

2.4.2 Education and Awareness

Many times, as farmers lack the time or are more inclined to farming than making decisions based on economic rationale, they find the idea of adopting DCSA too complicated or unnecessary. They prefer manual labor to automation and believe in farming instincts to DCSA. This is also interlinked with discordance between user knowledge and requirements to conceive a use case of digitalization from the technology provider side. The key would be prioritizing local knowledge and influencing farmers' perceptions.

2.4.3 Affordability and Accessibility of Technology

Initial investment cost, infrastructure issues, applicability of technology to identified use cases, and age of farmers were limiting farmers in the context of affordability and accessibility of technology. This could be overcome by institutional support, i.e., through government subsidies, investments towards improvising rural infrastructure, and identifying and establishing institutions that could support farmers in disseminating the digitalization of climate-smart agricultural practices. Enhancing institutional support will also help in promoting and increasing the adoption of low-cost digital climate-smart agricultural services.

2.5 Proposed Framework to Bridge the Gap: Digital Divide and Inequality

Digitization of climate-smart agricultural practices is to be explored in the background of the growing concern about the digital divide resulting in uneven socioeconomic development outcomes. In the future, the provision and promotion of DCSA services must consider not intensifying the digital divide and not deepening both spatial marginalization and labor. They say the problem will be further strengthened if public or institutional support is unavailable to the farmers. Through the proposal of a conceptual framework, as in Fig. 7, this research paper aims to study the know-how of instilling equitable and non-exploitative aspects in DCSA. (Rotz et al., 2019). The base layer of the framework stands on three conditions for successful digital transformation: design, access, and system complexities. This implies that the design of DCSA is tuned toward an impact, in this case, three pillars of CSA such as adaptation, mitigation, and sustainability. Digital technology accessibility is not only about seamless broadband coverage but also the context of bridging the digital divide. The system's complexity arises as more and more digital entities are interconnected, raising the need for technical experts and raising the economic costs of using a product or service.

The three pillars of this framework for promoting equitable access to the digitalization of climate-smart agricultural practices are structured as follows:

i. Devise farmer-led innovative and collaborative arrangements that could be facilitated through crowdsourcing farmers' requirements and iterative evaluation

ii. Enhance institutional support toward promoting low-cost digital climate-smart agricultural services
iii. Prioritizing local knowledge and influencing farmers' perception

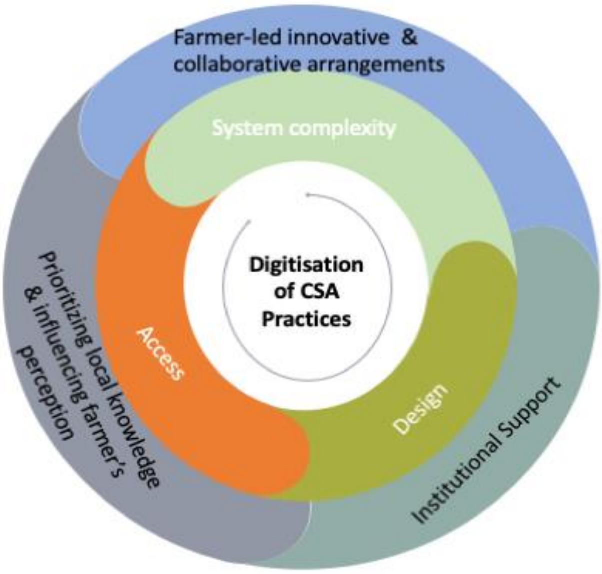


Figure 7: Conceptual Framework for equitable access to the digitalization of climate-smart agricultural practices

To summarize, DCSA must not be developed with the aim of further economic benefits but rather to improve the lives of vulnerable people in the rural sector without deepening the digital divide.

CHAPTER 3: STUDY AREA: TAMIL NADU, INDIA

Tamil Nadu is one of India’s 28 states, consisting of 38 districts as in figures 8 and fig 9. Chennai, the largest city, is its capital. It is located in the southern region of the country. Tamil Nadu lies between 8°5’ and 13°35’ north latitude and 76°15’ to 80°20’ east longitude. It is a prominent coastal state, with a coastline stretching 1,076 kilometers, and shares a maritime boundary with Sri Lanka.

The state is attributed with a diverse range of ecosystems, starting from the montane rainforests of the Western Ghats in the west, moving through the dry deciduous forests and thorn scrub of the southern Deccan Plateau, and extending eastward to tropical dry broadleaf forests, coastal beaches, estuaries, salt marshes, mangrove swamps, and coral reefs along the Bay of Bengal. Tamil Nadu's population is estimated at around 76.993 million as of 2024, which has slightly increased from 76.765 million in 2023.

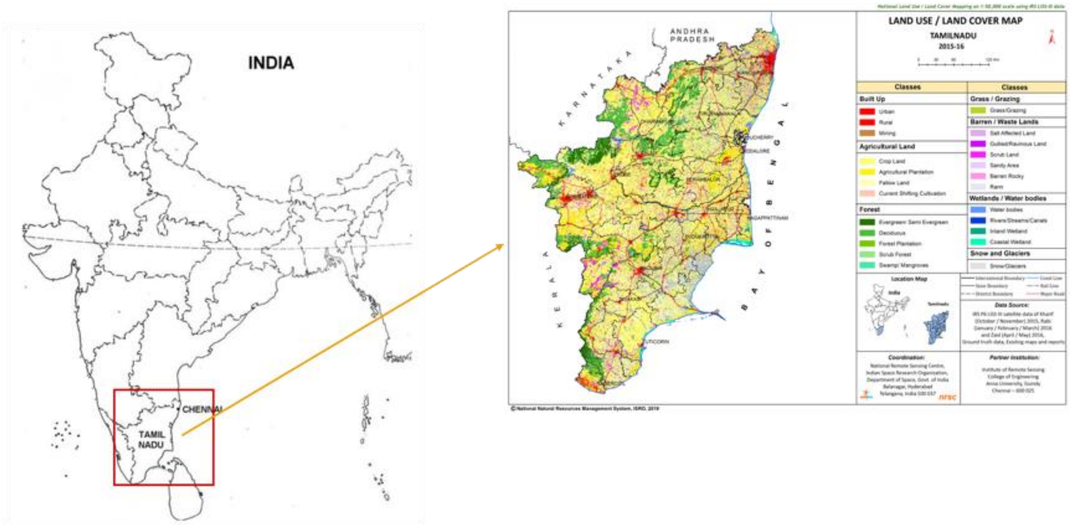


Figure 8: Map of Tamil Nadu, a southernmost coastal state of India

Source: National Natural Resources Management Systems, ISRO

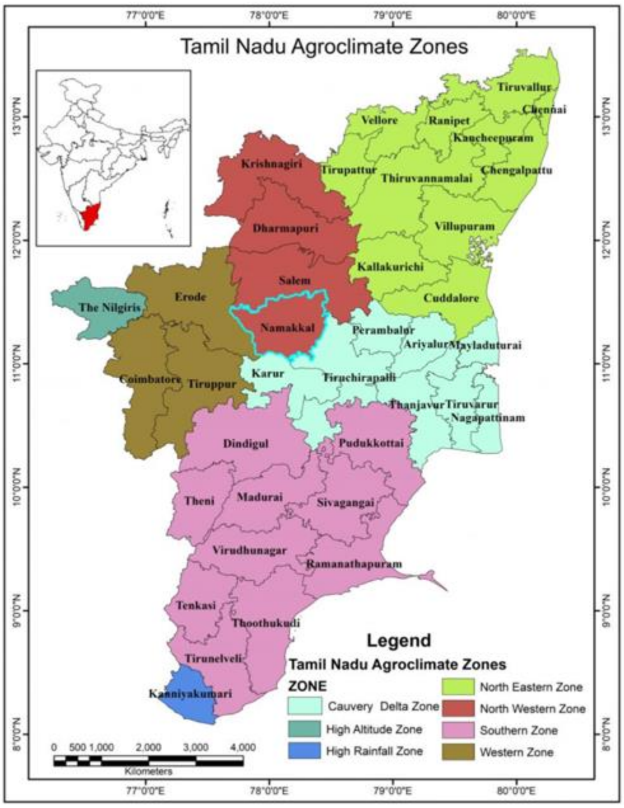


Figure 9: District Map of Tamil Nadu

3.1 State Profile and Regional Settings

Tamil Nadu is ranked as the tenth largest state in India by area and the seventh in terms of population. It extends approximately 130,058 square kilometers (50,216 square miles). Geographically, it is bordered by Kerala to the west, Karnataka to the northwest, and Andhra Pradesh to the north. Its eastern coast is lined by the Bay of Bengal, while to its south lies the Indian Ocean. Cape Comorin (Kanyakumari), the southern tip of the Indian Peninsula, is located in Tamil Nadu's southernmost part.

Tamil Nadu's landscape is featured by a diverse terrain. The western, southern, and northwestern regions are mostly hilly, comprising a mix of dry areas and patches of vegetation. The convergence of the Eastern and Western Ghats at the Nilgiri Hills is unique to Tamil Nadu. The Western Ghats running along the western boundary, forms a natural barrier against the moisture-laden clouds brought by the Southwest Monsoon. On the other hand, the eastern side consists of fertile coastal plains, while the northern area has a combination of hills and plains. Much of the central and south-central parts of the state comprises of dry plains.

Overall, Tamil Nadu's topography can be classified into eastern coastal lowlands and western mountainous regions.

1. **Coastal Plains**

a. *Coromandel Plains*: This fertile coastal strip stretches from Kanchipuram to Cuddalore, including areas such as Thiruvallur and Vellore.

b. *Cauvery Delta*: This delta region formed by the Cauvery River is agriculturally rich and economically vital, found in Thanjavur and parts of Tiruchirapalli.

c. *Southern Dry Plains*: This zone is known for its arid climate, comprising districts like Madurai, Dindigul, Ramanathapuram, Sivaganga, Virudhunagar, Tirunelveli, and Tuticorin.

2. **Western Hilly Terrain**

a. Western Ghats: This mountain range forming the state's western edge, includes the Nilgiri, Anaimalai, and Palni hills.

b. Eastern Ghats: These lower elevation hills stretch through the state's interior such as the Javadi, Kalrayan, and Shevaroy ranges.

c. Nilgiri Hills:The Nilgiris, boasting peaks exceeding 8,000 feet, is located at the junction of the two Ghats, making them a prominent feature of the state's geography.

River Systems

- Cauvery River: This river flowing eastward, originates in the hills and forms the productive Cauvery Delta.
- Other Major Rivers: The state's hydrology is further enriched by rivers like the Ponnaiyar, Palar, Vaigai, and Thamirabarani which all also flow eastward.

Climate

Tamil Nadu's climate is mainly influenced by monsoon activity, making it vulnerable to drought during weak monsoon years. The climate varies from humid rainforests to semi-arid and even desert-like conditions in the interiors. Agriculture which is heavily reliant on monsoonal rains, leads to uncertainty in crop output. The state experiences three main weather phases:

- Southwest Monsoon (June to September) with strong southwest winds
- Northeast Monsoon (October to December) driven by northeast winds
- Dry Season (January to May)

The state receives an average annual rainfall of about 945 mm (37.2 inches), with nearly half of it (48%) coming from the Northeast Monsoon and 32% from the Southwest Monsoon. Rainfall being the primary source of water replenishment, any disruption in the monsoon cycle causes acute water shortages and extended droughts.

Water resources:

Tamil Nadu holds merely 2.5% of the nation's total water resources. Agriculture being the primary water-consuming sector, utilizes around 75% of the state's available water.

The overall water potential of Tamil Nadu encompasses groundwater. It stands at 46,540 million cubic meters (MCM) out of which, surface water accounts for 24,864 MCM. Against these constraints, groundwater serves as the key source for expanding agricultural activities. Of the 1,166 Firkas across the state, groundwater status classifies 427 as Safe, 462 as Over-Exploited, 79 as Critical, 163 as Semi-Critical, and 35 as Saline. These categorisations highlight the pressing need for sustainable water-use methods, so as to safeguard future availability.

Soil resources:

Tamil Nadu extends over an area of roughly 13 million hectares (Mha), making up about 4% of the country's total land area. As part of the peninsular shield, the region consists of ancient geological formations of varied types, which have given rise to diverse soil groups. Around three-fourths of Tamil Nadu comprises of unclassified crystalline rocks from the Achaean era, while the rest is formed of sedimentary deposits. The state is broadly categorized into three major physiographic zones and ten different landform units. Climate conditions ranges from semi-arid on the plains to humid and sub-humid in hill areas, with yearly rainfall varying from 750 mm in some plains to over 2,400 mm at higher elevations. The soils of Tamil Nadu are classified into 94 families, grouped into six broad soil orders. Soil depth seldom hinders crop production, as just 14% of the land area consists of shallow or very shallow soils. Soil texture varies widely, from sandy to clay-rich types. About 18% of the land features sandy soils on the surface, 53% are with loamy textures, and 22% contain clayey soils. Drainage is generally not a significant barrier to farming, with 64% of soils moderately to well-drained, 15% excessively drained, and only 14% poorly or imperfectly drained. The widespread calcareous soils covers about 34% of the state's area. Based on land capability, 79% of the state's terrain is considered to be fit for cultivation, while 21% is not suitable for farming. Among cultivable land, Class II lands (productive) form about 34%, Class III lands (moderately productive) make up roughly 30%, and Class IV lands (fairly productive) represent 15% of the total area. Tamil Nadu's agricultural viability is significantly influenced by these soil attributes, thus shaping crop choices, yield levels, and sustainable farming approaches. In the long run, understanding these soil properties is vital for refining agricultural planning and promoting soil conservation.

There is high variability in soil at short distances of around 5 km. However, patterns tend to be consistent over larger areas, extending up to 140 km.

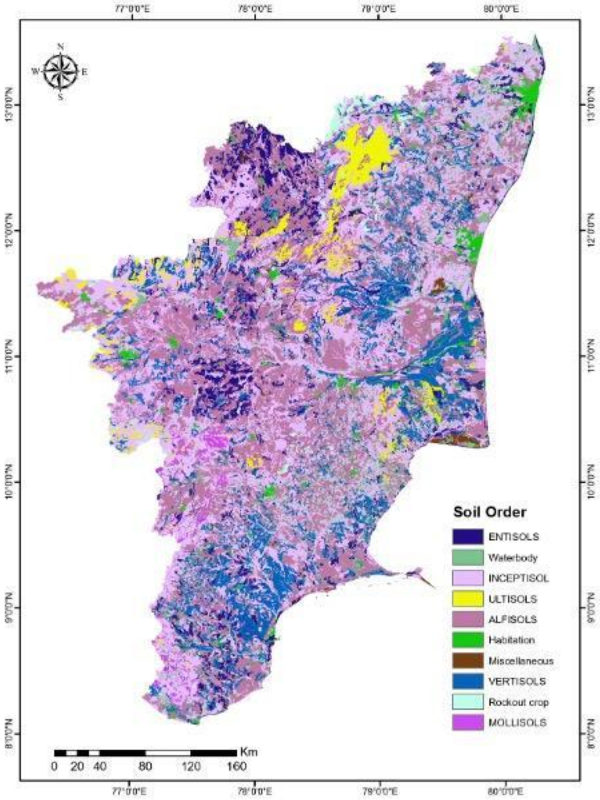


Figure 10: Soil Variation

Source: Mann Valam, Tamil Nadu Agricultural Portal

<u>Sources of irrigation:</u>

The details of net area irrigated using various sources of irrigation across the State during the year 2022-23 are as follows :

Table 2: Water source wise net area irrigated 2022-23

Source: Department of Economics and Statistics, Government of Tamil Nadu (2022-23)

Source Net Area	Availability (Nos)	Irrigated (lakh ha.)	% with reference to Net Area Irrigated
Canals	2,241	6.83	23.39
Tanks	41,123	3.99	13.66
Tube Wells & Bore wells	3,71,084	5.42	18.56
Open wells	14,69,659	12.92	44.25
Others	45,129	0.04	0.14
	Total	**29.20**	**100.00**

Nearly, 63% of the cultivated land is irrigated through wells, borewells, and open wells, while 23% is irrigated by canals and the remaining 14% by tanks.

Utilization of irrigation water resources:

A slight increase of 0.16% was found in the area irrigated by wells, borewells, and open wells, with 18.35 lakh hectares in 2021–22 to 18.38 lakh hectares in 2022–23.

3.2 Farming and Farmers' demographics

In Tamil Nadu, especially in rural areas, agriculture and its allied sectors form the backbone of livelihoods . Nearly two-thirds of rural households rely on agriculture primarily for their sustenance. The vital socio-economic role played by this sector is highlighted by the fact that, significantly, small and marginal farmers make up 93% of the farming population. Around 79.38 lakh landholders in Tamil Nadu cultivate a total of 59.71 lakh hectares. The 10th Agricultural Census by the Government of India shows that marginal and small farmers collectively hold 93% of all landholdings and manage 62% of the cultivable land. In contrast, medium and large farmers making up just 7% control the remaining 38%. The average landholding size in Tamil Nadu stands at 0.75 hectares, which is considerably lower than the national average of 1.08 hectares. The fragmented nature of land ownership in the state, as reflected in these figures underscore the urgent need for targeted policies to support small and marginal farmers for sustainable agricultural progress.

Table 3: Land use pattern of Tamil Nadu 2020-21 and 2022 to 2022 – 23 – A comparison

Land Use	**(lakh hectare)**		
	2020-21	**2022-23**	**Remarks**
Gross cropped area	61.55	62.60	1.05 lakh ha increase
Current Fallow lands	8.93	8.90	0.03 lakh ha decrease
Other fallow lands	18.65	18.48	0.17 lakh ha decrease
Net cropped area	48.33	48.37	0.04 lakh ha increase
Cropping Intensity	127.35	129.40	2.05% increase

A notable structural shift in landholding patterns, gender roles in agriculture, and a growing trend toward smaller operational farms is revealed by the 2015-16 Agricultural

Census, the tenth in the series conducted in Tamil Nadu . Below are the key insights from the census:

Decrease in average landholding size

The average size of operational holdings decreased down from 1.15 hectares in 2010-11 to 1.08 hectares in 2015-16,. This decline is reflecting continued land fragmentation, which is a trend with significant implications for agricultural productivity and long-term sustainability.

Increase in female participation in agriculture

There was a marked increase in female involvement in agriculture with the proportion of female operational holders rising from 12.79% in 2010-11 to 13.96% in 2015-16. Similarly, the share of land operated by women increased from 10.36% to 11.72%, indicating a gradual move toward greater gender inclusivity in agricultural ownership and management.

Growth in small and marginal holdings

Small and marginal holdings (0.00–2.00 ha) constituted 86.08% of all operational holdings in 2015-16, an increase from 85.01% in 2010-11. The growing dominance of smallholder agriculture is highlighted from their increased share of the total operated area from 44.58% to 46.94% .

Shift toward smaller landholdings

The data points to a steady shift toward smaller farms, accompanied by a decline in the share of semi-medium (2.00–4.00 ha), medium (4.00–10.00 ha), and extensive holdings (over 10.00 ha). The future prospects for farm mechanization, productivity, and the economic sustainability of agriculture in the state may be influenced by this structural change .

Operational holdings and cultivable land use

Tamil Nadu had a total of 79.38 lakh operational landholders in 2015-16, collectively managing 59.73 lakh hectares of cultivable land.

Table 4: Area production and productivity of principal crops 2021-2022
Source: Department of Economics and Statistics , Tamil Nadu Government

Crop		Area (Hect)	Production (Tonnes)	Productivity (in Kg./Hec.)
A. CEREALS	Paddy*	2217269	7906373	3566
	Cholam(Jowar)	397223	362109	912
	Cumbu (Bajra)	59956	146132	2437
	Ragi	74434	227476	3056
	Maize	400076	2826745	7066
	Small Millets	22995	29812	
	Total Cereals	**3171953**	**11498647**	
B. PULSES	Bengal gram	4065	3767	926
	Red gram	48314	45198	936
	Green gram	164183	62166	379
	Black gram	407247	268700	660
	Horse gram	65551	44747	683
	Other pulses	112740	28770	
	Total Pulses	**802100**	**498886**	
	Total Foodgrains (A+B)	**3974053**	**11997533**	
C. OIL SEEDS	Groundnut	372399	1047221	2812
	Gingelly	47467	27947	589
	Coconut @	457717	53518	11692
	Castor	6406	2027	316
	Sun flower	5582	5468	980
	Other Oil Seeds			
	Total Oil Seeds	**889571**	**1136181**	
D. OTHER CROPS	Cotton #	147907	302323	348
	Sugarcane **	147993	16166878	109
	Tobacco	1544	2336	1513
	Spices and Condiments	53173	26382	496
	All Other crops			
	Other Non-Food Crops			
	Total Other Crops	**350617**	**16497919**	
	Total Crops (A+B+C+D)	**6348140**		

The picture 1 below illustrates the life cycle of rice farming from pre-sowing, sowing, cultivating, harvesting, and post-harvesting. The highly laborious process of rice cultivation can be inferred by the same.

Picture 1: Life cycle of rice farming

3.3 Climate and Risks

The different agricultural zones based on districts, altitude, annual rainfall, and crops grown are categorised in the following table 5 :

1. North Eastern Zone (Altitude: 100-200m, Rainfall: 1105mm) comprises districts like Kanchipuram, Villupuram, and Tiruvannamalai. Rice, millets, pulses, sugarcane, mango, banana, jackfruit, turmeric, and spices are the major crops grown here.
2. North Western Zone (Altitude: 200-600m, Rainfall: 875mm) comprising districts like Dharmapuri, Salem, and Namakkal are featured by key crops such as sorghum, rice, millets, groundnut, cotton, tapioca, banana, tomato, turmeric, and flowers.
3. Western Zone (Altitude: 200-600m, Rainfall: 715mm) comprising districts like Erode, Coimbatore, and parts of Karur, mainly produces pulses, groundnut, ragi, turmeric, maize, banana, tobacco, guava, flowers, and vegetables.
4. Cauvery Delta Zone (Altitude: 100-200m, Rainfall: 984mm) comprising districts like Trichy, Thanjavur, and nearby districts, is known for rice, pulses, banana, coconut, citrus, and vegetables.
5. The Southern Zone (Altitude: 100-600m, Rainfall: 857 mm) comprising districts like Madurai, Sivaganga, and Thoothukudi are featured by key crops such as maize, pulses, groundnut, oilseeds, onion, banana, amla, and vegetables.
6. The High Rainfall Zone (Altitude: 100-200m, Rainfall: 1420mm) comprises districts like Kanyakumari. Here, bananas, jackfruit, tapioca, spices, and vegetables are grown.
7. Hilly and High Altitude Zone (Altitude: >2000m, Rainfall: 2124mm) comprising Nilgiris and Kodaikana lare featured by crops such as tea, coffee, spices, strawberries, avocado, and temperate fruits like apples and oranges.

Table 5: Agro Climatic Zones in Tamil Nadu
Source: TNAGRISNET

Zone	Districts	Altitude (m)	Annual rainfall (mm)	Crops grown
North Eastern	Kanchipuram, Chengalpet, Tiruvallur, Cuddalore, Villupuram, Kallakuruchi, Vellore, Tirupathur, Ranipet,Tiruvannamalai	100-200	1105	Rice, Pearl Millet, Sorghum, Gingelly, Finger Millet, Groundnut, Red Gram, Sugarcane, Cashew, Mango, Guards, Green Chillies, Brinjal, Tapioca, Yam, Banana, Jack, Guava, Watermelon, Turmeric, Tube rose, Crossandra and Lemongrass.
North Western	Dharmapuri, Salem, Namakkal	200-600	875	Sorghum, Rice, Millet, Groundnut, Horse Gram,Cotton, Sugarcane, Tapioca, Cotton, Gingelly, Chillies, Mango, Banana, Tobacco, Pulses, Jack, Tomato, Radish, Brinjal, Ladies Finger, Pepper, Arecanut, Cocoa, Coconut, Palmarosa, Chrysanthemum, Jasmine, Marigold, Rose, Tuberose, Cutflowers, Turmeric and Red Chillies.
Western	Erode, Coimbatore, Karur (part), Namakkal (part), Dindigul (part), Theni (part)	200-600	715	Sorghum, Pulses, Groundnut, Rice, Millets, Cumbu, Cotton, Sugarcane, Ragi, Black Gram, Sunflower, Green Gram, Gingelly, Red Gram, Turmeric, Maize, Banana, Onion, Castor, Tobacco, Guava, Onion, Guards, Tomato, Tea, Coffee, Coconut, Gloriosa, Flowers, Tapioca, Jasmine, Rose and other Vegetables.
Cauvery Delta Zone (CDZ)	Tiruchi, Perambalur, Pudukottai (part), Thanjavur, Nagapattinam, Mayiladuthurai, Tiruvarur, Cuddalore (part)	100-200	984	Rice, Cumbu, Maize, Cholam, Ragi, Black Gram, Green Gram, Coconut, Gingelly, Castor, Groundnut, Banana, Onion, Cashew, Betel vine, Citrus, Jack and other Vegetables.
Southern	Madurai, Sivagangai, Ramanathapuram, Virudhunagar, Tirunelveli, Tenkasi, Thoothukudi	100-600	857	Rice, Maize, Cumbu, Cholam, Ragi, Black Gram, Greengram, Groundnut, Fodder Crops, Gingelly, Castor, Cotton, Chillies, Banana, Jasmine, Coriander, Onion, Lime, Cashew and Amla.
High Rainfall	Kanniyakumari	100-2,000	1,420	Rice, Banana, Jackfruit, Mango, Tapioca, Cashew nut, Coconut, Clove, Vegetables & Tamarind.
Hilly and High Altitude	Nilgiris, Kodaikanal	> 2,000	2,124	Wheat, Garlic, Lemon, Lime, Pomegranate, Pineapple, Beans, Beetroot, Cabbage, Chowchow, Cotton, Pepper, Coffee, Potato, Banana, Mandarin, Orange, Pear, Cardamom, Cutflowers, Strawberry, Avocado, Tea and Ginger.

The projected changes in minimum temperature (°C) across various districts over three time periods: 2010-2040, 2040-2070, and 2070-2100, with reference to the baseline period of 1970-2000 is presented in the following table 5. It indicates a general rise in minimum temperatures across all districts. In the initial period (2010-2040), temperature rise varies between 0.55°C to 1.5°C, with the lowest increase in Tirunelveli (0.55°C) and the highest in Karur (1.5°C). In the mid-term period (2040-2070), temperature changes range from 1.65°C to 2.66°C, with most districts experiencing an increase of around 2.2°C to 2.6°C. By the long-term period (2070-2100), the temperature rise becomes more pronounced, varying between 2.65°C and 3.8°C, with Karur (3.8°C), Vellore (3.7°C), and Ariyalur (3.7°C) among the highest increases. Thus the overall trend suggests a steady warming pattern and temperature increases becoming more significant towards the end of the century. This trend potentially impacts climate-sensitive sectors like agriculture and water resources.

Table 6: District wise percentage change in minimum temperature degree Celsius with reference to 1970-2000
Source: Centre for climate change and adaptation research, Anna university, Chennai

District Name	Change in minimum temperature in ^{0}C with reference to 1970-2000		
	2010-2040	2040-2070	2070-2100
Ariyalur	1.4	2.6	3.7
Chennai	1.1	2.2	3.2
Coimbatore	1.2	2.3	3.3
Cuddalore	1	2.2	3.3
Dharmapuri	1.2	2.4	3.6
Dindigul	1.1	2.3	3.4
Erode	1.3	2.6	3.7
Kancheepuram	1	2.2	3.3
Kanyakumari	0.8	1.8	2.7
Karur	1.5	2.6	3.8
Krishnagiri	1.3	2.5	3.6
Madurai	1	2.2	3.3
Nagapattinam	1.1	2.2	3.2
Namakkal	1.3	2.5	3.7
Nilgiri	1.2	2.3	3.3
Perambalur	1.1	2.3	3.5
Pudukkottai	1.1	2.3	3.3
Ramanathpuram	1.1	2.2	3.2
Salem	1.2	2.4	3.6
Sivaganga	1.1	2.4	3.5
Thanjavur	1	2.1	3.3
Theni	1	2.2	3.2
Thiruvallur	1.1	2.2	3.3
Thiruvannamalai	1.3	2.5	3.6
Thiruvarur	1.1	2.2	3.3
Thoothukudi	1.1	2.2	3.1
Trichy	1.2	2.4	3.6
Tirunelveli	0.55	1.65	2.65
Tiruppur	1.42	2.62	3.62
Vellore	1.3	2.6	3.7
Villupuram	0.9	2.1	3.1
Virudhunagar	0.85	1.95	2.95

Coastal areas in Tamil Nadu have seen a noticeable rise in average maximum temperatures, with some stations recording increases as high as +0.54 °C per decade. In contrast, inland regions have experienced more significant increases in average minimum temperatures, reaching up to +0.31 °C per decade. Interestingly, a few inland stations have even reported a slight decrease in minimum temperatures, with declines of around −0.05 °C per decade (Jeganathan, Ramasamy, & Anbazhagan, 2018; Jeganathan & Ramasamy, 2019).

Temperature changes across various districts over three time periods: 2010-2040, 2040-2070, and 2070-2100 is presented in the following table 6. Most of the districts exhibit a negative temperature change in the initial periods, indicating a cooling trend, with Chennai (-9, -14, -4), Kancheepuram (-8, -12, -3), and Thiruvallur (-6, -13, -5) showing significant reductions. However, some districts like Kanyakumari (6, 11, 6), Nilgiri (-3, 5, 7), and Ramanathapuram (-4, 2, 9) show an increasing trend, particularly in the later periods. Towards 2070-2100, more districts begin to experience a positive temperature shift, including Thoothukudi (-1, 8, 19), Pudukkottai (-6, -1, 9), and Virudhunagar (-7, 1, 7), suggesting a warming trend in the long term. This data indicate a mixed climate change impact, with some regions cooling initially and towards the end of the century, others experience significant warming.

Table 7: District wise percentage change in annual rainfall with reference to 1970-2000
Source: Centre for climate change and adaptation research, Anna university, Chennai

Districts	2010-2040	2040-2070	2070-2100
Ariyalur	-6	-7	-3
Chennai	-9	-14	-4
Coimbatore	-3	4	6
Cuddalore	-6	-6	3
Dharmapuri	-5	-4	-3
Dindigul	-4	-3	1
Erode	-6	-6	0
Kancheepuram	-8	-12	-3
Kanyakumari	6	11	6
Karur	-3	-3	-2
Krishnagiri	-4	-5	-2
Madurai	-2	0	1
Nagapattinam	-7	-5	3
Namakkal	-4	0	-3
Nilgiri	-3	5	7
Perambalur	-6	-6	-3
Pudukkottai	-6	-1	9
Ramanathpuram	-4	2	9
Salem	-4	-1	-3
Sivaganga	-4	-2	4
Thanjavur	-6	-1	7
Theni	-7	0	4
Thiruvallur	-6	-13	-5
Thiruvannamalai	-6	-11	-7
Thiruvarur	-7	-2	8
Thoothukudi	-1	8	19
Trichy	-5	-2	-2
Tirunelveli	1	6	6
Tiruppur	-7	-3	2
Vellore	-6	-11	-6
Villupuram	-7	-9	1
Virudhunagar	-7	1	7

The coefficient of variation (CV) in rainfall is approximately 0.57, indicating that local rainfall varies by more than 50% from the average, reflecting high variability.

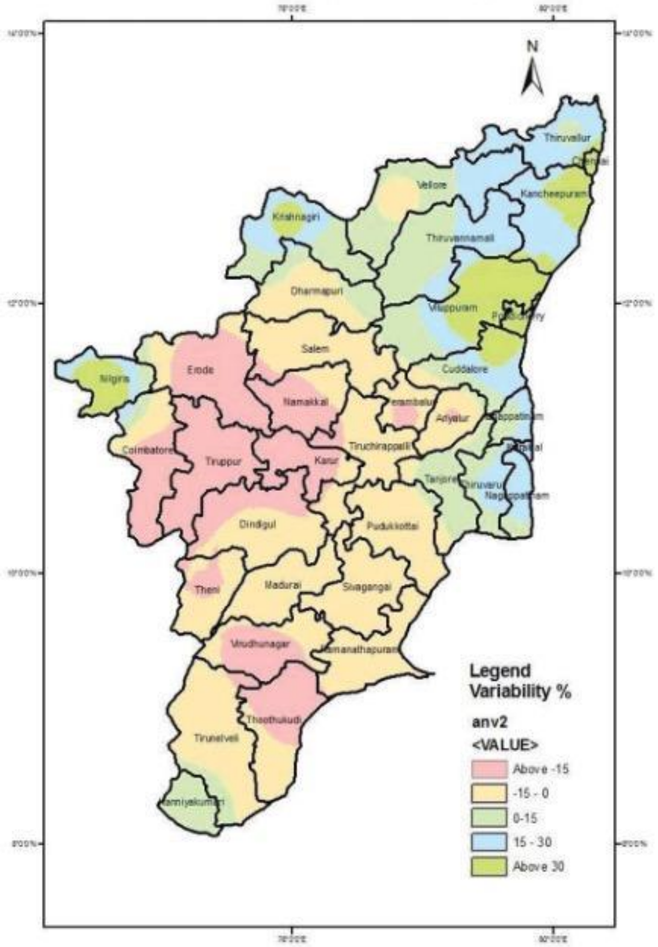


Figure 11: Rainfall variability

Source : (Raviraj et al)

The below graph explains the annual variation in the Aridity Index from 1982 to 2020, highlighting growing fluctuations in climatic dryness. Over the years, there has been a clear pattern of increasing peaks, with a notable spike in 2020, indicating a significant rise in arid conditions. Periods such as 2004 and 2020 show extremely high aridity values, suggesting severe reductions in water and moisture availability during these years. The overall trend points to greater climatic variability, with more frequent and intense dry spells. This increasing aridity underscores rising uncertainty in rainfall patterns and water availability (Gautam et al, 2024).

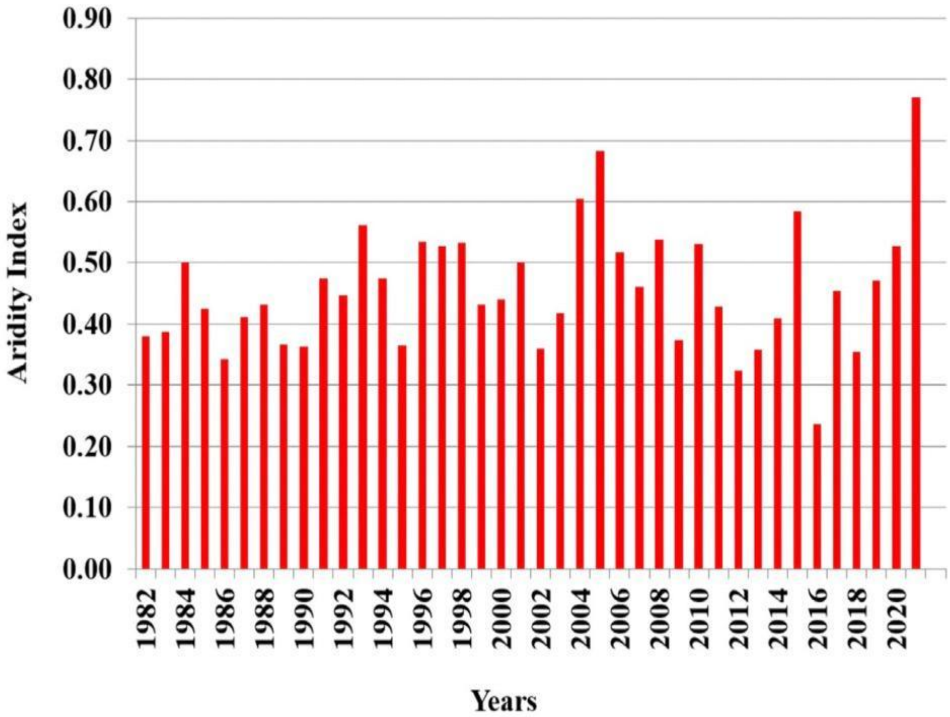


Figure 12: Aridity Index

Tamil Nadu State Action Plan on Climate Change presents the key policies and state performance related to climate change and sustainable agriculture. All its sectors have been aligned by the state with the National Action Plan on Climate Change (NAPCC) and it has formulated its own State Action Plan on Climate Change (SAPCC) in 2014. This was officially endorsed in 2015. Rashtriya Krishi Vikas Yojana (RKVY), Paddy Mission, Millet Mission, Pulses Mission, and the National Food Security Mission are the various agricultural programs and initiatives through which the state aims to boost farm incomes in terms of sustainable agriculture. Rain-fed area development, water-body restoration (IAMWARM), and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) are the other additional measures. Revised Breeding Policy for Cattle 2008 and the Tamil Nadu Bovine Breeding Act 2019 are the initiatives with which Tamil Nadu also promotes horticulture, animal husbandry, dairy development, and fisheries. The overall focus is on enhancing agricultural productivity, climate resilience, and sustainability. In line with the evolving challenges of climate change, the Tamil Nadu government has updated this plan to TNSAPCC 2.0, covering the period from 2022 to 2030. This revised plan was finalized and submitted for approval to the Union Environment Ministry in December 2024. The updated plan awaits formal approval as of February 2025.

Need for advisory services in the context of increasing climate risk:

The variation in soil, temperature and rainfall i.e climate variability implies that in Tamil Nadu farms microclimate exists. Crop selection depends heavily on factors like rainfall, temperature, soil moisture, and irrigation requirements. Farmers also need to assess risks such as drought or extreme weather before deciding what to plant. However, the information currently available is mostly at the district level, which is too broad to capture the variations that exist within smaller areas. To make more informed and effective decisions, farmers need localized data that reflects the specific conditions of their land rather which improves the effectiveness and productivity as compared to relying on generalized district-wide averages.

The key problems in agriculture that farmers face are across the agricultural value chain ranging from inputs to market. Regarding the farm inputs, aggregate demand from farmers are not met. Farmers increasingly rely on intermediaries such as pesticide or fertilizer dealers for quick recommendations which in turn results in unsustainable environmental degradation due to excessive usage of chemicals. Advisories provide farmers with relevant information to mediate the role of intermediaries and provide them with low-cost farm inputs, improves their knowledge base in the form of online or video based learning toward promoting better farming practices. Advisories also play an effective role in bridging the farmers with consumers directly and getting farmers a better price for their product. One such example is Agmarknet which provides real-time information on market trends, commodity prices, and mandi profiles across all the states in India. In the logistics and warehouse phase, advisory provide information to identify nearby storage facility and transportation options.

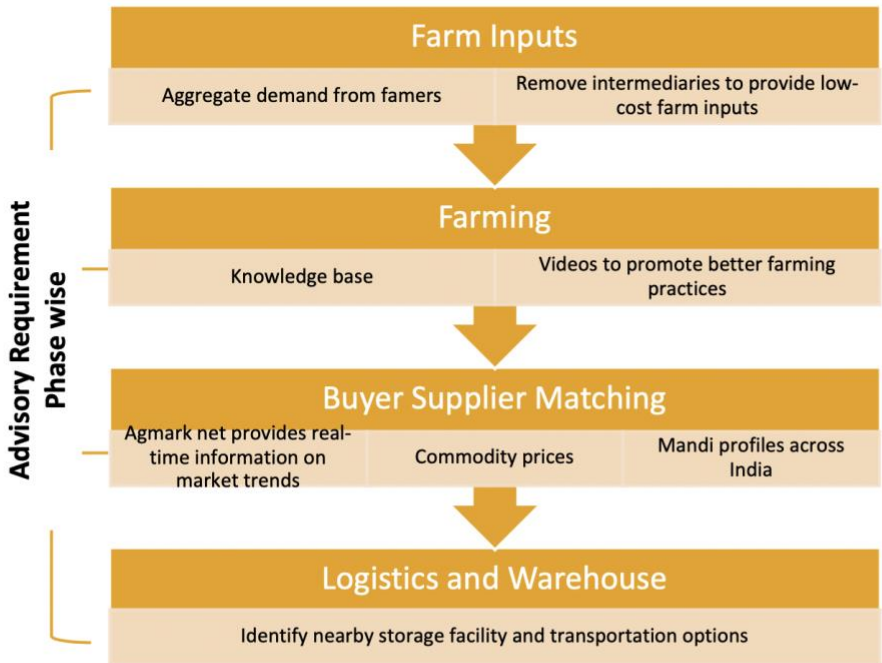


Figure 13: Role of advisories and solution to key problems in Indian agriculture
Source: Adapted (Sharan Jammanahalli Mahesh et al., 2022)

The time and cost to implement various technologies like blockchain-based record management, IoT automation, traceability of farm produce, smartphone-based AI quality assessment, predicting location-specific demand for agricultural products, AI-based crop health monitoring, and integrated advisory platforms for agricultural input and output vary significantly. Advisory services for agricultural input and output present a high-impact opportunity that requires minimal cost and time. The potential benefits for farmers can be achieved in a cost-effective manner within a relatively short period, making it an advantageous factor.

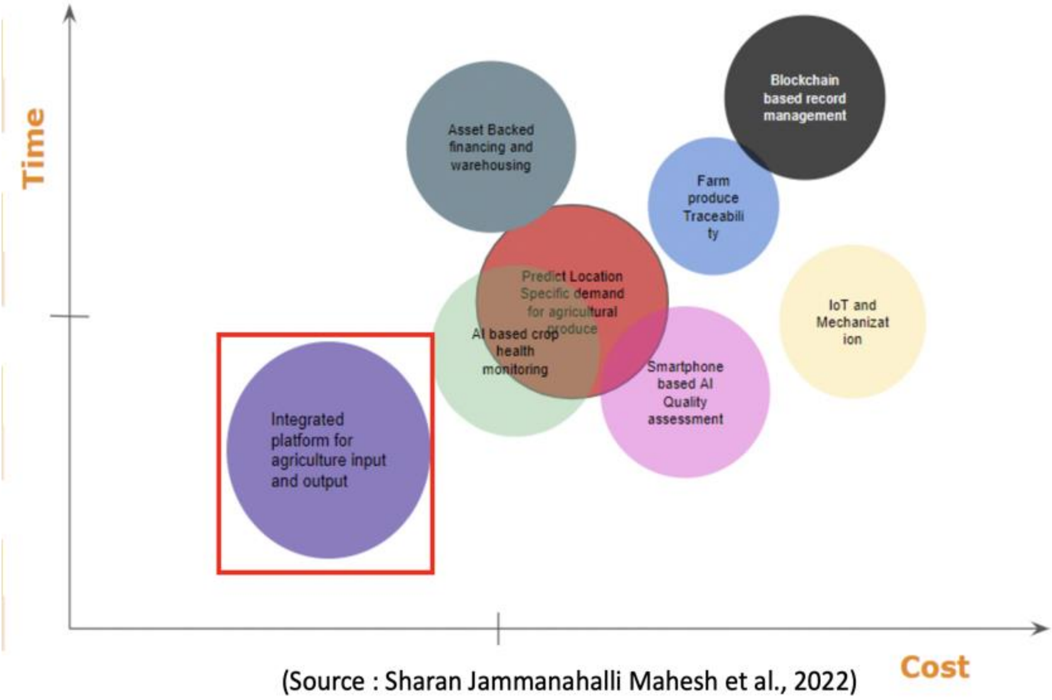


Figure 14: Advisory services – a low-cost high impact opportunity
Source: (Sharan Jammanahalli Mahesh et al., 2022)

The advisory services are disseminated to the farmers by one or more of the prevalent channels such as public, private or Non-governmental organization. The nature of the services in case of government is standardized services for policy good, tailored services for specific communities, personalized service for profit and scalability.

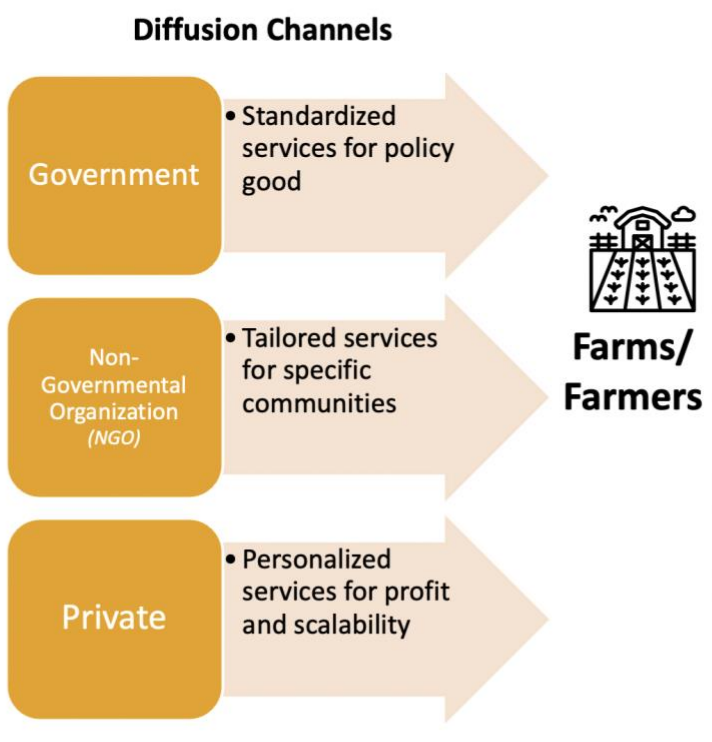


Figure 15: Diffusion channels involved in disseminating advisory service to farmers

The advisory services, as per the literature (Birner et al ., 2021) is classified under the three categories: digital platforms, advisory apps and farm management services.

1. Advisory apps: These apps facilitate farmers' decision-making about fertilizers or pesticides and the management of specific farm management activities. These applications sometimes have embedded photo-taking functionalities; thereby, farmers can capture a photo of a pest on a plant, upload it, and, in turn, receive advice from experts.
2. Digital platforms: They provide end-to-end solutions to farmers such as facilitate input supply, financial services, and marketing of outputs. They also help farmers to exchange information with other farmers.
3. Farm management software: They provide farmers with comprehensive information to manage the entire farm or some part of their farms. The systems vary depending on the underlying delivery models, stakeholders they serve and modeling approaches.

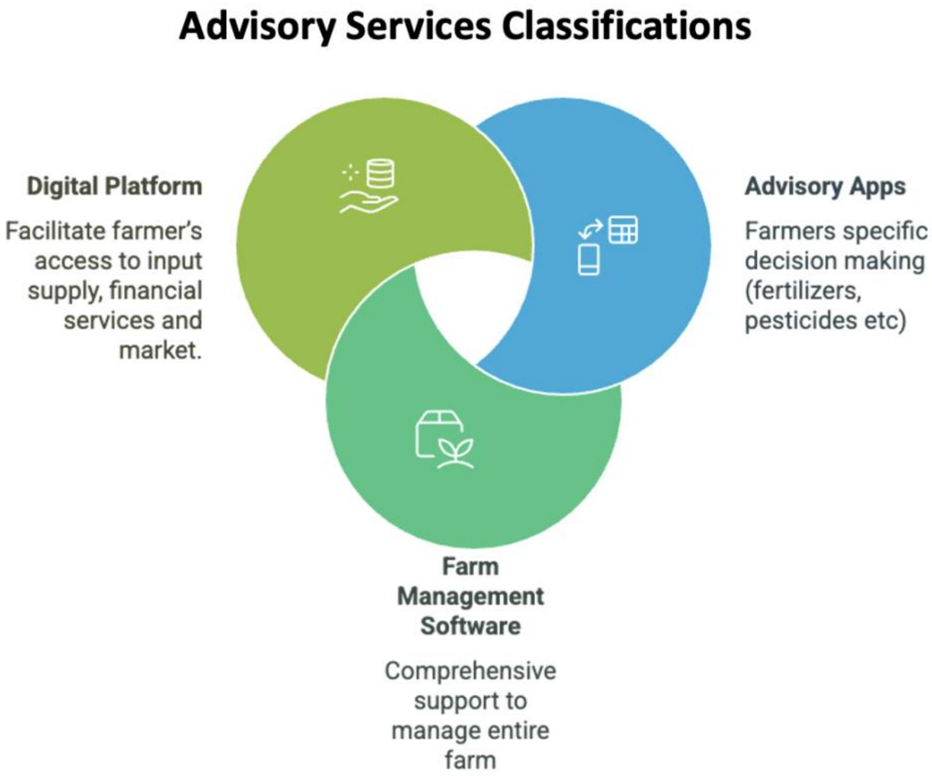


Figure 16: Classification of Advisory services
Source: adapted from (Birner et al ., 2021)

Characteristics of advisory:

It is mostly relevant that the provision of advisory services are owned by the government providers given the nature of advisory which are public and merit goods. The definition of different type of goods such as public, and merit, are provided below:

Public and Club Goods: Software solutions protected by intellectual property rights are referred to as club goods. Users typically pay a license fee, which grants the provider permission to use the farm data collected via the software. In contrast, advisory applications offer services that can be considered public goods when the advice is not tailored to specific farms. The public good characteristic of generalized agricultural advice extends beyond digital tools and is widely acknowledged as a form of market failure, thereby justifying public investment in agricultural extension services (Anderson & Feder, 2004).

Merit Goods: In the context of smallholder farmers and developing countries, agricultural advice is viewed as a merit good, one that farmers may not be willing or able to pay for. This reluctance is either due to a lack of perceived value beforehand or financial constraints rooted in poverty. The same applies to digital platforms and farm management software. As a result, public or donor funding, or alternative business models, may be necessary to stimulate the development and adoption of such digital agricultural technologies in developing countries.

3.4 Agricultural information and its pivotal role in the context of Tamil Nadu

3.4.1 Importance of agricultural information:

The critical factors in easing out the undertaking of agricultural activities are precise, accurate, trustworthy, and timely information. The agrarian information required by farmers is dynamic. Farmers need constant inputs at various stages. For example, they need weather forecast information, agricultural practices, pests, and disease management during crop production at the right time. Similarly, market intelligence is critical when the products are ready and require local market prices and information. The primary reason farmers face the brunt year after year is the need for timely and adequate information on soil, weather, and other influencing factors. Recently, it has been proved that mobility has influenced the easy transfer of technology, thereby addressing sustainable rural poverty reduction. (Kumar & Karthikeyan, 2019) And this has necessitated the increasing use of mobile-based services for agricultural information. (Arunachalam, 2020)

A World Bank study notes the four areas where the utilization of mobile applications promotes rural development: disease and climate information; improvement in access to extension services; easing accessibility of finance including credit, insurance, and payment methods; better access to market linkages. (Qiang et al., 2012)

3.4.2 Agricultural information for Extension and Advisory Services:

A research study conducted in Erode with farmers who use Reuters Market Light(RML) Service for agricultural information proved positive and satisfactory level high. The study was intended to comprehend the information utilization pattern of farmers using RML. Thomson Reuters' RML is a unique "bottom of the pyramid" mobile-based information service. RML service provides farmers with customized, localized, dynamic information sent as SMS to their mobile phones in the local language on weather forecasts, crop advisories, local crop prices, and agricultural news. The study highlights the effectiveness of agrarian information disseminated through mobile phones. (Palanisamy & Bharadwaj, 2018)

Even with agro advisory services provided to the farmers, they suffer from complex information flow and provide only generic advisories and are yet to meet the needs of the farmers. Better agro-information dissemination systems that provide need-based advisories are the need of the hour for the farmers. A recent study recommends the application and effectiveness of IoT technologies for Extension Advisory Services (EAS), facilitating error-free data collection and processing activities. (Jarial, 2022)

Agricultural Extension and Advisory services in Tamil Nadu, which encompasses different techniques such as ICT-based advisory interventions, participatory farm extension, and agribusiness mode of reinventing farm enterprises, have resulted in less success ratio than what was expected. (Abraham, 2020) highlights current challenges in EAS and recommendations for effective implementation of Extension Advisory services in Tamil Nadu.

3.4.3 Agricultural information in weather-based Information Dissemination Systems:

Amongst the myriad technological options available for addressing agricultural problems, the recurrence of failure in achieving desired crop production and crop losses are due to inconsideration of existing weather at the regional or local level while adopting a particular technology. Climate-smart agriculture is the answer to the challenges posed by emerging climate changes. Weather-smart agriculture is a significant component of climate-smart agricultural technologies. The local weather information provided as advisories by technocrats is called response farming. Response farming dependent on location and time-specific technologies have been tested as an effective strategy by TNAU in the context of climate change adaptation strategies. If weather-based information is disseminated to the farmer at the right time, he can produce enough for himself and the country. But because of capacity challenges in the extension system, technology transfer from the lab to land has been hindered. (Dheebakaran et al., 2019)

An agrometeorological study observed that district-level weather forecasts must be revised to address farmers' crop-level demands. In the iterative improvements of Agromet Advisory services, the next would be to provide weather information at the village level from the current weather information provided at the block level. (Prathap et al., 2017)

3.4.4 Agricultural information for Agri-Marketing Services:

The significant distress faced by the farmers is due to the instability in receiving marketing information because of the fluctuating price and volatile market demand for the produce. Though direct marketing of farm produce has reaped some benefits for the farmers, on the other hand, it is a complex challenge since farmers are left to compete with strong traders who are very well established in the market. The primary challenge concerning disseminating agricultural marketing information to the farmers is the limited knowledge of extension functionaries in agri-preneurship and agribusiness, market performance of new technology, technologies for value addition, and marketing. (Abraham, 2020)

The data and information are the cruces of agri-food systems. With the involvement of many stakeholders through the stages of agri-food systems, it becomes inevitable for data manipulation and evolving security issues with implementing Information and Communication technologies. The traditional way of centralized data management has raised risk factors paving the way to blockchain technology, where data and information are managed in a decentralized manner. This new technology helps address security issues and increases transparency across stakeholders creating trust and reducing transaction costs in the agri-food market. (Xiong et al., 2020)

3.5 Review of institutional framework for agricultural information dissemination

3.5.1 Extension and Advisory Services

The Agricultural Extension System of Tamil Nadu had undergone some major transformation since the early 1950s when community-based development was emphasized. With the beginning of the green revolution in the 1960s, the Intensive agricultural area program, 1980s Integrated crop management, and Training and Visit system were introduced. The start of the 21st century was a game changer in extension systems with the beginnings of ICT-based interventions such as the Agricultural Information Services Network (AGRISNET) and Farm Crop Management System (FCMS). The Central and State government has been significant players in providing ICT offerings for the agricultural sector. But that does not undermine the role of private players. In recent times valuable and customized agro advisory services are being provided by private players such as TCS with mKRISHI, Ekgaon Technologies with Onefarm, EID Parry with indiagrilline, SAAL with Farm Field, and Thomson Reuters with Reuters Market Light.

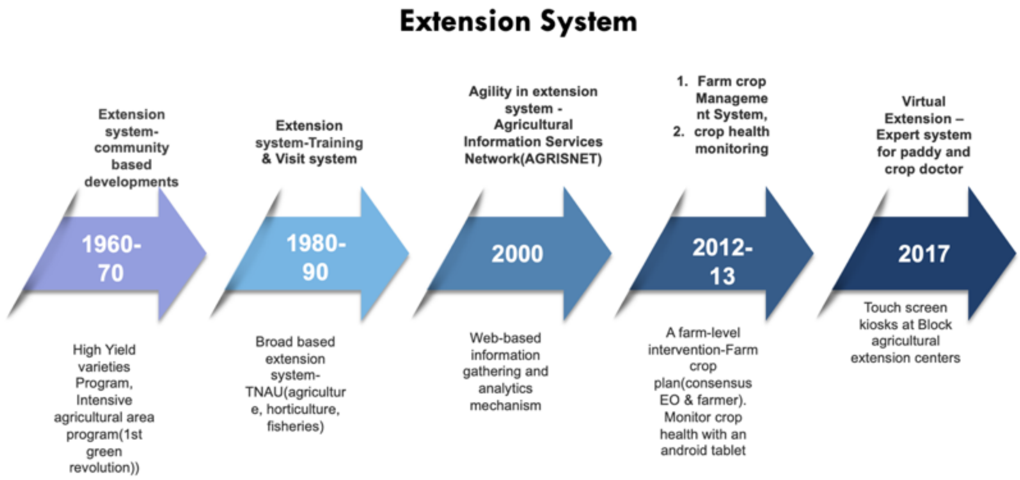


Figure 17: Evolution of Extension System
Source: Department of Agriculture, Tamil Nadu

Agricultural Information Services Network (AGRISNET):

Agricultural Information Services Network (AGRISNET) project was initially conceptualized and implemented by the Tamil Nadu government. It is a web-based information gathering, analytics mechanism, and decision support tool for agricultural extension workers and farmers. It is also now a central government project emulated in many other states. The vision of AGRISNET is to provide a G2C service and improved planning and monitoring at the state level. The repository of AGRISNET is not limited to disseminating information on weather, soil, welfare schemes, market trends, and new farm technologies, but also caters based on the specific needs of farmers. The Tamil Nadu AGRISNET portal is distinct in the following ways:

- G2G services incorporated in the backend network
- Government generates a customizable report based on which services to farmers are improved.

(Foundation India & Knowledge Centre, 2011)

Tamil Nadu Agricultural University initiative -TNAUAGRITECH:

TNAU (Tamil Nadu Agriculture University) Agritech Portal, with its 11 lakh pages, educates on Agri & allied sectors and is the first product of the e-extension center of TNAU. The portal facilitates agro-advisory services and agricultural-related information to farmers and all stakeholders of the agricultural supply chain. The other attributes of the portal are:

I. Transfer of technology to the last milestone of the farming
II. ICT-based demand driven farm advisory services
III. Problem diagnosis through video conferencing
IV. Information provider of schemes, programs, government policies

Amongst the public and private agencies providing mobile-based agro advisories, the state Department of Agriculture and Tamil Nadu Agricultural University are the two giants catering to the agricultural information needs of the farmers and extension workers in Tamil Nadu.

e-Velanmai (TNAU):

e-Velanmai, an initiative of TNAU, is an ICT-based, demand-driven extension model for disseminating technologies to farmers. The field coordinator supports a multi-disciplinary team of agricultural scientists on a need basis to provide agro-advisory services to the farmers using ICT tools. The experts refer to the TNAU Agri portal to answer problem-based (ex: pest-damaged symptoms) and decision-based (ex: marketing decision) inquiries to the farmers. However, the reach of e-Velanmai is limited as the registered farmer count only turns out to be 10 507. (Karthikeyan, 2017)

On the other hand, Uzhavar Aluvalar Thodarbu Thittam(UATT) application enables higher officials to monitor the field visits made by extension officers to village panchayats.

Uzhavan App:

With a single click, the Tamil Nadu government's Uzhavan app is a one stop solution that provides information on market prices, subsidy schemes, weather forecasts, etc. It has lowered the information searching time, availing of subsidies made faster, contacting the agricultural offices made more accessible and created more awareness about government schemes. It has also increased the bonding between the extension officers and farmers, thus reducing the time for disseminating agro strategies. (Kumar & Karthikeyan, 2020) Additionally, the algorithm-led Artificial Intelligence provides vital information to farmers on the premium of crop insurance, pest/ disease identification, and remedial measures.

The Uzhavan app needs to be further publicized extensively to attract more non-users as users. A significant constraint reported is that the app needs to provide timely updated information. Extension officers should be adequately trained regarding the usage of the Uzhavan application. (Chandrasekaran, 2020) It does not have an offline mode demanding internet usage at all times. Advisories should also be provided via voice and text messages considering farmers who might not have used an android phone. (Mathuabirami et al., 2019)

ATMA

Agricultural Technology Management Agency (ATMA) is India's nodal agency for extension reforms. In Tamil Nadu, the Department of Agriculture carries out extension-based agro-advisory services through ATMA. It has been reported that more than 75 lakh farmers have benefited through ATMA in Tamil Nadu.

Research studies have mentioned that the same farmers are chosen as beneficiaries for various demonstration projects and training, with no significant impact on adoption rate, farm productivity, and farm income. Importantly there is no feedback mechanism through which inputs can be collected from farmers of what worked well and what did not work. (Abraham, 2022)

Tamil man Valam Portal:

'Tamil Man Valam' portal will be launched soon by the state government in coordination with TNAU, facilitating the provision of soil fertility status, survey number-wise, and farmers' printing of soil health cards. Additionally, schemes related to paddy, pulses, oilseeds, and millets will be implemented to increase food production. (*Tamil Nadu to Launch Portal to Check Soil Fertility, Launch Farm Schemes - The Hindu BusinessLine*, n.d.)

Figure 18: Screen shots of ICT enabled extension and advisory services in Tamil Nadu

Table 8: Summary of ICT enabled extension and advisory services in Tamil Nadu

SL. NO.	ICT INTERVENTION	INITIATING AUTHORITY	FEATURES/ASSOCIATED SERVICES	HIGHLIGHTS IF ANY	FURTHER ACTION NEEDED
1.	AGRISNET	Central Government	Web based information gathering and analytics mechanism Decision support tool for extension workers	Incorporation of 2G services Generation of customizable report	—
2.	TNAUAGRITECH	TN Government	ICT based demand driven farm advisory services Transfer of technology to the last milestone of farming Information provider of schemes, programs, and government policies	Problem diagnosis through video conferencing	—--
3.	e-Velanmai	TN Government	Disseminating technologies to farmers	Clarifies problem based and decision-based inquiries of the farmers	Limited reach to be overcome by increasing the registration of farmers
4.	Uzhavan App	TN Government	One stop solution providing information on market prices, subsidy schemes, weather forecasts etc.	Algorithm led AI has reduced information searching time, increased the accessibility to agricultural offices and awareness about government schemes	Increase publicity to attract non-users Provision of timely updated information Adequate training of extension officers
5.	ATMA	Central Government's nodal agency	Extension reforms	75 lakh beneficiaries in TN	Feedback mechanism to be created Avoid repetition in choosing the beneficiaries
6.	Tamil man valam Portal	To be launched by TN Government	Provision of soil fertility statusand printing of soil health cards	Implementation of additional schemes to increase food production	—-

3.5.2 Weather-based agro advisories

The impact of climate change is inevitable in the agricultural sector, which is also, in one way, causing climate change. The climate trend in the Indian scenario is expected to rise by 2-4 degree Celsius by 2050, with slight differences in rainfall patterns during monsoon and significant changes in rainfall patterns during non-monsoon months. Looking at the Tamil Nadu scenario, observing rainfall trends from 1950 to 2010, poor rainfall distribution is consistent in all seven agro-climatic zones. The drastic change in quantity and distribution of rainfall has significantly impacted crop production over the years. These necessitate a growing need for efficient and effective climate-smart agricultural practices, employing cultivars tolerant to extreme climate conditions, enhanced water crop management practices, better weather forecasts, and crop insurance, which will help reduce the impact of climate change. (FAI ANNUAL SEMINAR 2021 Challenges in Fertilizer and Agriculture THE FERTILISER ASSOCIATION OF INDIA PREPRINTS OF SEMINAR PAPERS, n.d.) In the climate-smart agricultural ecosystem context, the weather-smart agricultural ecosystem is highly significant. Therefore, the critical information dissemination systems related to weather-based agro advisories are discussed in the below sections.

The Agro Climate Research Centre under Tamil Nadu Agricultural University is the focal point for weather forecasts and advanced climate and climate change research. The Agro Climate Research Centre predicts district-wise Southwest Monsoon and North East Monsoon rainfall.
The evolution of weather forecasting is depicted in the following figure:

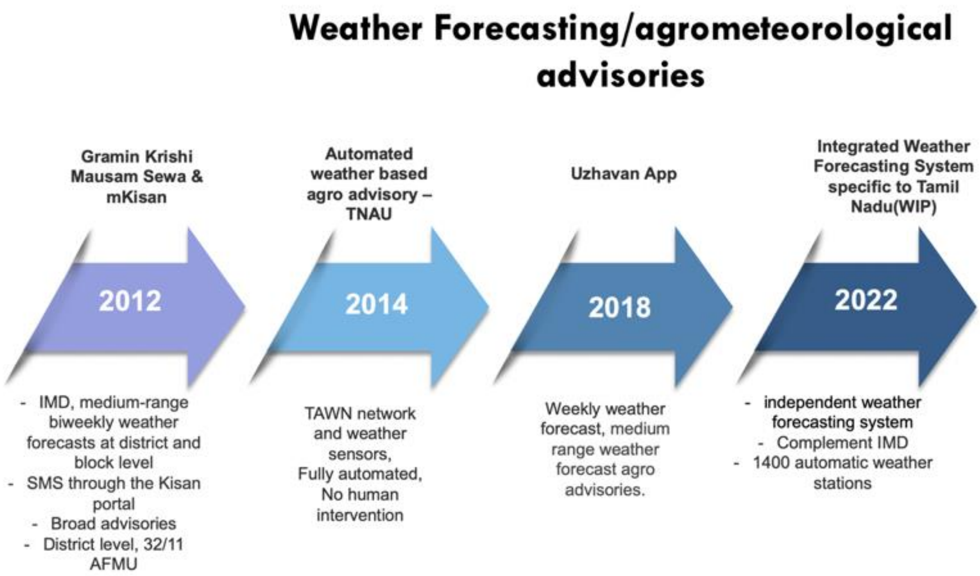


Figure 19: Evolution of Agrometeorological advisory system
source: Tamil Nadu Agriculture university

Gramin Krishi Mausam Sewa and mKisan:

The Agro Climate Research Centre, under the India Meteorological Department (IMD), Ministry of Earth Sciences, Government of India, has been implementing a scheme called "Gramin Krishi Mausam Sewa" (GKMS) in Tamil Nadu. The project facilitates the provision of weather-based agro advisories to the farmers at the block level. The IMD issues biweekly weather forecasts for the past week and the next five days. Based on the weather forecast data, the technical officer prepares an advisory bulletin and disseminates it through Krishi Vigyan Kendra, IMD web portals, and the State Department of Agriculture and Research Stations. In addition, a brief of the advisory publication is sent as an SMS to the farmers through the mKisan Portal.

The SMS shared via Gramin Krishi Mausam Sewa and mKisan is short and general advisories. They are not specific and are at the district level. Therefore, they do not cater to the particular crop needs of the farmer. Also, if the weather-based agro advisory services are not automated, there may be a high impact, as mentioned below:

I. Continuous observation of weather forecasts and bulletin advisories will be required.
II. A team of well-trained multi disciplined technical experts will be required at all stages.
III. Advisory will be missed during holidays because of the requirement for human intervention.

TNSMART:

The Tamil Nadu government has initiated a web-based GIS decision support system and a mobile application named TNSMART. It is built with an alarm system, rainfall monitoring mechanism, and daily weather forecast at the state-district-taluk level. It also involves a feedback mechanism for sending distress messages and meets emergency needs by providing users with dos and don'ts. Users can also upload pictures with location details. TNSMART helps the farmers to make climate-smart decisions and has played a significant role during the 2015 floods in Tamil Nadu. It has proved to be an effective disaster management tool that operates through communication & sourcing data. (*Tnsmart-Weatherinfo-Web GIS*, 2015)

TNAU– AAS App:

Tamil Nadu Agricultural University has pioneered the development of an automated agro-advisory service. TNAU-AAS is a web portal and android based application. Weather forecast results are calibrated to be 80% accurate, based on past data and five days in the future. With the help of sensors, the automatic weather stations give information on ten important weather parameters such as Tmin., Tmax., humidity, etc. So far, 54 weather scenarios have been devised, deploying high-performance computing tools. Every stage of farming, from land preparation to seedling, vegetation, reproduction, grain development, harvesting, and post-harvesting, is covered under this weather-based automatic agro advisory service. In addition, location and time-specific advice on the postponement of irrigation, fertilizer application, and plant protection measures against pests and diseases are given. (Dheebakaran et al., 2019)

TNAU-AAS is limited to 108 crops, six stages, and 54 weather scenarios. More crops need to be added. Also, the number of beneficiaries remains less in number. To reap maximum benefits, the app must be promoted well. Farmers already using this service must provide the right crop-specific and location-specific information. They should also provide feedback regarding the correctness of the advisory, which the technical officer and admin should address. Dynamic weather calendar, including the soil moisture and length of the growing period is to be implemented.

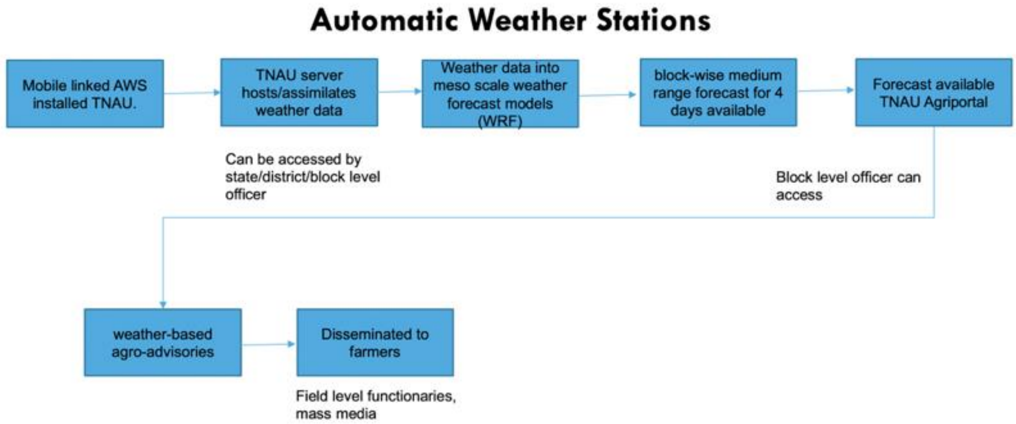


Figure 20: Functioning of Automated agro-advisory services
source: (Dheebakaran et al., 2019)

Figure 21: Screen shots of ICT-enabled weather-based agro advisory services in Tamil Nadu

Table 9: Summary of ICT-enabled weather-based agro advisory services in Tamil Nadu

SL. NO.	ICT INTERVENTION	INITIATING AUTHORITY	FEATURES/ ASSOCIATED SERVICES	HIGHLIGHTS IF ANY	FURTHER ACTION NEEDED
1.	Gramin Krishi Mausam Sewa and mKisan	IMD, GOI	Provision of weather based agro advisories at block level	Brief of advisory publication sent as SMS	Provision of specific advisories catering to particular crop needs of farmers To be automated
2.	TNSMART	TN Government	Web-based GIS decision support system Involves a feedback mechanism for sending distress messages and meets emergency needs	Effective disaster management tool that operates through communication and sourcing data	—--
3.	TNAU-AAS App	TN Government	Provision of information on ten important weather parameters Coverage of every stage of farming	Provision of location and time specific advice	More number of crops to be added Better promotion of app to reap maximum benefits Increase the number of beneficiaries

3.5.3 Agri Marketing and Agri-Business services

The Agricultural Marketing and Agri Business Department under the Ministry of Food Processing Industries, Government of India, serves as the focal point which translates marketing impulses into marketing interventions. The department's interventions are focused on protecting the interests of both farmers and consumers.

Broadly, agriculture marketing focuses on assessing the demand and supply of farm inputs, post-harvest management of food products from farms to consumers, enabling policies orientated towards pricing, purchase, and sale of agricultural produce, and digitalization of agricultural marketing department services.

A few key responsibilities of the Department of Agriculture Marketing and Agribusiness are the formation and promotion of Farmer Producer Organizations to support farmers' well-being, the creation of market linkages, and the creation of infrastructure facilities for post-harvest management, reducing post-harvest losses and increasing shelf life through cold storages, drying yards, godowns, dissemination of market information, ensuring unadulterated food through Agmark laboratories. (Abraham, 2020)

A significant point in the evolution of the Agricultural marketing department is the establishment of the Domestic and Export Market Intelligence Cell (DEMIC) in TNAU in 2004. The objective of DEMIC was to disseminate timely information on the price of agricultural commodities that will support the decision-making of various stakeholders such as farmers, traders, researchers, policymakers, and firms. The different medium via which information is disseminated is radio, TV, newspapers, and the tnagmark website.

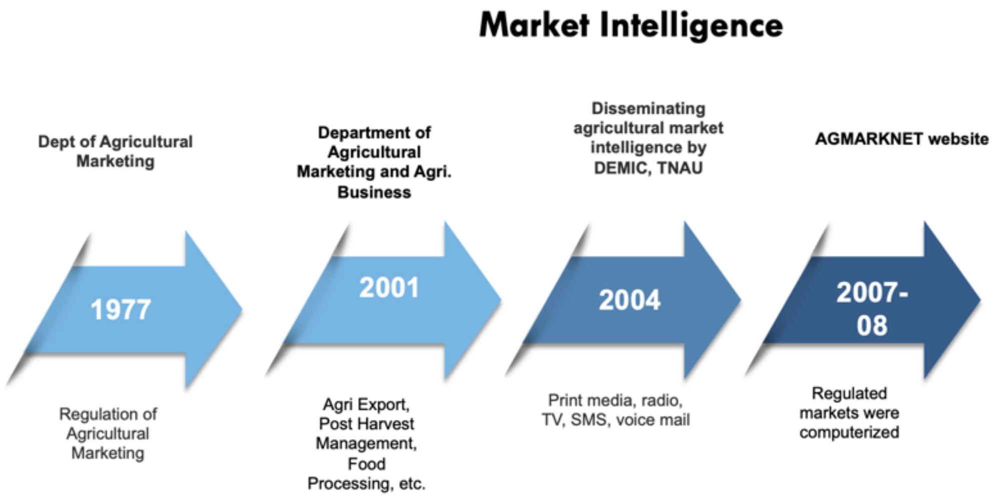


Figure 22: Evolution of Agri-marketing
By authors, from source: (*Department of Agricultural Marketing & Agri Business*, 2024)

The market-led extension (e-NAM):

e-NAM is an e-trading platform to facilitate farmers, traders, buyers, exporters, and processors to trade commodities at the national level. The electronic trading portal connects existing APMC markets to create a unified agricultural commodity market. A good feature of the platform is that the sale amount of the produce goes directly to the farmers. Another prominent feature is that it enables agricultural produce to be transported from one market to another smoothly.

A study has reported that the significant constraints faced by farmers in participation in eNAM in Tamil Nadu are: a lack of awareness about eNAM itself, computer skills, and delayed payment. (Rani et al., 2022)

Agmarknet:

The Agmarknet is a national agricultural marketing information portal that disseminates market
related information on agricultural produce. The regional portal in Tamil publishes knowledge in the local language, enabling and easing farmers' decision-making by providing daily market information.

A recent study examining the utilization of DEMIC and Agmarknet amongst sorghum farmers in Tamil Nadu revealed that less than 5% use these marketing services available from the government. Instead, many of them rely on local market intermediaries. The study recommends steps to increase awareness of online market services and impart farmers with training and knowledge on the latest agricultural technologies.

e-NAM

AgMARKNET

Figure 23: Screenshot of ICT-enabled market-based agro advisory services in Tamil Nadu

Table 10: Summary of ICT-enabled market-based agro advisory services in Tamil Nadu

SL. NO.	ICT INTERVENTION	INITIATING AUTHORITY	FEATURES/ASSOCIATED SERVICES	HIGHLIGHTS IF ANY	FURTHER ACTION NEEDED
1.	Market led extension (e-NAM)	GOI	Facilitates commodity trading at national level Creates unified agricultural commodity market	Sale amount received directly by the farmers Smooth transportation of agricultural produce from one market to another	To increase awareness level, farmers' computer skills To overcome delayed payment
2.	Agmarknet	GOI	Provision of daily market information through regional portal in Tamil	----	To increase the number of users To increase awareness about online market services To impart farmers with training and knowledge on the latest agricultural technologies

Figure 24 below is a digital agricultural service matrix map depicting the range of digital agricultural platforms available to farmers in Tamil Nadu. It categorizes the services under advisory, extension, weather, seed, soil, insecticide/pesticide, machinery, marketing, credit, etc. The platforms listed in blue are offered by the central government. Examples of the same are GKMS, KVK(ICAR), while the platforms mentioned in red are offered by the Tamil Nadu state government. It can be inferred from the picture that the key platform offered by the state government, which is the Uzhavan app, provides comprehensive support across multiple service categories such as advisory, weather updates, extension, information on insecticides or pesticide availability, etc.

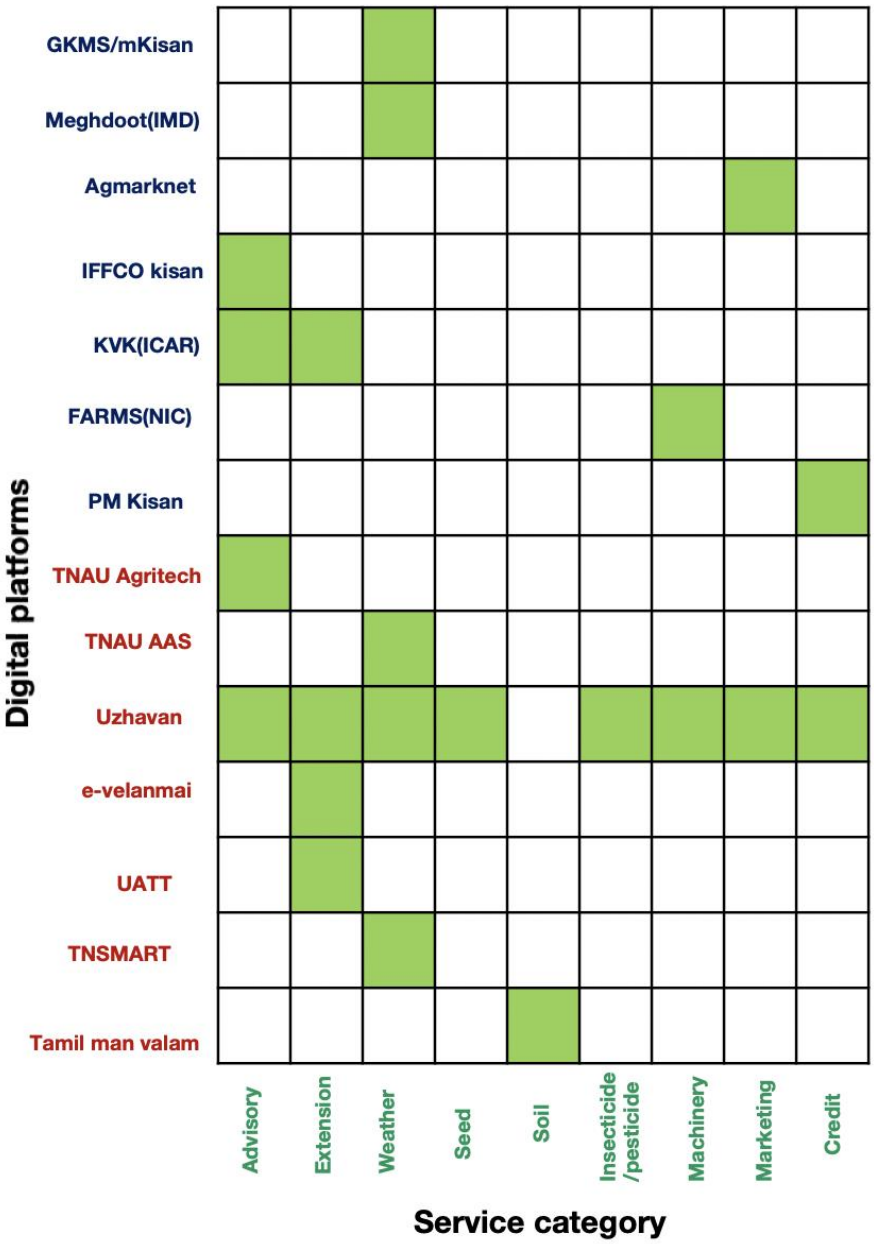


Figure 24: Digital Agricultural Services Matrix

Many advisories are issued by the central and state governments to Tamil Nadu farmers. The information and services often overlap. For this study, we focused on the Uzhavan app, as government representatives see it as a key advisory tool that offers comprehensive support throughout the agricultural value chain.

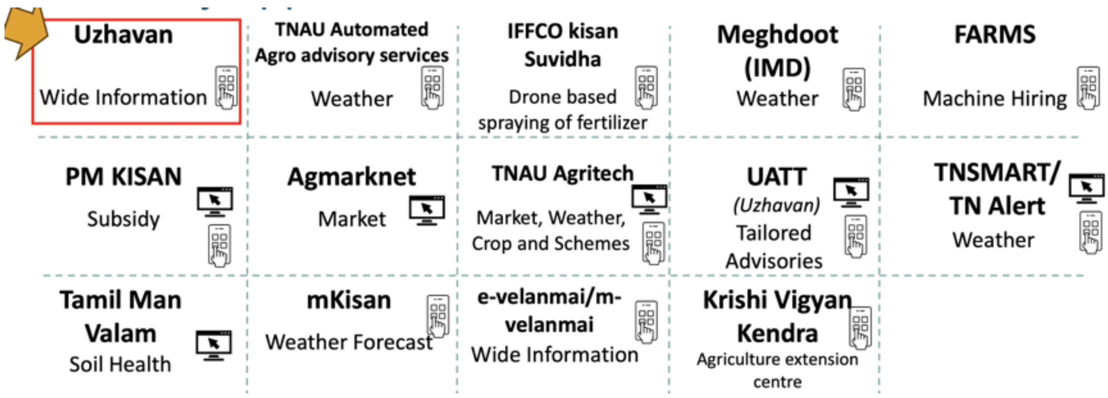


Figure 25: Advisory applications

The rate of adoption of the Uzhavan application remains low. Majority of the farmers 82% have not registered to this service.

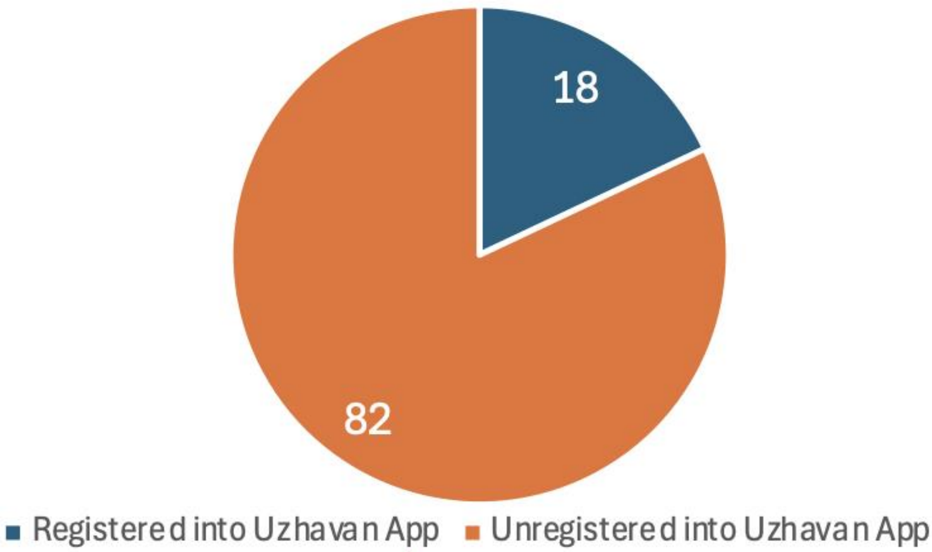


Figure 26: Adoption (%) of Uzhavan Application
Source: TN Agrisnet, 2024

The below table summarizes some of the key challenges mentioned in the literature review regarding the accessibility of the advisory applications to farmers.

Table 11: Challenges related to advisory applications

Saravanan, 2012 Abraham, 2022	Generic information, one-way flow of information
Fatima et al, 2017	Farm women are responsible for 80-90 % of the food production, in the state. But access to agricultural information is less.
Kumar & Karthikeyan, 2020	Progressive farmers, had frequent contact with extension agents, and had ample exposure to these services. Services are familiar to few farmers.
Mathuabirami et al., 2019	An Android phone is a must. Internet connectivity is a must. Information was not updated properly.
Nandhini A & Rohini, 2022	Does not cover all crops. Not dynamic information.
Rani et al., 2022	Lack of infrastructure and digital illiteracy issues have not been considered.

The specific barriers related to the accessibility of the Uzhavan application have been enumerated as below:
The ratio of extension agent staff to total farmers remains at the ratio of 1:1834, showing a high gap in bridging agricultural research with farmers.

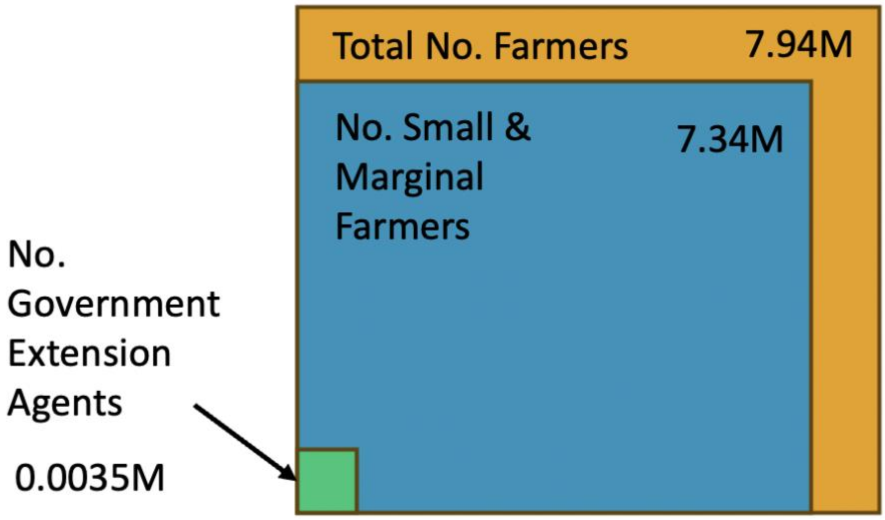


Figure 27: Extension Agent shortage

While on the supply side, it has been mentioned that digital illiteracy as the predominant reason for farmers low uptake or adoption of the advisory services.

Another gap in infrastructure is highlighted by NSSO (2021) data, which shows only 14.9% of rural households have a computer with internet, compared to 42% of urban households, revealing a significant divide. The NSO survey also shows a stark gender gap in mobile ownership, with 51.6% of rural women aged 15+ lacking personal mobile phones despite near-universal youth usage. Older feature (basic) mobile phones remain widely used, especially in the Southern Zone, where over 67% of farmers rely on feature phones for SMS, calls, and audio/video chat. Feature phones continue to be common among rural farmers in Tamil Nadu, particularly in less irrigated or rainfed areas like Madurai, where up to 80% depend on basic phones.

3.6 Implications for Organising Agricultural Extension in Tamil Nadu

1. Reclaiming Fallow Lands and Strengthening Agroforestry Initiatives

Strategic interventions aimed at land restoration are necessitated by the increasing prevalence of fallow and degraded lands in Tamil Nadu . While contributing to climate resilience and sustainable livelihoods, afforestation and agroforestry emerge as viable strategies to revitalize such lands . Institutional credit and capacity development must be used to incentivize initiatives such as community-managed nurseries for tree species including Casuarina, Teak, Eucalyptus, and Pongamia . Integration of educational institutions, grassroots organisations, and voluntary agencies can additionally catalyse community-driven agroforestry efforts. Contract farming on marginal lands can be facilitated through Public-private partnerships (PPPs), particularly with paper mills. For this, Panchayat-level institutions require both technical and financial empowerment to implement and oversee agroforestry initiatives effectively.

2. Technological Integration and Smart Farming for Resource Optimization

The overuse of inputs such as fertilizers and pesticides has led to declining soil health and increased production costs, as farming systems are becoming increasingly vulnerable to climatic uncertainties . It is imperative to shift towards data-driven, low-cost automation. Decision-support tools such as DSSIFER (2010) and the NUTMON Toolbox offer opportunities for real-time nutrient management and site-specific input recommendations. Significant improvement in fertilizer use efficiency and enhanced productivity can be obtained by integrating these tools into extension services. However, substantial investment in digital infrastructure and human resource development is necessary for this transition . Long-term sustainability can be ensured by reorienting agricultural policies that reduce dependence on subsidies, while promoting adaptive technologies which is crucial for the same.

3. Farmer Capacity Building and Customised Advisory Services

Continuous capacity building of farmers is essential to meet the evolving demands of modern agriculture. Organised cluster-level training on emerging technologies, crop management practices, and climate-resilient strategies is vital, especially for small and marginal farmers. Digital tools such as TN-AGRISNET, e-Velanmai, and the Farm Crop Management System must be made more accessible and user-friendly. To address the information needs of digitally illiterate farmers, the state should consider expanding the cadre of extension volunteers (e.g., ATMA’s Farmer Friends). Furthermore, yield gap analyses and awareness programs can be conducted at the grassroots level. This can help farmers achieve optimal crop productivity by aligning their practices with scientific benchmarks.

4. Digital Infrastructure and e-Village Portals for Information Access

Robust infrastructure at the village level is necessary for digital transformation in agriculture. The development of crop-specific portals and e-village platforms can revolutionize the dissemination of information related to seed availability, input demand, cropping patterns, and market access. Better policy targeting and scheme implementation can be enabled by regularly updating these portals before each cropping season . Each e-village must be supported by trained curators or ICT technicians to ensure real-time solutions are available to farmers. This will enhance transparency and efficiency in input distribution and agricultural planning.

5. Enhancing Mechanisation, Post-Harvest Management, and Value Addition

A pivotal role is played by mechanisation to improve farm efficiency, particularly for pre- and post-harvest operations. Access to modern machinery, especially for smallholders and women farmers can be facilitated through Custom Hiring Centres (CHCs), established under PPP models . Post-harvest technologies (PHTs) such as banana fibre extractors, groundnut decorticators, and maize shellers should be additionally promoted to minimise losses and enhance the value of produce. Rural youth and women can be trained in food processing, packaging, and value addition through collaborations between the state and institutions such as the Indian Institute of Food Processing Technology (IIFPT) . Branding and social marketing of produce should also be emphasised to help farmers access premium markets. Funding for village-level PHT units can be mobilised by facilitating linkages with corporate social responsibility (CSR) initiatives. This will reduce the dependence on intermediaries and increase farmers' incomes.

6. Inclusive Extension and Institutional Reform

The majority of Tamil Nadu's farming population which comprises over 90% small and marginal farmers can be served better by restructuring the current extension infrastructure . A dedicated extension mechanism can provide targeted support for this group, based on their unique constraints. Timely interventions are essential to ensure improvement in the extension worker-to-farmer ratio. Similarly, schemes should include landless cultivators and tenant farmers, who are often excluded due to absentee landlordism. Participatory Rural Appraisal (PRA) methods can be used to verify land records, which enables equitable access to government programs. Furthermore, through skill development, entrepreneurship should be promoted in fisheries and livestock. Private sector participation can provide livelihood alternatives for unemployed rural youth and women.

7. Sustainable Resource Management, Market-Driven Diversification, and Policy Realignment

Erratic monsoons and the over-cultivation of high water-demand crops like paddy and sugarcane exacerbate Tamil Nadu's agriculture which already faces pressing water constraints. Water stress can be addressed through community-based watershed development programs, following models such as IAMWARM. Ecological sustainability can be fostered by encouraging policy incentivized cultivation of less water-intensive crops (e.g., pulses, millets, vegetables). Alongside this, as a long-term solution to regional water imbalances, the concept of virtual water trading and water markets should be explored.

Agricultural diversification must also be aligned with market demand. Integrated Farming Systems (IFS) and cost-effective technologies to generate year-round income, should be promoted through Extension strategies. Innovations such as Farmers' Field Schools (FFS) can provide participatory platforms for knowledge exchange and skill development. The impact of technologies, training, and input usage should be assessed with monitoring and evaluation mechanisms, so as to inform policy adjustments.

Finally, agricultural policies should support market-led development, agro-tourism, and rural entrepreneurship instead of subsidy-driven approaches. Enhanced role of ICTs, formal documentation of farmer-led innovations, and integration of extension services with consumer trends will be key in revitalizing Tamil Nadu's extension framework.

3.7 State Agricultural Extension Policy and Capacity (Abraham, 2020)

A comprehensive and multi-tiered approach to agricultural extension, involving public institutions, private entities, farmer groups, and the integration of information and communication technologies (ICTs) has been developed by Tamil Nadu. Efforts to strengthen the capacity of extension personnel and enhance knowledge dissemination to farmers are at the core of this approach, which is primarily achieved through structured training programs, participatory initiatives, and institutional collaboration.

Key institutions such as the State Agricultural Extension Management Institute (STAMIN), Farmers Facilitation Centres (FFCs), and the Water Management Training Centre (WMTC) lead the public agricultural extension services. They collectively conduct regular training and skill development programs for both farmers and extension staff. Approximately 0.29 lakh farmers were trained by STAMIN and FFCs in the 2016–17 period alone. WMTC equipped over 1,100 field-level extension personnel with essential skills in emerging agricultural technologies and practices.

Simultaneously, collective farming practices has been fostered by the state, by supporting around 2,000 Farmers Producer Groups (FPGs), positively impacting over 2 lakh farmers. These groups not only promote collective marketing but also serve as platforms for capacity-building and knowledge exchange.

The Krishi Vigyan Kendras (KVKs) under the Tamil Nadu Agricultural University (TNAU) have also played an instrumental role in delivering on- and off-campus training, field demonstrations, and seasonal campaigns, with their focus spanning over a range of topics including Integrated Crop and Pest Management (ICM & IPM), precision agriculture, organic farming, mechanization, nutrition gardening, and ICT-based farming tools. KVK activities reached around 0.32 lakh beneficiaries, including youth and women during 2016–17.

Another major contributor to Tamil Nadu's extension landscape is the The Agricultural Technology Management Agency (ATMA) . A variety of educational and extension initiatives like farmer field schools, district-level training, exposure visits, and cultural campaigns such as *Kala Jatha* have been implemented by ATMA. In each district, over 250 extension activities are carried out annually, thereby reaching more than 75 lakh farmers across the state. ATMA also promotes renewable energy use in agriculture, low-cost animal husbandry practices, and post-harvest technologies, besides its emphasis on production technologies. It effectively disseminates technical content by leveraging tools like Pico Projectors .

However, several challenges are faced by ATMA. Its insights into real-world impact is limited due to the inconsistent evaluation of its programs, especially third-party assessments. The Farmer Friend (FF) initiative that aims to support grassroots information delivery, suffers due to inconsistent quality of personnel and occasional political interference in recruitment. The much noted disconnect between training content and farmers' current needs suggest more demand-driven, locally tailored extension strategies.

A supportive role is played by NABARD (National Bank for Agriculture and Rural Development) which finances capacity-building activities through partnerships with KVKs, NGOs, farmer producer organizations (FPOs), and academic institutions. Farmers are trained in areas such as livestock management, organic farming, and value chain development for milk and vegetable production through NABARD's Capacity Building for Adoption of Technologies (CAT) program . Furthermore, entrepreneurship among rural youth and women is also supported by NABARD, especially in small- and medium-scale agro-processing ventures.

Specialized training in modern and sustainable farming practices are offered through private extension services which have also become crucial. Organizations such as UPASI, Dhan Foundation, and Hatsun Agro provide support in areas like organic farming, water conservation, ICM, and value chain enhancement. These efforts are complemented by non-governmental organizations (NGOs) like CREATE and VK-NARDEP, through awareness campaigns and training in nutrition gardening, traditional farming systems, and community-based initiatives.

Manpower limitations remain a pressing concern despite these advancements. Tamil Nadu employs approximately 2006 technical officers, including Agricultural Officers (AOs), Assistant Agricultural Officers (AAOs), and Seed Officers. However, effective coverage is challenging with an estimated 83 lakh farm families. Each extension officer would need to support over 3,200 farmers annually. The presence of just six AAOs per block at the block level is inadequate, particularly when each block contains multiple revenue villages. The responsiveness and personalization of extension services could be improved by restructuring the manpower allocation, based on village-level requirements, .

Staffing shortages have also affected the horticulture and fisheries sectors. Horticulture employs over 2,600 technical officers, the majority being lower-level assistants, with fewer senior officers available for strategic planning and field support. In fisheries, the key area of field-level support is weak, as a notable percentage of posts remain vacant.

The state has turned to digital platforms and ICT tools to bridge the information gap. The Agriculture Management and Information System (AGRI-MIS) maintains a database of 68 lakh farmers.This helps in targeted planning and delivery of extension services. Due to the urgency and volume of updates, WhatsApp reporting, although effective in enhancing real-time communication and transparency, occasionally burdens field staff. Farmers as well as extension agents widely access TNAU's e-extension services that include an agritech portal, video conferencing, and mobile apps. Still, there remains a gap in farmer awareness and technical capacity hindering the use of these platforms effectively.

The current extension model is criticized in terms of knowledge management, for being output-focused. It emphasizes the number of technologies disseminated rather than their actual impact on livelihoods. There is a need for robust monitoring systems as pointed out by the limited tracking of outcomes related to income, sustainability, or gender inclusion. Integration of crop pattern data and real-time analytics can enhance the existing ICT tools like TN-AGRISNET and FCMS. Village-level e-crop portals staffed with trained curators should be established to support more responsive, location-specific advisory services.

Opportunities for capacity development are further presented by Post-harvest management (PHM) and marketing. Many farmers lack the training to manage cold chains, packaging, and logistics. Despite strong potential in the food and textile industries, technologies for value addition in crops like banana and traditional rice varieties are underutilized. These gaps could be filled by promoting processing, branding, and direct marketing through state-supported initiatives, including cluster-based training programs, rural technology parks, and leveraging Corporate Social Responsibility (CSR) funds .

The extension framework should also emphasize agri-business and entrepreneurship, particularly among rural youth and women. Advisory services can be decentralized by encouraging the formation of Agri-Clinics and Agri-Business Centres, especially at the village level. Entrepreneurship should also be supported through training and policy backing in fisheries, seed production, and feed formulation. Sustainable and community-led development could be fostered by engaging local communities—including retired professionals and volunteers—in the management of shared resources like farm ponds.

3.8 Major Capacity Gaps and Extension Strategies in Tamil Nadu's Agricultural Extension System(Abraham, 2020)

1. Need for upgraded Technical Training despite the ongoing training programs, to keep pace with evolving cropping patterns and climate challenges, extension workers require updated knowledge on advanced crop varieties, fertilizers, plant protection, farm machinery, and post-harvest technologies. Farmers are increasingly relying on private dealers for up-to-date advisory services.
2. Limited Expertise in Agripreneurship Agripreneurship and agri-business models have grown. But still, many extension personnel lack sufficient knowledge to train rural youth in these areas, which could otherwise boost self-employment and rural economic opportunities.

3. Gaps in Market-Oriented Extension Extension workers often lack awareness of market preferences for new crop varieties. For instance, it is evident from the fact that the adoption of TKM 13 was hindered by continued consumer and trader preference for BPT 5201. This underscores the need for market intelligence in extension services.
4. Inadequate Exposure to Agro-Tourism Though agro-tourism is an emerging area, extension functionaries currently have minimal training or exposure. Focused efforts are essential to build capacity in this niche sector.
5. Limited Knowledge in Organic Input Production Many field-level workers have limited practical knowledge in producing bio-fertilizers and organic manures, due to workload and scheme-oriented tasks. This necessitates collaborative training with NGOs and farmer groups.
6. Neglect of Value Chain and Value Addition Training Extension services have so far focused traditionally on crop production, neglecting value chain management and value addition techniques. Hence, there is a critical need for training in these areas to boost farmer income and market readiness.
7. Inadequate Support for Horticulture and Cropping Pattern Shifts Extension workers require support in strategic planning and technology dissemination at the local level, as water scarcity and climate change drive a shift toward horticultural crops.
8. Fallow Land Utilization Challenges Extension workers should promote community-based strategies and awareness campaigns to revitalize fallow lands sustainably, because

the rise in fallow land requires targeted education on low-water crops, agroforestry, and plantation-based models.

A comprehensive rethinking of existing policies, institutional frameworks, and delivery mechanisms is necessary to organise agricultural extension in Tamil Nadu. The impact of extension services can significantly be strengthened by emphasizing digital transformation, capacity building, agroecological sustainability, inclusive support for marginalized groups, and market-oriented diversification. A resilient and inclusive agricultural development in the state could be achieved by a restructured extension system, grounded in participatory, community-based approaches and empowered by technology.

3.9 Conclusion

Tamil Nadu is one of the leading states in digital agricultural initiatives. The government has made significant strides to integrate Information and Communication Technology (ICT) into agriculture. The AGRISNET portal and Uzhavan app provide farmers with critical information on market trends, weather conditions, subsidies, and government schemes, thus, helping them to make informed decisions. Tamil Nadu's foresight in launching AGRISNET in 2004 has positioned it as a pioneer in digital agriculture. This has influenced other states to adopt similar models. The integration of central government platforms such as GKMS-mKisan, eNam, Agmarknet, and PM-KISAN mobile apps into Tamil Nadu's ecosystem has enhanced accessibility additionally, by offering services in Tamil. Digital extension services are further supported by public and private players, including NABARD's Krishak Sarathi, MS Swaminathan Research Foundation, and All India Radio's agricultural programs. In Spite of these advancements, low adoption rates, lack of awareness, and minimal promotional efforts however still remain as major challenges and prevent the full utilization of these digital tools.

Tamil Nadu's 2022-2023 agriculture budget has introduced IoT-enabled irrigation, drone training for pesticide spraying, AI-based pest monitoring, and micro agro-climatic zones. But the digital literacy gap among farmers, high implementation costs, and a shortage of extension officers hinder widespread adoption. Due to the disconnect between technological innovations and on-ground implementation, many farmers struggle to access and effectively use these digital tools. Furthermore, seamless service delivery in rural areas is restricted by power consumption issues, data security concerns, and limited internet bandwidth. This gap can be bridged by tailoring the ICT policies to the needs of the farmers. It is also important to ensure that timely market intelligence, weather forecasting, and financial assistance information are made available in local languages. Farmer engagement and participation can be improved by involving the panchayat unions in localizing and disseminating digital agricultural services.

Artificial Intelligence (AI) has tremendous potential to revolutionize Tamil Nadu's agricultural sector by enhancing crop monitoring, pest control, and yield predictions.

However, the impact of AI-driven solutions is limited due to the current focus on data collection rather than effective data modeling. AI adoption in farming could be promoted by establishing regional AI research centers and fostering collaboration among NGOs, self-help groups (SHGs), researchers, and agricultural technology startups. The Nan Mudhalvan Scheme, which focuses on skill development among students, could be leveraged to train college students to educate farmers on digital agricultural tools and AI applications. Moreover, government-backed AI tools and smart farming technologies should be made accessible at subsidized rates. At the same time, training and awareness programs for farmers should be strongly emphasized.

A widespread technology adoption can be ensured with a structured approach to digital transformation in agriculture focusing on a 3S strategy—Scale, Skill, and Service. This necessitates a collaborative effort among government agencies, technology providers, startups, research institutions, and farmer cooperatives. A public data ecosystem could be developed to further enhance research and innovation in precision farming, to the benefit of all stakeholders. Additionally, ICT tools can be made more farmer-friendly in Tamil Nadu by promoting digitalized literature and local language resources. Digital transformation in agriculture can further be accelerated with the involvement of private sector also, through organizations like Reliance Foundation and ITC e-Choupal.

Looking ahead, the scope for future research lies in developing sustainable smart farming practices, improving food supply chain efficiency, and reducing post-harvest losses. In this scenario, agricultural productivity can be optimized and risk can be minimized through the integration of remote sensing, big data analytics, and AI-driven decision-making. Knowledge-sharing and policy formulation can be enhanced by building open-access digital data repositories for farmers, researchers, and policymakers. As Tamil Nadu continues to embrace digital agriculture, a fully digitized, resilient, and climate-smart agricultural sector can be achieved by addressing key issues such as infrastructure gaps, farmer education, and accessibility barriers.

CHAPTER 4: RESEARCH METHODOLOGY

4.1. Participatory Rural Appraisal

Participatory Rural Appraisal (PRA) is a research methodology in which local communities are actively involved by the researcher to reflect upon field realities and identify development priorities. The crux of the participatory rural approach is participation, empowerment, and local knowledge. The different steps involved in PRA include facilitating dialogue, collective decision-making, and shared learning among community members. Various visual tools are used for conducting the same. Other field interview methods fall under conventional top-down approaches, while PRA keeps local people at the center and supports them in expressing their views. They are seen as co-investigators rather than passive respondents. They assess their own needs and actively contribute to planning and implementation of development interventions. This methodology works particularly well in the rural context, where traditional knowledge systems and social dynamics play an important role in shaping people's livelihoods and resource usage.

4.1.1. Introduction

The adoption and diffusion process related to DCSA is pivotal in ensuring farmers' sustained adoption and improved climate resilience in agriculture. Adoption and diffusion are the two terms that refer to the process of an idea spreading over some time, whereas diffusion refers to the collective adoption process over time. The three crucial adoption diffusion theories related to innovation are Rogers' innovation diffusion theory (IDT), the concerns-based adoption model (CBAM), the technology acceptance model (TAM), and the united theory of acceptance and use of technology (UTAUT). These theories explain why individuals adopt or reject an innovation. According to(Hall and Hord, 2015), who proposed the CBAM model, the school is the primary organizational unit for making the change process successful, and it also explains the critical role of external change facilitators in facilitating the same. CBAM model provides components such as stages of concern, levels of use, and innovation configuration, which depicts the mechanics and dynamics of the change process and helps capture a subjective view of many people with different perspectives and interests. Therefore, the CBAM model is appropriate for capturing different stages or phases of the change process and has been successfully used primarily in the educational context. (Ohlemann et al., 2023) CBAM model examines adoption from the perspective of adoptees, capturing individuals' concerns and their influence on the integration of innovation. It focuses on top-down mandated change in the context of an administrator or leader diffusing an innovation to the teacher, who acts as the final consumer. The CBAM model provides a framework for administrators to capture the concerns of teachers, provides an idea of how teachers will adapt to change, and enables them to anticipate future needs.

The technology acceptance model and the united theory of acceptance and use of technology are the two frameworks that are popularly used to study technology adoption in formal environments. UTAUT is a successor of the TAM and has close theoretical ties. Their key components include performance expectancy, effort expectancy, social influence, and facilitating conditions, which measure productivity-related factors and are more aligned with formal organizations. They capture information on the intention and use of technology in a structured environment, thus missing on holistically measuring the individual's technology acceptance.(Evan T. Straub, 2009)

The key components of Rogers' diffusion of innovation (DOI) theory include innovation, communication channels, social systems, and time.(Everett M. Rogers, 2003) It focuses on how innovation disseminates in a social system over time. It helps to analyze how innovation spreads both at individual and societal levels. Therefore, DOI can be adaptable for both formal and informal adoption contexts. Most previous diffusion research referencing DOI has focused on agricultural adoption and consumer behavior, primarily in informal settings. This theory is a leading framework referenced in the literature on agricultural adoption.(Evan T. Straub, 2009)

More specifically, even in the study area, studies have been oriented toward understanding the persuading factors influencing farmers' utilization of DCSA based on farmer and operator characteristics and farmers' interaction with extension officers, etc., as the independent variables and technology attributes have not been explored so far to the best of the understanding. (Aravindh Kumar et al., 2020; Chandrasekaran, 2020; Kumar & Karthikeyan, 2020; Mathuabirami et al., 2019; Nandhini A≡ & Rohini, 2022; Palanisamy & Bharadwaj, 2018; Rani et al., 2022).

For the initial observation the researcher aimed to explore farmers' perceptions regarding the availability and accessibility of DCSA in terms of technology attributes and factors influencing the adoption of DCSA practices (Ingram et al., 2022). The researcher believes this question will be essential to widen the scope of existing evidence on the uptake of DCSA based on technology-related attributes, which will be examined in this study through a conceptual framework (DOI). The communication channel is the core of DOI, and this aspect will be the focus of the study. The relevance of DCSA to the farming community and its significance demands an investigation against the backdrop of socio-economic and gender inequality in the study area. Hence, in this study, an initiative has been taken to investigate farmers' perceived values and benefits of DCSA in terms of DOI's technological attributes and depending on the communication channel, which will be elaborated in the 4.1 4 methodology section. To the best of the researcher’s knowledge, this study is the first to examine influential factors for DCSA adoption from the standpoint of Diffusion of Innovation theory attributes of technology in the Tamil Nadu case study area.

4.1.2. Conceptual framework of DOI

Rogers's Diffusion of Innovation (DOI) theory has been used to understand farmers' perceptions of DCSA diffusion regarding its technology attributes. Regarding any technological innovation, the adopter or non-adopter decision-making process is driven by information-seeking and processing activity, which reduces uncertainty about the advantages and disadvantages. The adopters are categorized based on their innovativeness, the degree to which the individual is comparatively earlier in adopting the innovation than other members of the social system over time. The five broad adopter categorizations mentioned in DOI are innovators, early adopters, early majority, late majority, and laggards. The innovators are venturesome people who first adopt and also help with launching the innovation in the society; early adopters are role models who help in conveying the subjective evaluation of the innovation to others; early majority adopt before the average member of the society, while late majority adopt after the average member of the society. Laggards are people who doubt the innovation and show resistance toward adopting it. The attributes that individuals perceive regarding innovation support the explanation of the difference in the adoption rates. According to Rogers's theory of diffusion of innovation, under the variables defining the adoption rate, the five key perceived attributes of innovation are relative advantage, compatibility, complexity, trialability, and observability.

For better readers' comprehension, a precise description of the five dimensions of technology attributes defined in the diffusion theory is provided below, and a conceptual framework diagram is depicted in Fig.28.

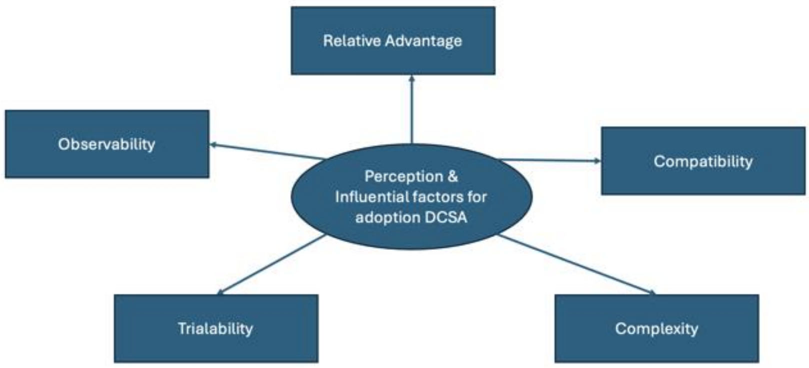


Figure 28: A conceptual framework to understand the perception of the adoption of DCSA services

Source: Adopted and adapted from theory of innovation diffusion

1. Relative advantage is the perceived advantage of an idea or a technology over what has existed.
2. Compatibility is defined as the level to which an idea or technological innovation is consistent with existing values, beliefs, needs of potential adopters, and past experiences.

3. Complexity is the level at which an innovation is perceived as challenging to use and understand.
4. Trialability is the ability to experience an idea or technological innovation on a trial or installment plan.
5. Observability is defined as the degree to which the effectiveness of an innovation or the implementation of an idea will be visible to others.

To summarize, innovations perceived by individuals as having high relative advantage, compatibility, observability, trialability, and lesser complexity are adopted more easily and rapidly than other innovations.

4.1.3 Study area

The study is based on two field studies (location shown in Figure.19); one was conducted in the Chengalpattu district in Tamil Nadu (Type A), and the other was conducted with farmers associated with the village knowledge center at Embalam village, Union Territory of Puducherry (Type B). The two locations identified for the study are distinct in terms of extension models and extension functionaries bridging farmers with DCSA. The two extension models identified for the study are the top-down approach, as concerned with Type A farmers, and the bottom-up approach or participatory approach, as concerned with Type B farmers. The top-down extension model refers to the key role played by government-led extension functionaries in disseminating agricultural information, subsidies, schemes, and introducing new agricultural technologies. In the bottom-up approach of the extension model, local knowledge and farmers' inputs are used mainly to design agricultural programs and practices. (Samson Olayemi et al., 2021)

In DOI, extension functionaries are referred to as change agents. A change agent is an individual who influences the client's innovative decision-making process in a direction recognized as preferable by the source initiating the change. The socio-economic status of the client is increasingly related to the change agent contact. The change agent contact is highly related to the client's innovativeness. Therefore, it is said that the change agents mediating innovation diffusion are said to increase socio-economic inequality amongst their audience, or in other words, change agents least help the clients who need the most of their help. Regarding Type A, change agents are the government-led extension functionaries, and in Type B, change agents are the villagers themselves, mostly the women from the community.

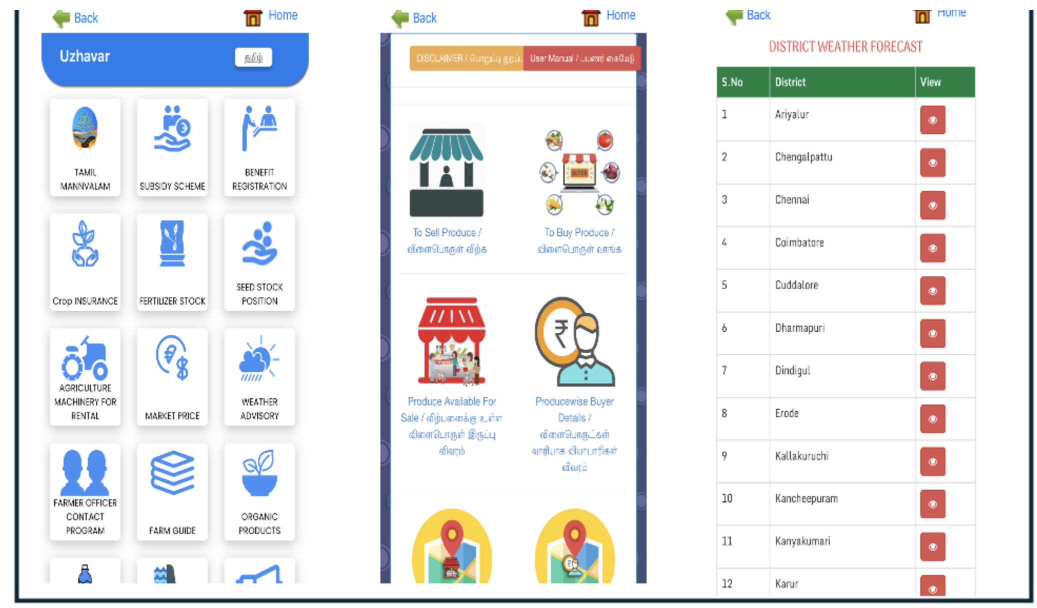
Figure 29: Two study regions: Chengalpattu in Tamil Nadu (Type A) and Embalam in the Union territory of Puducherry (Type B).
Source: (GoogleEarth, 2025; MapsofIndia, 2020)

Type A: Chengalpattu district, Tamil Nadu: Government-led extension functionaries.

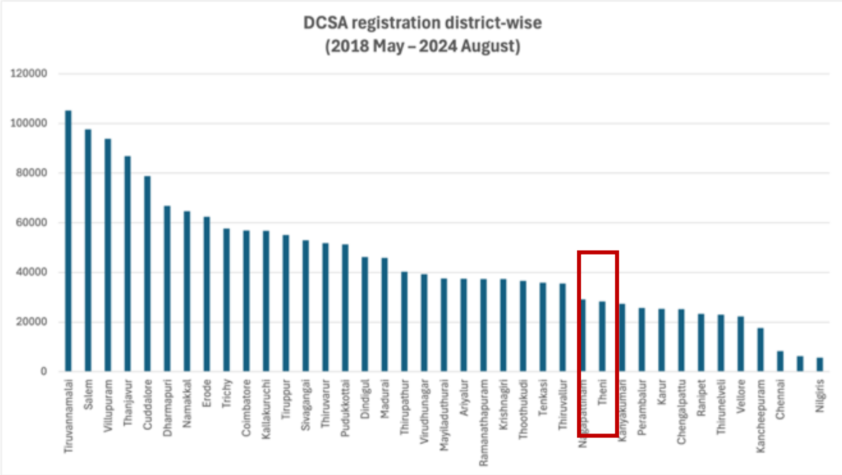
Chengalpattu district is on the northeast coast of Tamil Nadu. It is in proximity and bounded in the north by Chennai district. The main economic activity of the people in the region is crop production (rice is a major crop), and it is also a rice-efficient cropping zone. According to the climate risk assessment report, Chengalpattu falls under high-risk agriculture in the near century, amongst other districts such as Ranipet, Ariyalur, Vellore, Kancheepuram, etc. Chengalpattu district has also been identified to have a very high decline in rice production during 2021- 20250 because of the increased intensity of rainfall and flash floods due to the northeast monsoon. Findings from a spatiotemporal analysis study project negative impact due to climate change with a reduction of crop yield, especially of rice, by 13.1% and 18.73% for the district by the mid and end of the century, respectively (CCCDM Anna University, 2024) (Ramachandran et al., 2017). Climatic projections for the district reveal an increase in the number of drought days by 3-23%. This mandates the need for mainstreaming climate change adaptation, especially to build climate resilience in agriculture (TNGCC, 2024)(V. Singh et al., 2024). The ratio of government extension officers or change agents to the farmers in the state of Tamil Nadu has been mentioned as 1: 1834. This low number of extension officers has been attributed to the state's human resource shortage (agricultural specialists).

A key DCSA service used in the state of Tamil Nadu called the "Uzhavan" mobile application, as described in Fig 20[a], provides various agricultural information, including soil status, subsidy registration, weather forecast, market price, e-market, crop insurance, and farm guide, amongst many others.(TNagrisnet Uzhavan app, 2024) The district-wise registration details are mentioned in Fig20 [b], and farmer registration status is mentioned in 20[c], where only 18% of the total farmers in the state have registered to the DCSA service since its inception in 2018. On the one hand, Chengalpattu is in the northeast monsoon and high-risk agriculture; on the other, it also has one of the lowest DCSA registration rates in the state.

Tamil Version



English version



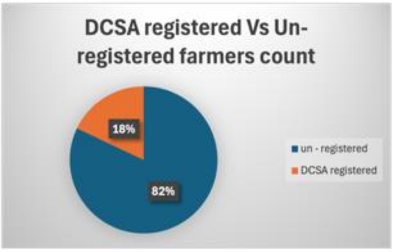


Figure 30: Key DCSA service in Tamil Nadu: Uzhavan Mobile Application [a], District-wise registration status[b], and DCSA registered vs unregistered farmers count[c].

Source:

[a] Top: (Uzhavan App TN, 2024)

[b] Bottom left: and [c] Bottom right: (TNagrisnet registration, 2024)

<u>Type B: Embalam village, union territory of Puducherry: Supported by local villagers</u>

The second field study area is the Embalam village, which is in the union territory of Puducherry and is close to the Chennai district. Agriculture is the main occupation, and rice is the major crop grown. The Village Resource Center (VRC) and Village Knowledge Center (VKC), an initiative of MS Swaminathan Foundation, were established in 1999 in the Embalam village. The village resource center is located at the block level; in other words, it oversees the responsibility of a cluster of villages. VRC acts as a hub to understand the knowledge needs of the farmers, translate the information into value-added knowledge, and provide it to the different other VKCs associated with the VRC. (Anabel et al., 2018) The village knowledge center is situated at the village or panchayat level. VRC and VKC are established through an institutional building as its capacity building aspect as shown in fig xas show. VRC provides agricultural-based services leveraging information and communication technology tools for developments such as video conferencing, audio conferencing, phone-in programs, etc. The locale-specific content is prepared by MSSRF scientists in consultation with experts from agricultural universities and institutions in the region. VKC acts as a knowledge platform providing effective knowledge and information-sharing networks, specifically in the context of climate variability and climate change scenarios in agriculture. The village management committee supervises the activities at the institutional building, and the members are appointed in consultation with villagers, making this a community-based organization. This is the key step toward the initiative's sustainability by creating a sense of ownership and commitment amongst villagers. The other key element of the program is strategic partners or subject matter experts in agriculture, horticulture, and health departments. The information these strategic partners provide and their collaboration is vital for delivering holistic advantages to the rural community. The next important factor is the knowledge worker, who facilitates as a local change agent, a person familiar at the village level. This person will be solely responsible for creating awareness about the initiatives and training programs and providing locale-specific information to the farmers. They bridge the farmers with digital agricultural information through ICT-based infrastructure at the village level. This VKC/VRC concept aimed to reduce the disparity between the urban and rural communities, especially regarding access to information, by leveraging digital tools through a bottom-up approach, steering persons from the local community to heed the knowledge revolution (MSSRF, 2024).

Picture 2: Village Knowledge Center, institutional building with ICT facilities at Embalam

The picture 3 shows the various activities that MSSRF Village Knowledge Centre supports farmers by offering services like soil testing, plant clinics, online help, training programs, and video-based learning all in partnership with local panchayats.

VKC in colloboration with Village Panchayat

ACTIVITIES: plant clinic, mobile soil and water testing

ICT facilities – Online Services

Government Awareness Program - Helpline

Certification course – Organic Farming

Video Based learning sessions

Picture 3: Various digital agriculture services-based activities in MSSRF Village Knowledge Centre

4.1.4. Methods

The field studies conducted were performed using participatory rural appraisal tools (focus group discussion and semi-structured interviews) with rice farmers at two different locations: 30 farmers from the Chengalpattu district in Tamil Nadu, and the other was conducted with 20 farmers associated with the village knowledge center at Embalam village, Union territory of Puducherry. Most farmers who participated in the focus group discussions also participated in the survey after checking with them their consent. The data was collected from 07 February 2023 to 21 February 2023 at Puducherry and from 18 January 2024 to 30 January 2024 at Chengalpattu. Snowball sampling, a non-probability sampling technique, was used whereby the researcher identified initial samples, and the subsequent respondents were introduced by the already interviewed respondents as referrals. This sampling technique was relevant as a specific trait was identified under the two farmer samples and helped to gather in-depth qualitative data. Amongst the farmers who participated in the study, 60% were from the Chengalpattu area, whereas 40% were from Puducherry. The following two subsections describe the two specific primary data collection methods adopted for this research.

Focus Group Discussion (FGD)

A total of 4 focus group discussions (2 in each of the two selected study areas) were conducted with farmers, wherein an average of 12 participants attended each session. To keep the findings harmonized and enable comparative analysis of farmers' responses under two different locations, a standard checklist with a few guiding questions was developed during the FGDs. The questions formulated aligned with the five technology attribute dimensions, as depicted in Figure 18. The key points of discussion during the

FGD included the recognition of climate change impact, awareness of climate change adaptation and mitigation measures, the farmers' information needs, source of information, availability, accessibility to such information, and, notably, their perception of the digitalization of climate-smart agricultural information services.

Emphasis was placed on the free flow of discussion, which was enabled through open-ended questions, which helped to proceed with the natural flow, and probing allowed us to understand the drivers and barriers toward accessing such digital agricultural information from two samples of farmers. Thus, the focus group discussions helped to gather qualitative insights and identify information on factors and perception items of interest to the study, as tabulated in Table 12.

Table 12: List of perception items based on technology attribute DOI
Source: Focus Group Discussion

Technology Attribute	List of Perception Items
Relative Advantage	Using Uzhavan app* has made improvement in the reception of digital agricultural information
	Uzhavan app helps me to be prepared for weather changes and gives update on market prices
	Uzhavan app helps me to get updated information on Subsidies and government schemes
	Using Uzhavan app enables me to identify the location of the seeds' availability, fertilizer shops, and stock level
	The effectiveness of receiving digital agricultural information does not improve with using Uzhavan app
Compatibiltiy	Using Uzhavan app is compatible with the configuration of my mobile phones
	Uzhavan app provides all access in the Tamil language making it easy to use
Complexity	Using Uzhavan app requires less mental effort
	Using Uzhavan app is much frustrating
	It is easy to learn using Uzhavan app
Trialability	I will not lose much if I try using Uzhavan app even if I do not like it much
	I am able to use Uzhavan app on a trial basis to see how it can help me in farming
	I have adequate opportunities to explore Uzhavan app to see what it can do
Observability	People around me can clearly notice the positive changes brought by Uzhavan app usage
	The effects of using Uzhavan app are easy to demonstrate to others

* *Type A farmers in Chengalpattu use the Uzhavan app. The Uzhavan app is substituted for the type B farmers with digital agricultural services provided by MSSRF at the VKC.*

Survey

Quantitative findings from the survey complement the qualitative findings derived from FGD. The survey involved conducting semi-structured interviews with 50 farmers. A semi-structured questionnaire was developed for the study, and the key questions revolved around obtaining information on farmer characteristics, DCSA adoption rates, and the farmer's perception of DCSA adoption concerning the perceived attributes of technology from DOI theory. The semi-structured questionnaire was formulated to receive responses to a series of DCSA perception items from two farmer sample groups. The questionnaire is presented in Appendix A. The list of DCSA perception items was from the focus group discussions, as tabulated in Table 11. In the current study, innovators, early adopters, early majority, and late majority are referred to as Adopters of DCSA. While the respondents who identified as non-adopters were placed under DOI's laggards category. The adoption count of DCSA as per the DOI framework and adopter farmer characteristics regarding age, gender, education, landholding size, and income have been summarized in the 4.1.5. Results section.

Regarding the DCSA perception items, Factor analysis has been employed to identify underlying relationships between variables by grouping them into factors and identifying the factor structure of the items related to the perceived attributes of technology of DOI theory. The statistical software package SPSS 23.0 was used to conduct the analysis. Following the factor analysis of perception items, an institutional comparison chart (radar chart) was created based on the interview responses to understand the perception of farmers availing of DCSA services from two different institutions based on the five technology attributes dimension from the DOI theory.

Picture 4 : Focus group discussion with farmers at Village Knowledge Center, MS Swaminathan Research Foundation, Embalam

Picture 5: Farmer survey from Chengalpattu

4.1.5 Results

The section consists of five main sections aligned with the technology attributes of the DOI framework. Under each area, the research findings from both qualitative and quantitative aspects of the two research methods employed, focus group discussions (FGD) and semi-structured surveys, have been summarized in two sub-sections (Chengalpattu and MSSRF-VKC farmers).

As mentioned in the methodology section 4.1.3, based on the DOI framework, five adopter categories are innovators, early adopters, early majority, late majority, and laggards; table 12 below summarizes the DCSA adoption count of interviewed farmers from the Chengalpattu and MSSRF-VKC across the five categories.

Table 13: Adoption count
Source: Interview data

Farmers	Innovator	Early Adopter	Early Majority	Late Majority	Laggard	Active Margin
Chengalpattu	1	3	6	3	17	30
MSSRF-VKC	1	9	8	1	1	20
Active Margin	2	12	14	4	18	50

From the above table 13, it can be inferred that most respondents (56%) from the Chengalpattu sample consider themselves under the non-adopter or laggard category. Meanwhile, MSSRF-VKC farmers top the early adopter (45%) and early majority (40%) stages of diffusion of innovation.

Amongst the DCSA adopter categories of farmers, Table 14 presents the farmer characteristics of the adopter(innovator, early adopter, early majority, and late majority) categories. MSSRF-VKC had a better engagement with farmers of all ages, especially women, those in school-level education or illiterate, and small-scale farmers.

Table 14: Adopter Farmer characteristics
Source: Interview data

Adopter farmer Characteristics

	Chengalpattu	MSSRF-VKC
Age(>38 years)	14%	86%
Gender(% female)	35%	45%
Education (illiterate or school level)	44%	56%
Landholding size (marginal to small, < 1acr	18%	83%
Income(less than 15,000 INR per month)	34%	56%

1.1 Relative advantage

Relative advantage is the degree to which DCSA is perceived as being better than the idea it supersedes. The degree of relative advantage is often related to economic profitability, social prestige, or in other similar ways. The other sub-attributes related to this would be low investment cost, saving time and effort, decreased discomfort, and immediacy of reward.

- **Chengalpattu farmers' view**
  Farmers used mobile phones to search for DCSA-based agricultural information, primarily to learn production techniques and market prices. They were also interested in subsidy-related information, for which they had used mobile phone-based services. Regarding perceived relative advantage, farmers related the use of DCSA services to improving farm profitability. Despite answering that they felt the impact of climate change, few used DCSA services to refer to weather forecasts, mentioning that they were unreliable or had never tried using them.

- **MSSRF VKC farmers' view**
  VKC farmers recognized the suitability of leveraging digital technologies to seek information on climate change adaptation measures and improve farm profitability. In the earlier cases of farmer samples, gender bias existed. In the case of Chengalpattu farmers' case, though women played a significant role in farming and related activities, they lacked ICT-based agricultural information because they did not possess ICT devices as commonly as their male counterparts did. Therefore, they were missing in the decision-making process. However, in the VKC farmer's case, women's participation rate was comparatively higher in terms of accessing information leveraging ICT, as in Table 13.

1.2 Compatibility

Compatibility is the degree to which DCSA is perceived to be consistent with farmers' values and beliefs, indigenous knowledge systems, previously introduced ideas, and needs. This also needs to be explored to identify compatibility perceived by farmers among interrelated ideas, i.e., a solid basis for interlinking DCSA services in easier-to-adopt packages.

- **Chengalpattu farmers' view**
  Almost 80% of the farmers had quoted time consumption, non-compatibility, low literacy, and digital illiteracy issues as one or more constraints regarding accessing mobile phone-based agricultural information. They felt it was non-compatible with their laborious daily farming activities. They were using very basic mobile phones that never supported such features, and it was expensive to invest in a device compared to the perceived benefits they thought it might fetch them.

The other 20% of interviewed farmers who regularly use DCSA or have used mobile phone-based advisory applications mentioned that the advisories or information are usually text-based. They felt voice-based advisory services could be more convenient for farmers to comprehend, irrespective of literacy or digital capabilities. For instance, they recollected the convenience of watching a video of a production technique in comparison to referring to text-based advisories.

- **MSSRF VKC farmers' view**

  The VKC farmers never felt that accessing ICT devices for agricultural information was something unrelated to their day-to-day occupational activities. The ICT-enabled village knowledge center caters to the wide range of information needs of the people, such as agricultural information, Health Insurance Card distribution camp (Ayushman Bharath), Soil collection (725 types of soil from 3 villages), video-based career guidance program, online zoom meeting for pest and disease management. People from diverse backgrounds visit the VKC center, i.e., people of different ages, sexes, and socio-economic statuses. This could also be inferred from Table 3, where farmers of higher age groups, low literacy levels, small land-holding farmers, and low-income categories represented better adoption. Visiting and availing information from VKC was a way of life for them.

1.3 Complexity

The complexity of DCSA services is defined as farmers' perceived challenges in the social systems, which are negatively related to their adoption.

- **Chengalpattu farmers' view**

  Farmers whose second occupation was farming were generally better educated. Though they were not landowners, they considered DCSA services somewhat comprehensible, usable, and beneficial for receiving information on agricultural inputs, farm practices, and market prices because of their literacy level and other work exposure.

  However, despite their literacy levels, some progressive farmers were interested and open to learning about utilizing DCSA if only they were selected as subsidy beneficiaries and were chosen for training.

- **MSSRF VKC farmers' view**

  The users at VKC do not need to own their devices to avail themselves of DCSA-based advisory services. Upon visiting the VKC, they will be guided by a knowledge worker who belongs to the same community, who will assist them with the needed information. This made things easy for the farmers. They also felt the advisory was relatable and trustable as they were guided by a change agent in the same community.

1.4 Trialability

Trialability is the degree to which DCSA services may be experimented with or experienced within a limited time. DCSA's trialability based on farmers' perceptions of the social system is positively related to its adoption rate. A personal trial is believed to remove any uncertainty in the farmer's mind regarding the DCSA service.

- **Chengalpattu farmers' view**

  Despite the Tamil Nadu government's supply of DCSA interventions (Uzhavan app), some farmers lacked awareness of such services. Farmers prefer extension officers to visit and resolve queries by interacting with them on the field. Most of the farmers feel that in-person consultation is effective. The farmers were concerned about very few visits from an agricultural officer or sometimes said they were not visited. There are applications like Uzhavar Aluvalar Thodarbu Thittam (UATT) to monitor field officers' farm visits. The system is diligent and methodical (as mentioned by an agricultural officer in the study area). However, the concern is the acute human resource shortage caused by a low ratio of extension officers to farmers. Multidisciplinary skill sets and knowledge of the extension workers are also required. All this could contribute to the low trialability of DCSA services.

  Regarding receiving agricultural information, they felt that consulting with fellow farmers, following up on their instincts, or consulting with the pesticide/fertilizer dealer, whom they call crop doctor, was the most efficient way, in their opinion. They felt it was more convenient in terms of quickness in receiving the solution and cost-effectiveness. They rely on face-to-face interaction to solve their problems and queries. They felt they had not recognized a need to use DCSA and lacked time to learn about it.

  In contrast, DCSA farmer users found mobile phone-based services leveraging AI-based disease identification and recommendation effective. However, the follow-up through the feedback mechanism service, where farmers raised inquiries for clarification, usually took around 1-2 days of turnaround time, which they found was too long for them. Though trialability existed to some extent, late responses and follow-up feedback due to human resource shortage decreased trialability.

- **MSSRF VKC farmers' view**

  Farmers who either used or never used one of the DCSA services showed increased knowledge of their availability. They relatively acknowledged the awareness of DCSA use cases. This is mainly because they could experience the VKC, which is accessible and available in their neighborhood without any barriers (gender, literacy level, socio-economic status, etc.). The existence of VKC increased the trialability of DCSA services.

1.5 Observability

Observability refers to the level up to which the results of DCSA services are visible to others. There are two sides to this: one is easily observable and communicable to the other members of the society, and the other is difficult to observe and communicate. DCSA's observability based on farmers' perceptions of the social system is positively related to its adoption rate.

- **Chengalpattu farmers' view**
  What are the options available to adapt to climate change, and how can different DCSA services be beneficial? If and only if the advantages and disadvantages of each option are communicated by the change agent and made observable to farmers, he/she might be able to decide. Most of the farmers consider input dealers as their reliable source of information since the contact frequency of the extension agent was low. Sometimes, they expressed concern over receiving different recommendations for their problem (for example, pest identification or suitable seed to be sown) if they were to approach two different dealers. In unison, they regard their fellow farmers as the most trusted source of agricultural information through the proven benefits they can observe once the farmer adopter explores DCSA service or even other agricultural technologies.

- **MSSRF VKC farmers' view**
  During COVID-19, a WhatsApp group for delivering advisory services was created. It had farmers and agricultural scientists from MSSRF as its members. Farmers were encouraged to send their queries through Voice messages. Queries started coming about crop and pest infestations. They were also able to post pictures of the infested crop. Agricultural scientists took to answering the queries in the WhatsApp group through voice-based messages, which farmers acknowledged as very helpful and effective. Since information is provided through a demand-driven approach, farmers felt the solution was more contextualized. Many farmers who had previously hesitated to consult experts in the group were even influenced to see the effectiveness of the advisory process and began raising queries.

Table 15 below summarizes interview responses from two farmer samples based on the five dimensions of technology attributes defined in the diffusion theory.

Table 15: Farmer's response from the lens of perception of technology attributes - innovation diffusion theory

Technology attributes	Chengalpattu farmers	Puducherry farmers
Relative advantage	Economic advantage was the main motivation for DCSA usage.	Increased awareness of DCSA usage for climate change adaptation measures and gender equality addressed through women representatives as change agents.

Compatibility	Audio or video-based information content is more compatible with day-to-day farming activities.	Information provision not restricted to agricultural information was key to the increased user base.
Complexity	Higher socio-economic conditions and government subsidiaries eased the complexity aspect of DCSA.	Infrastructure (network, digital devices) provided in the VKC; women change agent to assist the villagers in accessing information eased DCSA-related complexity
Trialability	The human resource extension agents shortage is the main reason for farmers' lack of awareness of DCSA services and usability. DCSA Government intervention (AI-based pest identification) is effective but has a slow turnaround time compared to in-person consultations.	Accessibility, equitability, and usability of the village knowledge center in the neighborhood are the main reasons for increased awareness and usage rate of DCSA services.
Observability	Fellow farmers who are DCSA adopters and agricultural input dealers influence adoption decisions mostly.	Accessibility to consult with agricultural specialists and demand-driven approach to receiving digital agricultural information was observable even to reluctant farmers through the communication exchanges on a WhatsApp group.

Table 16 presents the factor analysis results for the list of perception items. It identified five major factors: relative advantage, compatibility, complexity, trialability, and observability. These factors represent dimensions that influence farmers' perceptions of the specific DCSA service. Each perception item is categorized under one of these factors based on high loadings. A factor loading value greater than 0.7 indicates a strong correlation with the factor. Cronbach's alpha was evaluated, and a scale was constructed for each set of items. A Cronbach's Alpha value above 0.6 reflects the robustness of the scales used in the model, indicating high reliability. All factors exhibit high Cronbach's Alpha values (ranging from 0.81 to 0.88), demonstrating strong internal consistency and reliability of the measurements for each factor. Four factors have eigenvalues greater than 1: relative advantage (6.5), compatibility (1.8), complexity (1.5), and trialability (1.2), which account for significant variance in the data. Complexity and trialability explain the most variance (2.97% and 2.81%), followed by relative advantage at 2.73%. The Mean of Scale (SD) indicates each factor's central tendency and the variability of responses, suggesting differing perceptions among respondents regarding these factors. Finally, the p-values help clarify statistical significance, indicating whether the identified factors are reliable for explaining perceptions in these contexts. Concerning the Chengalpattu farmers' data, all p-values were at or below 0.05. This finding indicates that the results obtained from these tests are statistically significant, providing strong evidence against the null hypothesis. In some instances, results were marginally significant, suggesting that although the findings may not be as robust, they indicate noteworthy trends across all tested conditions. This level of statistical significance implies that the observed effects are unlikely due to random chance, reinforcing the validity of the outcomes under review. Conversely, for the MSSRF-VKC farmers' data, it was determined that all p-values from the statistical analysis are below the 0.05 threshold, indicating a high level of statistical significance. Most of these p-values are considerably lower than this benchmark, suggesting that the findings are statistically significant and robust across all tested conditions. This substantial statistical evidence enhances the credibility of the results and supports the reliability of the conclusions drawn regarding the MSSRF.

Table 16: Factor Analysis of Perception Items
Source: Interview data

Factor analysis of perception items					
	Factors				
Perception Items	Relative Advantage	Compatibility	Complexity	Trialability	Observability
Using Uzhavan app has made improvement in the reception of digital agricultural information (RA)	0.835				
Uzhavan app helps me to be prepared for weather changes and gives update on market prices (RA)	0.822				
Uzhavan app helps me to get updated information on Subsidies and government schemes (RA)	0.806				
Using Uzhavan app enables me to identify the location of the seeds' availability, fertilizer shops, and stock level (RA)	0.794				
The effectiveness of receiving digital agricultural information does not improve with using Uzhavan app (RA)	0.792				
Using Uzhavan app is compatible with the configuration of my mobile phones (Compatibility)		0.823			
Uzhavan app provides all access in the Tamil language making it easy to use (Compatibility)		0.806			
Using Uzhavan app requires less mental effort (Complexity)			0.850		
Using Uzhavan app is much frustrating (Complexity)			0.825		
It is easy to learn using Uzhavan app (Complexity)			0.808		
I will not lose much if I try using Uzhavan app even if I do not like it much (Trialability)				0.835	
I am able to use Uzhavan app on a trial basis to see how it can help me in farming (Trialability)				0.812	
I have adequate opportunities to explore Uzhavan app to see what it can do (Trialability)				0.794	
People around me can clearly notice the positive changes brought by Uzhavan app usage (Observability)					0.825
The effects of using Uzhavan app are easy to demonstrate to others (Observability)					0.803
Eigen Value	6.5	1.8	1.5	1.2	1
Percent Variance	2.73%	0.72%	2.97%	2.81%	1.21%
Cronbach's Alpha	0.88	0.85	0.83	0.82	0.81
Mean of Scale (SD)	1.65	0.85	1.72	1.67	1.1
p value:					
Chengalpattu	0.05	0.047	0.034	0.038	0.048
MSSRF-VKC	0.01	0.000	0.002	0.013	0.011

* Uzhavan app is used by Type A farmers in Chengalpattu. The Uzhavan app is substituted for the type B farmers with digital agricultural services provided by MSSRF at the VKC.

The figure 31 below summarizes the key barriers reported by farmers into four themes: digital literacy, capacity building, access to technology, and access to information, highlighting practical challenges that hinder the effective use of digital tools for climate-smart agriculture.

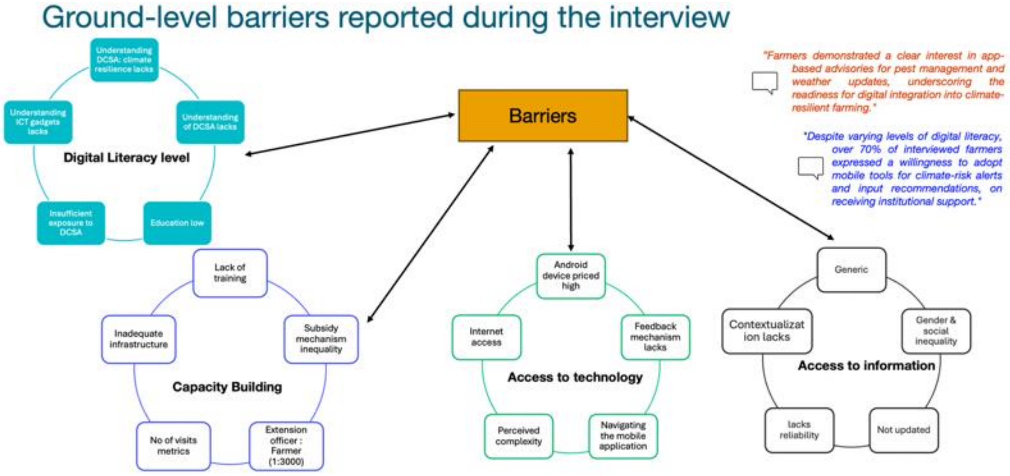
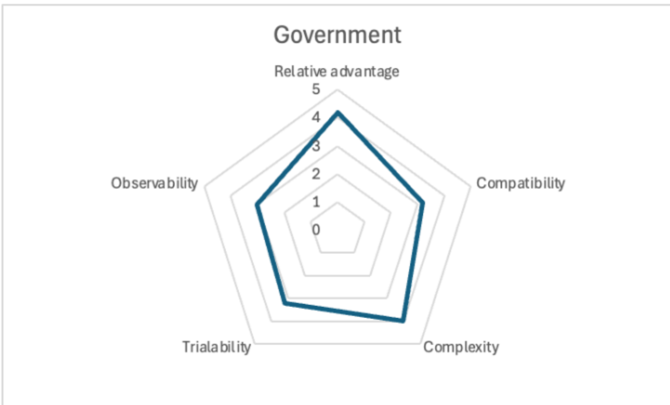
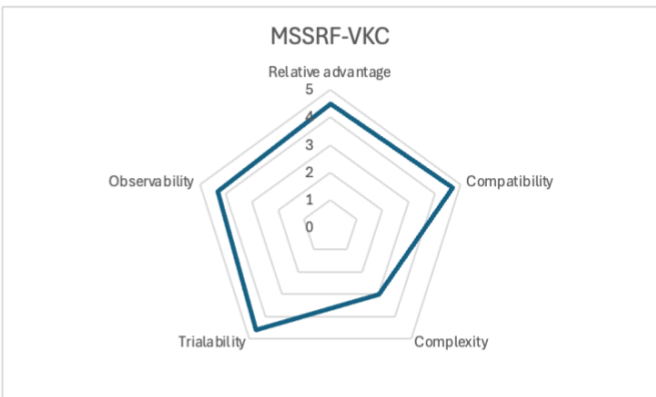


Figure 31: Ground-Level Barriers to Adoption of advisory services identified Through Farmer Interviews

An institutional comparison of farmers availing services from different institutions (public & NGO) from the standpoint of Diffusion of Innovation theory attributes of technology has been presented in Figure 32. The MSSRF-VKC fairs well in all attributes, with increased relative advantage, compatibility, trialability, observability, and reduced complexity.





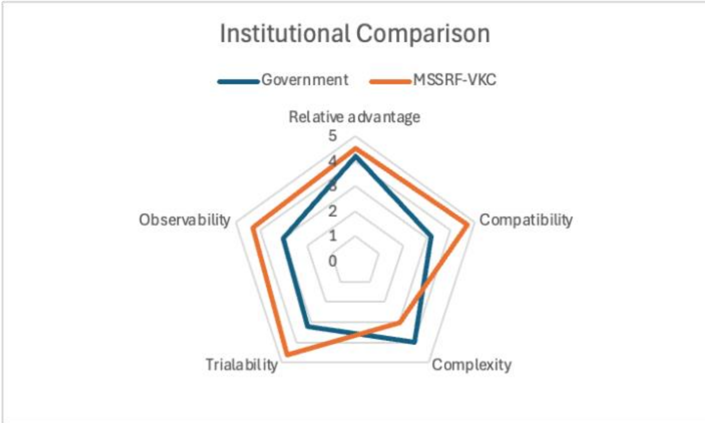


Figure 32: [a] Farmers affiliated with the public extension system, [b] Farmers affiliated to MSSRF – Village Knowledge Center, [c] Institutional comparison.
Source: Interview data

4.2 Stakeholders' perception

Stakeholder analysis is a methodical process by which we can understand and evaluate, the interests, influence, and interactions of different individuals and groups who are affected by or are capable of influencing a particular project, policy, or initiative. This is an essential tool in development planning and project management. It allows practitioners to chart stakeholders' roles, power levels, and potential impacts on results. By examining both formal and informal actors: including government bodies, community members, NGOs, businesses, and marginalized populations, stakeholder analysis ensures inclusive decision-making. This tool helps to anticipate potential conflicts, and aligns strategies with the needs and expectations of participants. Importantly, this approach leads to more effective, participatory, and sustainable initiatives.

The table x presents a list of key stakeholders who were interviewed as part of the stakeholder analysis for the study on factors influencing farmers' adoption of Digitalization of Climate Smart Agricultural (DCSA) services and practices. The objective of the analysis was to explore inclusive strategies that promote equitable access to DCSA technologies, thereby minimizing the digital divide and preventing the exacerbation of existing socio-economic inequalities among farmers.

A total of 12 participants representing a diverse range of roles and organizations were interviewed. The participants were chosen for their expertise and engagement in different stages of agricultural innovation, policy, technology, and grassroots implementation. The stakeholder group included:

- Representatives from agribusiness startups and technology firms (e.g., Agritech Experts, Agronomists, CEOs)
- State government officials involved in agricultural policy and extension services
- NGO representatives working on eco-technology and agricultural sustainability

- Individuals from startup incubators and accelerators supporting agricultural innovation
- Independent experts and mentors guiding innovation in climate-resilient agricultural practices

This multi-stakeholder approach enabled the study to capture holistic insights into the opportunities, barriers, and strategic directions for enhancing DCSA adoption, particularly among marginalized farming communities.

Table 17: List of stakeholders

	Role	**Organization**
1	Agritech startups, Associate Vice president	StartupTN
2	Agri business Promotion	State Govt
3	Extension Agent	Pvt Tech company
4	Agronomist	Tech company
5	Agritech Expert	Tech company
6	Agricultural Innovation startup mentor	Independent
7	Vice President Strategic Initiatives	Startup Incubator/Accelerator
8	CEO	Agritech Startup
9	Agricultural scientists	NGO
10	Director, Eco technology	NGO
11	State Government Agricultural Officer	State Govt
12	District Agricultural Officer	State Govt

Picture 6: Few snapshots from Stakeholder interview

4.3 Discussion

Digitalization of climate-smart agriculture services leveraging mobile has been perceived as an effective alternative for improving many aspects for farmers along the agricultural value chain. (Akudugu et al., 2023) As identified through the observations from the field study, barriers to DCSA utilization are coherent with findings from literature studies, such as institutional voids, lack of digital devices, and the digital divide. (Campuzano et al., 2023; Dibbern et al., 2024; Sindakis & Showkat, 2024) The state government supplied DCSA intervention mandates for farmers with Android mobile phones to receive digital agricultural information. This has made the service more accessible to farmers with higher socio-economic conditions. Institutional support in the form of equipping the local change agent with the capacity for disseminating digital agricultural information, ICT infrastructural support, and providing locale-specific content has improved the adoption rates in a more equitable scenario amongst MSSRF-VKC farmers, as summarized in Table 14.

This section discusses factors influencing farmers' adoption of DCSA practices under three main pillars. It provides recommendations for promoting DCSA adoption with greater equality rather than deepening the digital divide and unequal socio-economic status (Jabbar et al., 2022b) (Jabbar, Liu, et al., 2023) (Jabbar, Wei, et al., 2023):

4.3.1 Contextualized digital agricultural information with improved accessibility:

While the benefits of DCSA are often emphasized, it is crucial to contextualize and provide it according to farmers' needs. One important reason Chengalpattu farmers rely on fellow farmers and fertilizer dealers for agricultural information is to receive relevant information. This holds true for MSSRF-VKC farmers, who received tailored advisories from agricultural scientists over a WhatsApp group.

The adoption of DCSA largely depends on providing service on a demand-driven approach contextualized to local needs and challenges. This includes incorporating mechanisms to receive constant feedback from farmers and incorporating the same into the DCSA service provision.

Regarding the MSSRF model, it is evident through observation of the VKC farmer sample that this model makes it easy to diffuse DCSA services; the importance of steering the initiative through local change agents helps understand the farmer's needs precisely, aligned with farmers' values and belief systems resulting in increased adoption. DCSA interventions are most successful when led by a local stakeholder (Dinesh et al., 2018).

4.3.2 Community-Led, Bottom-Up Approach to Address Gender and Socio-Economic Disparities:

The Tamil Nadu agricultural scenario has been characterized by higher gender and socio-economic disparities. This can be defined in terms of the gender wage gap, female labor workforce participation rate, and access to resources and funds by small and marginal-scale farmers. The female labor workforce participation rate in Tamil Nadu is higher (43%) than the national average, although there has been a sharp decline in the state recently. (World bank, 2017)Also, women in rural Tamil Nadu have slightly higher casual wage jobs than men. (Sundari, 2021) However, it has one of the highest gender wage gaps. Though rural men in Tamil Nadu have comparatively higher daily wage rates than the national average, the average rural female wage is less than 60% of the male wage. (MOSPI, 2024)(PLFS, 2024)The marginal and small-scale farmers form most of the farmer representation in Tamil Nadu, holding 93% of the total cultivable landholdings in Tamil Nadu. (TN-ENVIS, 2024)

With the above context, regarding Chengalpattu farmers, primarily farmers who were landowners whose land size was greater, who were also beneficiaries of government subsidies and in contact with extension officers, or who had farming as a second occupation, perceived DCSA as having the relative advantage, being compatible with existing infrastructure and farming needs, higher trialability and observability and somewhat less complicated. The adoption rate among women was comparatively less, as described in Table 12. However, in contrast, in the case of MSSRF-VKC, when village women steer the project as local change agents, panchayat heads, and community leaders as other stakeholders, the dissemination and adoption of digital agricultural information is more equitable.(Nagadeepa et al., 2024)

Therefore, promoting equitable and non-exploitative digital agricultural advisory services, especially in the context of developing nations and small-scale farmers, is an important aspect to be instilled in future policy and related research (Rotz et al., 2019). Improving access to information, credit facilities, and subsidies and developing market skills can help broadly address gender and socio-economic disparities.(Boateng et al., 2024) (Dwomoh et al., 2023)Expand the evidence base by generating sex-disaggregated data and mainstreaming gender and social equity issues, which should be diligently considered at all stages of the DCSA project (planning, design, implementation, monitoring, and final evaluation). (FAO, 2022)Integrating such a transformative approach should be closely linked to the agricultural extension to ensure more gender-equitable relationships and equal distribution of resources to people from different strata of society. (Tina D. Beuchelt, 2016) Equitable adoption of DCSAs is seen with a community-driven, bottom-up approach.

4.3.3 Building sustainable institutional support alongside government schemes and promotional efforts of DCSA:

Adaptation policies must focus on providing information about available DCSA technologies and establishing financial resources and institutional support that enable farmers to adopt relevant DCSA services [2]. The primary way to promote DCSA services is through widely used mass media, such as TV or radio, by advertising these services in programs that farmers are likely to watch. (Quarshie et al., 2023) Even when DCSA is promoted, it should be highlighted for addressing specific needs rather than being presented solely as a technological upgrade.

A new model for DCSA promotion could be identified from the Chengalpattu farmer sample. Part-time farmers, i.e., had another non-farming occupation as their primary occupation, relied on mobile-based agricultural information found it to have higher relative advantage, compatibility, trialability and, observability, and low complexity. The farmers from the Chengalpattu district uniformly appreciated the state government's "direct kolmudhal" (direct purchase of the produce). They quoted it as their reason for continuing farming with satisfaction amidst the pandemic. It had fetched them double their income and reduced their trouble negotiating and selling the product at the market directly. The same scheme has encouraged many people to take up agriculture as a side hustle besides their other occupations. Government subsidies and innovative schemes like this indirectly promote the adoption of DCSA by encouraging rural youths to consider farming as they realize it could be a lucrative option.

Almost all farmers interviewed recognized climate change impacts, but the reaction and response toward adopting DCSA services as a climate change adaptation measure was evident with VKC beneficiaries. The low adoption of DCSA practices in the Chengalpattu farmers' sample highlights the need to go beyond the sole promotion of DCSA services, sustain momentum in its utilization, and identify solutions to strengthen their enabling environment. (Finger et al., 2019) The existence of the MSSRF Village Knowledge Centre, its institutional support, and its provision of ICT-enabled agricultural information helped improve the farmers' perception of various technology attributes of DCSA and, in turn, resulted in better adoption of DCSA amongst such farmers.

As depicted in the evolution of agricultural information dissemination in Figure 2, the involvement of diverse stakeholders has been increasing in agricultural extension delivery activities. However, this poses challenges such as scalability and the initiative's sustainability(Andrieu et al., 2017)(Li et al., 2022). There is also a gap between agricultural research and the dissemination of advisories because of capacity issues in human resources and the gradual withdrawal of government extension machinery for information delivery. (Krishna & Naik, 2020)

Establishing a sustainable institutional support model will be the key to adopting DCSA services. (Jabbar et al., 2020) (Jabbar et al., 2022a) Financial support in the form of government programs and subsidies is also seen to improve adoption. It is recommended that the possibility of integrating agriculture extension in the DCSA development and dissemination process be explored.

4.4 Conclusion

Digitalization is often related to and assumed to show proven benefits in large-scale farming systems. However, the future lies in exploring and leveraging the power of digitalization for small-scale landholding farmers, as it has the potential in terms of adaptability and granularity of control (Ingram et al., 2022).DCSA services will specifically be more important in the context of developing countries and small-scale landholding farmers as adaptative measures to climate change. During the field study, it was observed that community-based, demand-driven, and contextualized agricultural information was a prerequisite for DCSA promotion and adoption. This study has identified the need for innovative extension models involving diverse stakeholders. This would facilitate the effective adoption of DCSA services for small-scale landholding farmers without accentuating the socio-economic inequality and the digital divide. This study focuses only on rice growers in a particular state in India, which cannot apply to the entire country. It will be necessary to devise context-specific policies due to the heterogeneity of agrarian communities. Farmers who adopt DCSA are using it to advance economic profits rather than as an adaptative measure to climate change or to improve the lives of more vulnerable populations. The study's implication is that irrespective of whether farmers relate the use of DCSA as an adaptative measure toward climate change, it could be promoted as a means of improving productivity or market access or farm management even if it could indirectly contribute to climate change as a means of achieving the end goal. Globally and especially in the context of the study area, many variance-type research or investigations have been conducted to understand factors influencing the adoption of DCSA services. For the next steps, the researchers recommend conducting more process-based studies (qualitative analysis) to empirical (quantitative) in the case study area, which they believe will help understand the dynamic perspective of causes and sequences of events leading to adoption and non-adoption of DCSA services.

CHAPTER 5: BUILDING AN ANALYTICAL FRAMEWORK FOR THE STUDY

5.1 Introduction

The farmer’s perception of agricultural information is significantly shaped by various factors such as if its is aligned with the cultural context, practical needs, and digestible formats and trusted communication channels. Importantly, if they receive information that is contextualized, localized, and very specific to the crops and local conditions. Importantly, if they receive information that is contextualized, localized, and very specific to the crops and local conditions, they consider it even more valuable.

Farmers usually prefer face-to-face communication, radio or TV broadcasts, and community meetings. As agricultural information is concerned, clarity, relevance, and availability of the information in the local language, and information format play a crucial role. (Msoffe & Ngulube, 2016) The important factor in shaping farmers’ perception is the source of the information and the support he/she receive during the process. Supposedly, if the information is delivered by trusted individuals who could be fellow farmers or the extension agent, and backed by consistent follow-up, it helps in the process of confidence-building and motivates the farmer to apply the insights into practical relevance. The other factors that play a key role in shaping the experience and interpretation of agricultural information by farmers are: literacy level, infrastructure access, socio-economic status, personal experience, and cultural beliefs. User-friendly, inclusive, and responsive information systems can lead to greater satisfaction, stronger engagement, and better uptake of agricultural innovations.

A shift from top-down information dissemination to community-centered strategies that involve understanding farmers’ information-seeking behavior, their preferred sources, and the barriers they face can ultimately improve farmers’ perception. This approach fosters trust, relevance, and utility which are the key ingredients in encouraging meaningful use of agricultural information; and that can lead to improved productivity and livelihoods. (Sule, B. A. et al., 2021)

The frequency and quality of interactions with extension agencies play a pivotal role in disseminating agricultural information. Both public and private extension services are instrumental in building farmers' capacities, as highlighted by Kabir and Islam (2023). Farmers' exposure to and adoption of digital tools can significantly be influenced by trust in these institutions and the usefulness of information provided by them. (Sailevu et al., 2025)

Farmers' proactive behavior in seeking agricultural knowledge is crucial for the adoption of new practices. (Riaz et al., 2022)indicates that the use of mobile apps, participation in training sessions, and consultations with peers or local leaders are common methods for information acquisition. Such behaviors indicate farmer's readiness to engage with digital platforms and tools.

Awareness of and engagement with DCSA practices are essential for sustainable agricultural development. (Ewulo et al., 2025)have shown that familiarity with specific DCSA tools, such as precision farming and digital irrigation systems, correlates with positive attitudes toward digital transformation in agriculture. The adoption of climate-resilient digital practices are facilitated by this awareness.

Farmers' understanding of climate change and its effects on agriculture influences their adaptation strategies. Research by Azumah et al. (2017) reveals that farmers who perceive changes in rainfall patterns, temperature fluctuations, and increased pest incidences are more likely to adopt adaptive farming measures; and this recognition is pivotal for the implementation of climate-smart agricultural practices. (Ricart S, 2025)

The availability and accessibility of infrastructure, such as farm machinery centers, digital kiosks, and ICT tools, are fundamental for the adoption of digital agricultural practices. Timely access to quality inputs and reliable connectivity enhances farmers' capacity to implement digital solutions effectively, as suggested by Tambunan et al. (2024).

Farmers' adoption of digital agriculture is significantly influenced by knowledge of government policies, subsidies and digital schemes. (Degila et al., 2023) emphasize that awareness of initiatives like AgriStack and eNAM can motivate farmers to utilize government-supported digital platforms which in turn promote equitable access to digital agricultural services.

The below figure 33 elaborates on the research gaps from key literature and draws implications from them, which in turn have been incorporated into the analytical framework in section 5.2.

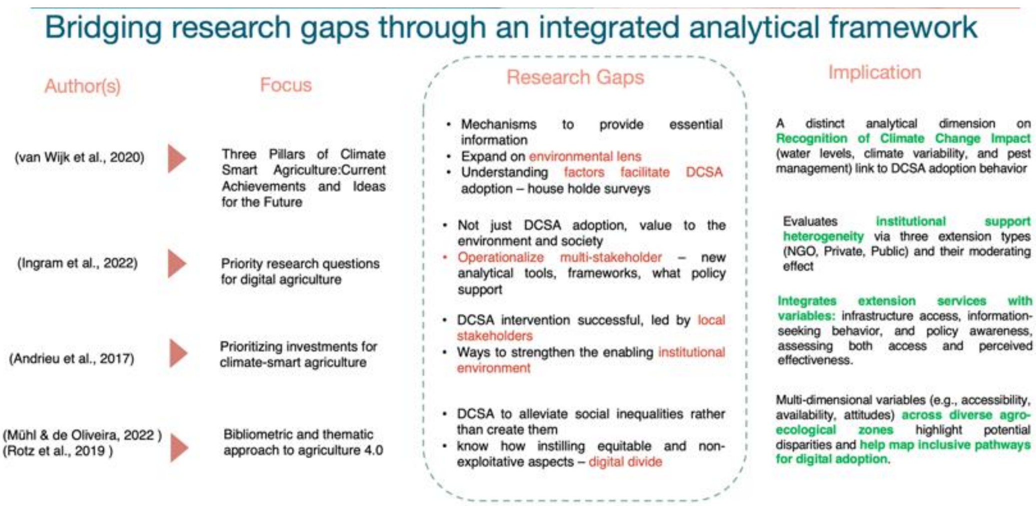


Figure 33: Bridging research gaps through an integrated analytical framework

5.2 Factors shaping farmers perception and institutional influences on DCSA adoption

To comprehend the factors that influence farmers' perception of the adoption of digitalization of climate-smart agricultural services (DCSA), a conceptual framework was developed to capture the dynamics of perceptual and institutional factors. The framework encompasses multi-dimensional variables that shape farmers' perception, ranging from their awareness of government schemes, awareness of DCSA practices and adoption, recognition of climate change impact, interaction with institutions, especially their contact and perception of extension agencies. In the model, we acknowledge the fact that the mere availability of DCSA services does not directly translate into adoption; rather, it is predominantly influenced by socio-cognitive factors such as trust, awareness, perceived usefulness, along with accessibility to infrastructure services. All these factors have been categorized and taken into account under the different latent constructs of our framework, offering a comprehensive lens to examine barriers and enablers toward DCSA adoption. We believe this is key to designing inclusive strategies that promote equitable dissemination of DCSA without deepening the digital divide and socio-economic inequality.

1. Farmers' Perception of Digital Agricultural Dissemination (DAD): This construct represents how farmers view, trust, and are willing to adopt DCSA.
   <u>Indicators:</u>

- Perceived usefulness of digital services
- Perceived reliability of digital information
- Willingness to adopt digital practices
- Perceived improvement in productivity

2. Extension Agency Contact (Institutional Support): This construct denotes the frequency, quality, and type of contact related to various extension agencies (NGOs, public, private).
<u>Indicators:</u>

- Frequency of contact with extension officers
- Trust in information from NGOs/public/private sources
- Usefulness of extension services
- Exposure to digital tools via extension agents

3. Agricultural Information Seeking Behavior: This construct is intended to capture farmers' proactive behavior in accessing and consuming agricultural knowledge, especially DCSA.
<u>Indicators:</u>

- Use of mobile apps, helplines, or websites
- Visits to demo farms or agri-kiosks
- Participation in training sessions
- Seeking advice from peers or local leaders

4. Awareness and Adoption of Digital Climate-Smart Agriculture (DCSA): This construct focuses on how much the farmer is familiar with DCSA practices and which are the DCSA tools and services he engages with.
Indicators:

- Awareness of specific DCSA tools (apps, platforms)
- Adoption of precision farming or digital irrigation tools
- Knowledge of climate-resilient digital practices
- Attitude towards digital transformation in agriculture

5. Recognition of Climate Change Impact: This construct represents how well farmers understand and perceive the effects of climate change and its impact.
Indicators:

- Perceived changes in rainfall, temperature, and pests
- Awareness of climate-induced risks to crops
- Knowledge of adaptive farming measures

6. Infrastructure Facilities: This construct denotes the availability and accessibility of various infrastructure services.
Indicators:

- Access to farm machinery centers or digital kiosks
- Availability of seeds/fertilizers on time
- Access to ICT tools and mobile connectivity

7. Awareness of Government Policies and Support: This construct captures how much farmers know about policies, schemes, and incentives in general and specifically related to DCSA.
Indicators:

- Awareness of government subsidies/incentives
- Knowledge of digital schemes (like AgriStack, eNAM)
- Use of government-supported digital platforms

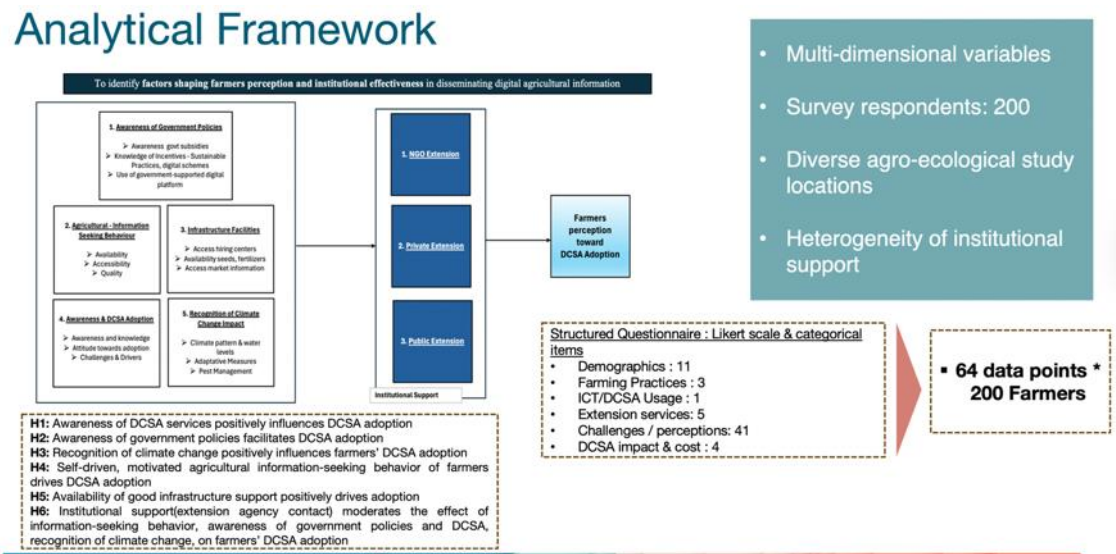


Figure 34: Framework for Understanding Farmers' Perception and Institutional Influences on advisory Adoption

5.3 Empirical analysis details

The multifaceted nature of digital agricultural engagement can be understood through a structured lens provided by the conceptual framework, outlining farmers' perceptions and institutional influences on DCSA adoption. However, contextual grounding in diverse agro-ecological and institutional settings is required to translate these dimensions into real-world insights. To this end, based on their distinct agricultural characteristics and varying patterns of information access, the study was conducted across four districts of Tamil Nadu i.e. in Thanjavur, Pudukottai, Kancheepuram, and Chengalpattu. These districts not only reflect a spectrum of climatic and farming conditions but also illustrate the heterogeneity in institutional support systems, including the roles of NGOs, public extension agencies, and private entities. The fieldwork, involving a survey of 200 farmers, is aimed to validate and enrich the conceptual framework, by examining how farmers across different zones perceive, access, and respond to digital climate-smart agricultural services in practice.

The empirical analysis in the study involve a structured and multi-stage approach using both descriptive and advanced statistical techniques to evaluate farmers' perception and adoption of Digital Climate-Smart Agriculture (DCSA) practices. A total of 64 variables are analyzed to identify the underlying factors, relationships, and structural patterns influencing adoption across varied agro-ecological zones and institutional setups.

Initially, the dataset is summarised and basic trends are understood through Descriptive Statistics. Mean, standard deviation, and communalities (which indicate the shared variance among variables) are the measures used to calculate and explore the distribution and central tendencies across the dataset. A baseline understanding of the behavior of different variables individually and in relation to one another is obtained through this foundational step.

Next, Principal Component Analysis (PCA) is utilized as a data reduction technique, the objective of which is to group interrelated variables into components. This step helps to simplify the dataset without significant loss of information and is particularly valuable in preparing the data for subsequent Exploratory Factor Analysis (EFA)**.** The aim is to identify latent constructs and reduce the dimensionality of the data. EFA is conducted using PCA with varimax rotation. The retention criteria rigorously applied are only the factors with eigenvalues greater than 1, loadings above 0.5, Kaiser-Meyer-Olkin (KMO) values above 0.6. Bartlett's test of sphericity with significance ($p < 0.05$) is considered valid.

After the confirmation of latent variables, Regression Analysis is performed to assess the impact of the extracted factors on DCSA adoption across four agro-ecological zones, region-wise. The regression models are location-specific. DCSA perception is the dependent variable and the latent factors from EFA are independent variables. The influence and significance of each factor in the respective zones are interpreted using metrics such as R^2, beta coefficients (β), and p-values.

The factor structures derived from EFA are validated through Confirmatory Factor Analysis (CFA), using the AMOS software. The adequacy of the model is assessed using Fit indices, with criteria including Comparative Fit Index (CFI) values above 0.90, Root Mean Square Error of Approximation (RMSEA) values below 0.08, and Chi-square/df ratios under 3. All these indicate a good model fit. The constructs identified earlier and statistically held across different sample groups, are ensured in this step.

The final level of analysis applies Structural Equation Modelling (SEM)**.** Hypothesized relationships are tested using SEM through path analysis. This includes both direct and indirect effects among the variables. Additionally, a multi-group SEM approach is employed to compare institutional differences (NGO, Private, and Public). A deeper understanding of how institutional contexts influence DCSA adoption is provided through this analysis. It also reveals structural disparities in the way, information, resources, and support systems are distributed among farmer groups.

Thus, in this study, SPSS is primarily used for conducting descriptive, PCA, EFA, and regression analysis, while AMOS is employed for CFA and SEM. An in-depth examination of the dataset is ensured through the integration of all these statistical techniques. This comprehensive empirical strategy makes the findings robust and adds meaning to the development of context-specific policy and intervention strategies.

This figure 35 below outlines the statistical techniques used in the study ranging from descriptive analysis to structural equation modeling along with their purposes, criteria, and corresponding software (SPSS and AMOS).

Analysis Type	Purpose	Details/Criteria	Software
Descriptive Statistics	Summarize data trends (64 variables)	Mean, Standard Deviation, Communalities(shared variance among variables)	SPSS
Exploratory Factor Analysis (EFA)	Identify latent constructs and reduce dimensionality	PCA with varimax rotationRetention: Eigenvalues >1, Factor Loadings >0.5, KMO >0.6, Bartlett's p<0.05	
Principal Component Analysis (PCA)	Data reduction and grouping of interrelated variables	Used to extract components before EFA	
Regression Analysis (by region)	Assess impact of variables on DCSA adoption in 4 agro-ecological zones	Location-wise models; DV: DCSA Perception; IVs: Extracted Factors; Metrics: R^2, β, p-values	
Confirmatory Factor Analysis (CFA)	Validate factor structure derived from EFA	Fit indices: CFI >0.90, RMSEA <0.08, Chi-square/df <3	AMOS
Structural Equation Modelling (SEM)	Test hypothesized relationships, assess direct and indirect effects (path analysis), SEM was applied institution-wise to detect structural differences between institutions	Path analysis, Multi-group SEM (NGO, Private, Public)	

Figure 35: Empirical analysis details

CHAPTER 6: ASSESSING FARMERS PERCEPTION AND INSTITUTIONAL EFFECTIVENESS

6.1 Introduction

The study was conducted across four districts of Tamil Nadu—Tiruvarur, Pudukottai, Kancheepuram, and Chengalpattu—selected for their distinct agricultural characteristics. Tiruvarur, located in the Cauvery Delta zone, ranks among the highest in rice production within the state, while Pudukottai falls within a water-stressed region. In contrast, Kancheepuram and Chengalpattu are categorized under the north-east monsoon high-risk agricultural zone. The selection of these districts also reflected differences in sources of agricultural information accessed by farmers. In Tiruvarur and Pudukottai, non-governmental organizations (NGOs) predominantly catered to the information needs of farmers, whereas public and private institutions played a relatively minor role. In Kancheepuram, farmers primarily relied on private and public institutions for agricultural information, while in Chengalpattu, public extension systems were the sole source. A total of 200 farmers, 50 from each district, were surveyed to understand the dynamics of agricultural information dissemination and access across these diverse agro-ecological and institutional landscapes.

6.2 Profile of the four districts

6.2.1 Pudukkottai

Pudukkottai District is situated in the heart of Tamil Nadu, approximately 365 kilometers from Chennai, covering an area of 1,949 square kilometers. Once a princely state, Pudukkottai boasts a rich cultural heritage, evident in its fortresses, temples, cave paintings, and numerous historical monuments. Many of its villages have ancient origins and are frequently mentioned in Tamil Sangam literature.

The district is blessed with abundant natural resources, both on land and along its eastern coastline, where it is bordered by the Bay of Bengal. It shares boundaries with the districts of Trichy, Sivaganga, Ramanathapuram, and Thanjavur.

Remnants of ancient Tamil kings—such as fortresses, canals, and water tanks—remain significant attractions. Notable landmarks include the temple at Avudayarkoil, the rock-cut shrine at Kudumiyanmalai, and the famous cave paintings of Sittanavasal. Religious harmony is reflected in the presence of diverse places of worship: Kattubhava Pallivasal (a revered Muslim site), the Christian monument at Avur, and Jain temples in Annavasal. Tourism highlights also include the peacock sanctuary at Viralimalai, scenic cave temples, and hilltop shrines, making Pudukkottai a captivating destination for history and nature enthusiasts alike.

Geographical Location:

Pudukkottai district was formed in January 1974 by bifurcating areas from Tiruchirappalli and Thanjavur districts. Covering an area of 4,663 square kilometers, it includes a coastline stretching 42.8 kilometers. Geographically, it is situated between 78.25° and 79.15° Eastern Longitude, and 9.50° and 10.40° Northern Latitude. The district is bordered by Tiruchirappalli to the north and west, Sivaganga to the south, the Bay of Bengal to the east, and Thanjavur to the northeast.

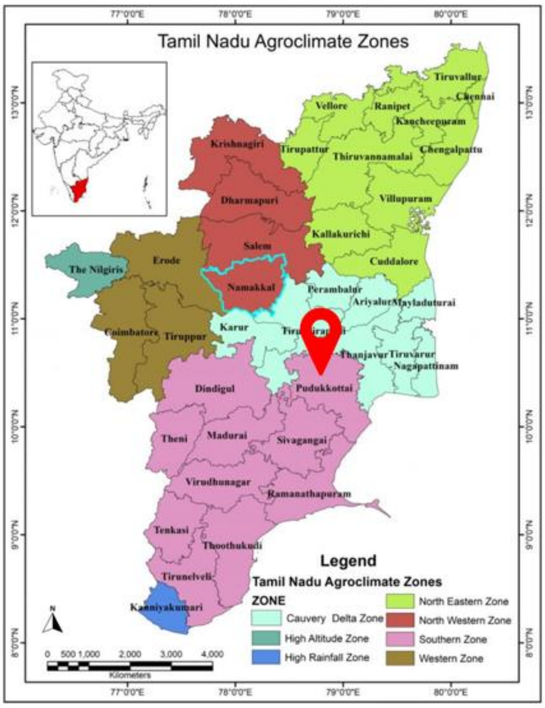


Figure 36: Pudukottai location

Topography:

The history of Pudukkottai serves as a reflection of the broader history of South India. In and around this region, one can find numerous traces of ancient human settlements, along with some of the earliest known lithic inscriptions in the South. Over the centuries, dynasties such as the Pandyas, Cholas, Pallavas, Hoysalas, Vijayanagar rulers, and Madurai Nayaks governed this area. They nurtured its communal institutions, promoted trade and industry, and adorned the land with remarkable temples and monuments.

Administrative set-up:

District Head Quarters	:	Pudukkottai
No. of Revenue Division	:	3 (Pudukkottai, Aranthangi, Illuppur)
No. of Taluks	:	12

Table 18: Pudukottai Administrative setup

Sl.No.	Revenue Division	Taluk	No. of villages
1.	**Pudukkottai**	Alangudi	73
		Gandarvakottai	37
		Pudukkottai	40
		Thirumayam	81
		Karambakudi	50
2.	**Aranthangi**	Aranthangi	105
		Avudaiyarkoil	96
		Manamelkudi	72
3.	**Illuppur**	Illuppur	58
		Kulathur	65
		Ponnamaravathi	49
		Viralimalai	37

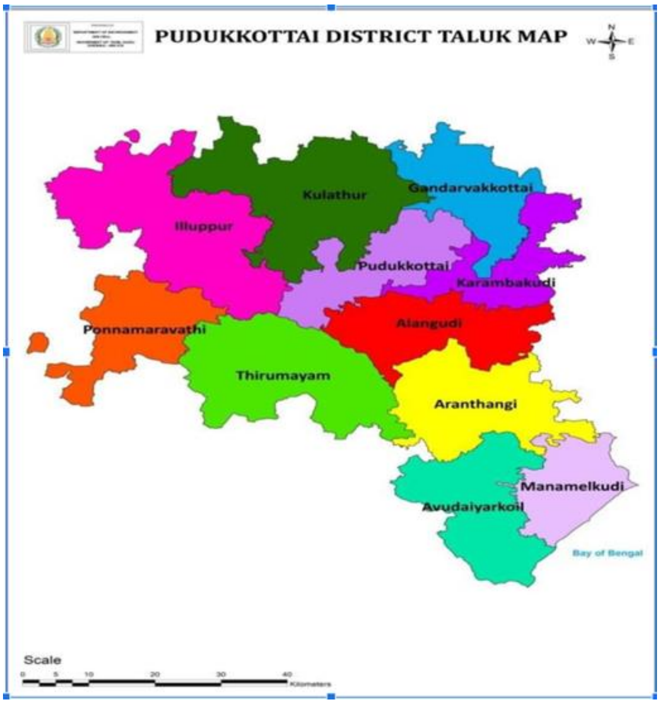


Figure 37: Pudukottai district taluk Map

Land Resources:

The total geographical area of Pudukkottai district is 4,663 square kilometers. The dominant soil type found here is red loam. However, nearly one-fourth of the region is affected by salinity or alkalinity. The table below outlines the district's land distribution:

Table 19: Pudukottai land resources

Land	**Area in ha**
Wet	1,03,418
Dry	1,84,057
Forest	24,010
Barren & uncultivable	9,807
Land Used for Non Agriculture Purpose	1,25,672

Cultivable Waste	14,677
Pasture Lands	5,484
Trees and Tope	6,546

Agriculture and Horticulture:

Agriculture serves as the primary livelihood for the majority of the population. However, the dominance of dryland farming makes it highly vulnerable to frequent monsoon failures, which significantly hampers agricultural output. Between 1980–81 and 1995–96, cereal cultivation and production experienced noticeable fluctuations. The peak area under cereal cultivation was recorded in 1985–86, covering 127,174 hectares, while the highest production, at 314,560 tonnes, occurred in 1993–94. The maximum yield, reaching 3,030 kg per hectare, was achieved in 1994–95. For pulses, the greatest area coverage, production, and yield per hectare were all recorded in 1985–86. However, during the following decade, these figures declined and varied inconsistently.

Picture 7: Community labor and dry-season resilience.

The important crops cultivated are as follows:

Table 20: Pudukottai Crops grown

Category	Common name
Cereals	Rice Cholam Varagu Ragi Maize Cumbu
Pulses	Red gram Cowpea Horse gram Black gram Green gram
Oil seeds	Ground nut Coconut Gingelly Soya bean
Condiments	Chillies Tamarind
Sugars	Sugarcane Palmyra
Fibres	Cotton

6.2.2 Thanjavur

Geographical location of the district:

Thanjavur district is situated between 9°50’ and 11°25’ north latitude, and 78°45’ and 79°25’ east longitude. It is bordered by Thiruchirapalli and Cuddalore districts to the north, Thiruvarur and Nagapattinam districts to the east, the Palk Strait and Pudukottai district to the south, and Pudukottai and Thiruchirapalli districts to the west. Covering a total area of 3,602.86 square kilometers, the district accounts for approximately 2.77% of the total area of the state.

Figure 38: Thanjavur location

Administrative profile of the district is given in the table below:

Figure 39: Thanjavur District Taluk Map

Table 21: Thanjavur Administrative setup

Number of taluks	8
Number of revenue villages	906
Taluk	Revenue villages
Kumbakonam	124
Orathanadu	125
Papanasam	120
Pattukkottai	175
Peravurani	91
Thanjavur	93
Thiruvaiyaru	89
Thiruvidaimarudur	89

Agriculture and horticulture:

Thanjavur district has long held a distinguished reputation for its rich agricultural heritage and is aptly known as the "Granary of South India." Nestled in the delta region of the renowned Cauvery River, the district is interlaced with an extensive network of irrigation canals. This coastal area is lush with vibrant green paddy fields, tall coconut palms, sprawling mango and plantain orchards, and other verdant vegetation.

Geographically, Thanjavur is primarily a deltaic plain consisting of both old and new delta regions. The old delta is nourished by the canals and channels of the Cauvery and Vennar rivers, while the upper part of the new delta is irrigated through the Grand Anaicut canal. Groundwater is also extensively utilized to initiate the early cropping season and avoid losses due to the North-East monsoon, allowing for the cultivation of two main crops—Kuruvai and Thaladi.

The fertile soils of the new delta region support a diverse range of crops, including coconut, mango, guava, pulses, cotton, gingelly (sesame), groundnut, and banana. Oil palm and soybean are also cultivated in areas with reliable irrigation and drainage systems.

Picture 8: Farmer in lush Cauvery delta (water abundance)

The major crops grown in Thanjavur include paddy, pulses, gingelly, groundnut, and sugarcane. Minor crops such as maize, soybean, and red gram are typically cultivated in rice fallows. Groundnut serves as a key crop in the new delta area. Paddy is the dominant crop, grown across three seasons: Kuruvai, Samba, and Thaladi. Additionally, pulses like black gram and green gram, along with cash crops such as cotton and gingelly, are commonly grown. Sugarcane is cultivated in both the old and new delta regions, while banana is mainly grown in the Padugai lands.

Table 22: Thanjavur land resources and crop

A. Total Cultivated area (ha)	**2,41,292**	
B.Net area sown (ha)	**1,92,030**	
C. Area sown more than once (ha)	**49,262**	
D. Area & Production of Principal crops	**Area in ha**	**Production in Tonnes**

Rice	155	703
Millets & other cereals	Nil	Nil
Pulses	16	6
Sugarcane (In terms of cane)	15	1502
Groundnut	7	23
Gingelly	6	2
Cotton (bales 170 kg. Lint each)	1	1
E. Agricultural Land Holdings (2000-01)		
i. Holdings	291264	
ii. Area & average size of holdings (ha)	227674 & 0.78	
F.a) Important food crops	paddy, sugarcane, green gram, black gram & banana	
b) Important non-food crops	groundnut, coconut & gingelly.	

6.2.3 Kanchipuram:

Geographical location of the district

Kanchipuram district is located on the northeastern coast of Tamil Nadu. It is bordered to the west by Vellore and Thiruvannamalai districts, to the north by Tiruvallur and Chennai districts, to the south by Villuppuram district, and to the east by the Bay of Bengal. Geographically, it lies between 11°00' to 12°00' North latitude and 77°28' to 78°50' East longitude. Covering a total area of 4,393.37 square kilometers, the district also boasts a 57-kilometer-long coastline. The district headquarters is the historic temple town of Kanchipuram.

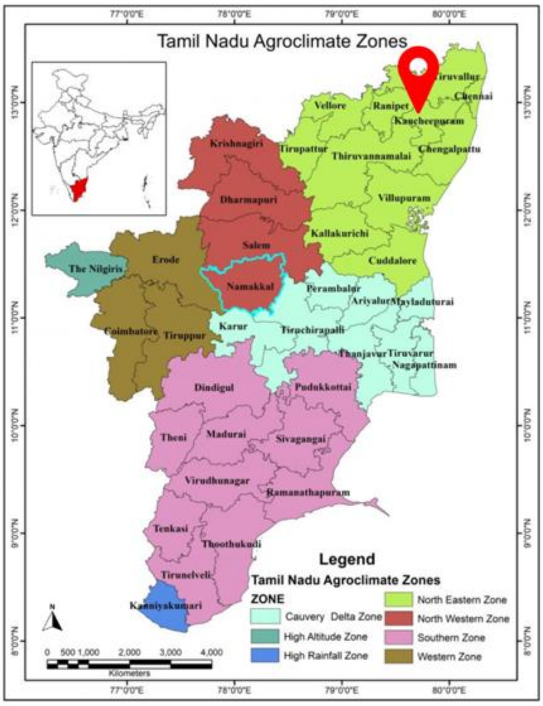


Figure 40: Kanchipuram location

Administrative profile

For administrative purposes, the district is divided into four revenue divisions, encompassing 11 taluks and 1,137 revenue villages. For developmental purposes, it is organized into 13 development blocks, which include 648 village panchayats.

Figure 41: Kanchipuram District Taluk Map

Agriculture and horticulture:

Agriculture serves as the primary occupation for 47% of the district's population. Paddy stands out as the principal crop grown in the region, while other significant crops include groundnuts, sugarcane, various cereals and millets, as well as pulses. Irrigation in the district mainly depends on the Palar River, along with tanks and wells.

Picture 9: Farmer walking with seedlings along bund-lined paddy, temple-tank irrigation and cultural ties.

Following table shows the details of agriculture in the district:

Table 23: Kanchipuram land resources and crop

Classification	**Area in ha**
Total Cropped Area	1,98,543
Net Area Sown	1,60,090
Area sown more than once	38,453
Area Under Principal Crops	
Rice	1,45,966
Millets and Cereals	1,217
Pulses	2,966

Sugarcane	7,586
Groundnut	28,766
Gingelly	912
Cotton	53

6.2.4 Chengalpattu

Geography

Chengalpattu district is located along the northeastern coast of Tamil Nadu, covering a total area of 2,945 square kilometers. It is bordered by Chennai district to the north, Kancheepuram and Thiruvannamalai districts to the west, and Viluppuram district to the south. To the east, the district has a 57-kilometer-long coastline along the Bay of Bengal.

The district experiences a tropical wet and dry climate. Its proximity to both the thermal equator and the coast helps moderate seasonal temperature extremes. January is typically the coolest month, with an average temperature of around 25°C. Chengalpattu receives an average annual rainfall of approximately 1,400 mm, the majority of which occurs during the northeast monsoon in October and November.

One of the major rivers of Tamil Nadu, the Palar, flows through Chengalpattu for about 54 kilometers. It enters the district at Palur village and empties into the Bay of Bengal between Vayalur and Kadalur villages. The Adyar River forms the district's northern boundary, while the Ongur River lies to the south. Other smaller rivers flowing through the district include Neenjal Maduvu, Pukkadurai Odai, and Kiliyar. The district also supports extensive irrigation, with 528 major irrigation tanks, each irrigating an area of more than 100 acres (or 40 hectares).

Agriculture:

Agriculture is the primary occupation for most residents of this district. Despite its proximity to Chennai, farming remains an essential livelihood for the local population. Rice is the dominant crop cultivated across the district, with Madurantakam, Cheyyur, and Thirukkazhukkundram taluks being the leading producers. Sugarcane is also grown in certain areas, and the Tamil Nadu Government operates a cooperative sugar mill in Padalam village, located in Madurantakam taluk. Groundnuts are widely cultivated in regions facing water scarcity or low rainfall. Cheyyur and Thirupporur taluks are known for cultivating cash crops such as groundnuts, urad dal, moong dal, karamani, sesame, and others. Vegetables like brinjal and okra are also grown in the Thirupporur, Thirukkazhukkundram, and Madurantakam regions. Watermelons are typically cultivated in Kodur, Cheyyur, and neighboring areas during the summer season. Additionally, Karunguzhi is known for its production of betel leaves.

Picture 10: Coastal district and proximity to urban markets.

6.3 Distribution and Socio demographic characteristics of the farmer survey participants

Figure 42 shows distribution of the survey respondents across the 4 districts in the state of Tamil Nadu namely Tiruvarur, Pudukottai, Kancheepuram, and Chengalpattu. The significance of the research locations is that Tiruvarur falls under the Cauvery delta zone ranking one of the highest in rice production, while Pudukottai falls under water stressed zone, Kancheepuram and Chengalpattu falls under north-east monsoon high-risk agriculture. Another categorization was that NGO was catering predominantly to the agricultural information needs of the farmers in Tiruvarur and Pudukottai while they also received from Public and private institutions insignificantly. Survey respondents from Kancheepuram had predominantly accessed the private and public institutions, while respondents from Chengalpattu relied completely on public extension systems for their agricultural information. Although the initial plan was to survey 50 respondents from each of the four selected districts, aiming for a total sample size of 200, only 182 valid responses were obtained after data consolidation and quality checks. These 182 datasets were subsequently used for statistical analysis in the study.

INSTITUTIONS	NGO		PRIVATE	PUBLIC
DCSA Adoption rate	High	Medium	Low	Low
DISTRICT	Tanjore	Pudukottai	Kancheepuram	Chengalpattu
Agro - Climatic Zone	Cauvery Delta Zone	Southern zone, water-stressed	North-East Monsoon, tank irrigation	North-east Monsoon, high-risk agriculture
SURVEY VILLAGES	1. Vilangudi 2. Thirppazhanm 3. Punalvasal	1. Onankudi 2. Thirumalairayasamuthiram 3. Melappatti	1. Venkatesapuram 2. Thenpakkam 3. Sirukaranai	1. Kollammedu 2. Pin Padhar Kootam 3. Pon Vilaintha Kalathur
SAMPLE SIZE (Farmers)	50	50	50	50

Figure 42: Distribution of survey respondents across 4 districts in Tamil Nadu (n=200).

The questionnaire presented in appendix B gathers information from farmers to understand their demographics, agricultural practices, and challenges related to climate-smart agriculture (CSA). It collects details about gender, age, marital status, education, occupation, income, and landholding patterns. It also explores farming experience, water management strategies, and adaptation measures for changing weather conditions. The survey assesses farmers' access to ICT tools like smartphones, internet, and laptops, as well as their use of digital platforms for farming information. It evaluates access to agricultural extension services, the frequency of interaction, and sources of climate-related data.

The form identifies key challenges faced in adopting digital CSA practices, such as literacy barriers, network issues, and a lack of training. It seeks farmers' opinions on various aspects of digital tools, including ease of use, reliability, availability of data, and support from extension agencies. Farmers were asked to express their perceptions regarding the usefulness of these tools for crop management, weather forecasts, market access, and government schemes. It also examines awareness of government policies and subsidies provided through digital means. Finally, the questionnaire measures the impact of farming apps on efficiency and losses, costs related to apps, and other financial considerations like internet and training expenses.

The frequencies of the demographic variables are presented in detail as below in table 24.

Table 24: Frequencies of demographic variable

Socio-demographic factors and Personal Variables	Pudukkottai		Thanjavur		Kanchipuram		Chengalpattu		Total	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Gender										
Male	34	66.7	46	88.5	21	72.4	44	88.0	145	79.7
Female	17	33.3	06	11.5	08	27.6	06	12.0	37	20.3
Total	51	100	52	100	29	100	50	100	182	100
Age										
Less than 18	00	00	03	5.8	00	0	00	0	03	1.6
18-28	02	3.9	04	7.7	01	3.4	02	4.0	09	4.9
29-38	09	17.6	06	11.5	09	31.0	10	20.0	34	18.7
Above 38	40	78.4	39	75.0	19	65.5	38	76.0	136	74.7
Total	51	100	52	100	29	100	50	100	182	100
Marital status										
Married	48	94.1	45	86.5	28	96.6	48	96.0	169	92.9
Unmarried	03	5.9	07	13.5	01	3.4	02	4.0	13	7.1
Total	51	100	52	100	29	100	50	100	182	100
Education										
Illiterate	12	23.5	02	3.8	00	0	05	10.0	19	10.4
School level	30	58.8	36	69.2	29	100	40	80.0	135	74.2
UG	03	5.9	10	19.2	00	0	05	10.0	18	9.9
PG	03	5.9	03	5.8	00	0	00	0	06	3.3
Agriculture Education	03	5.9	01	1.9	00	0	00	0	04	2.2
Total	51	100	52	100	29	100	50	100	182	100
Occupation										
Farming only	26	51.0	40	76.9	22	75.9	40	80.0	128	70.3
Farming Business	20	39.2	12	23.1	06	20.7	08	16.0	46	25.3
Farming Entrepreneur	02	3.9	00	0	00	0	02	4.0	04	2.2
Farming House Keeping	01	2.0	00	0	01	3.4	00	0	02	1.1
Farming NGO	02	3.9	00	0	00	0	00	0	02	1.1
Total	51	100	52	100	29	100	50	100	182	100
Monthly Income										
Less than 15000	45	88.2	33	63.5	09	31.0	35	70.0	122	67.0
15001 to 25000	03	5.9	11	21.2	20	69.0	12	24.0	46	25.3
25001 to 30000	02	3.9	04	7.7	00	0	03	6.0	09	4.9
More than 30000	01	2.0	04	7.7	00	0	00	0	05	2.7
Total	51	100	52	100	29	100	50	100	182	100

Family members										
Less than 3	08	15.7	14	26.9	01	3.4	02	4.0		
4 to 6	32	62.7	37	71.2	27	93.1	46	92.0		
Above 6	11	21.6	01	1.9	01	3.4	02	4.0		
Total										
Location										
Rural	51	100	49	94.2	06	20.7	48	96.0	154	84.6
Urban	00	0	02	3.8	23	79.3	00	0	25	13.7
Semi-Urban	00	0	01	1.9	00	0	02	4.0	03	1.6
Total	51	100	52	100	29	100	50	100	182	100
Landholding										
Own	47	92.2	45	86.5	27	93.1	08	16.0	127	69.8
Rented	03	5.9	01	1.9	02	6.9	35	70.0	41	22.5
Leased	01	2.0	06	11.5	00	0	07	14.0	14	7.7
Total	51	100	52	100	29	100	50	100	182	100
Acres of land										
Below 1 acre	31	60.8	33	63.5	04	13.8	38	76.0	106	58.2
1 -2 acres	12	23.5	09	17.3	15	51.7	07	14.0	43	23.6
2 – 4 acres	04	7.8	06	11.5	06	20.7	02	4.0	18	9.9
4 – 10 acres	03	5.9	03	5.8	04	13.8	03	6.0	13	7.1
Above 10 acres	01	2.0	01	1.9	00	0	00	0	02	1.1
Total	51	100	52	100	29	100	50	100	182	100
Land used for Agriculture										
Below 1 acre	26	51.0	31	59.6	04	13.8	38	76.0	99	54.4
1 -2 acres	12	23.5	10	19.2	15	51.7	07	14.0	44	24.2
2 – 4 acres	10	19.6	05	9.6	06	20.7	02	4.0	23	12.6
4 – 10 acres	01	2.0	06	11.5	04	13.8	03	6.0	14	7.7
Above 10 acres	02	3.9	00	0	00	0	00	0	02	1.1
Total	51	100	52	100	29	100	50	100	182	100
Experience in Farming										
Less than 1 year	03	5.9	5	9.6	00	0	00	0	08	4.4
1 to 5 years	08	15.7	6	11.5	02	6.9	00	0	16	8.8
5 to 10 years	04	7.8	6	11.5	08	27.6	00	0	18	9.9
Above 10 years	36	70.6	35	67.3	19	65.5	50	100	140	76.9
Total	51	100	52	100	29	100	50	100	182	100

The figure 43 below presents the sociodemographic and farm characteristics of the survey respondents in 4 survey locations in terms of gender, age, occupation, income, education, landholding, land used in agriculture, and experience in farming.

Figure 43: Sociodemographic and farm characteristics of the selected sample across four districts (research locations) in Tamil Nadu

6.4 Barriers that hinder farmers' DCSA adoption

Figure 44 illustrates the results of the Friedman test rank analysis concerning the various barriers encountered in accessing DCSA. Respondents in Pudukkottai faced network problems as a significant barrier, while those in Tiruvarur identified information shared through sources at odd hours as the main obstacle. In Kancheepuram, respondents are hindered by illiteracy and a lack of technical knowledge regarding DCSA, along with poor public relations from agricultural extension workers among other barriers. Respondents in Chengalpattu are affected by multiple factors in terms of DCSA adoption, such as poor public relations from agricultural extension workers, illiteracy, network issues, and language barriers. This indicates a gap between the extension system and farmer respondents, especially in the Chengalpattu district.

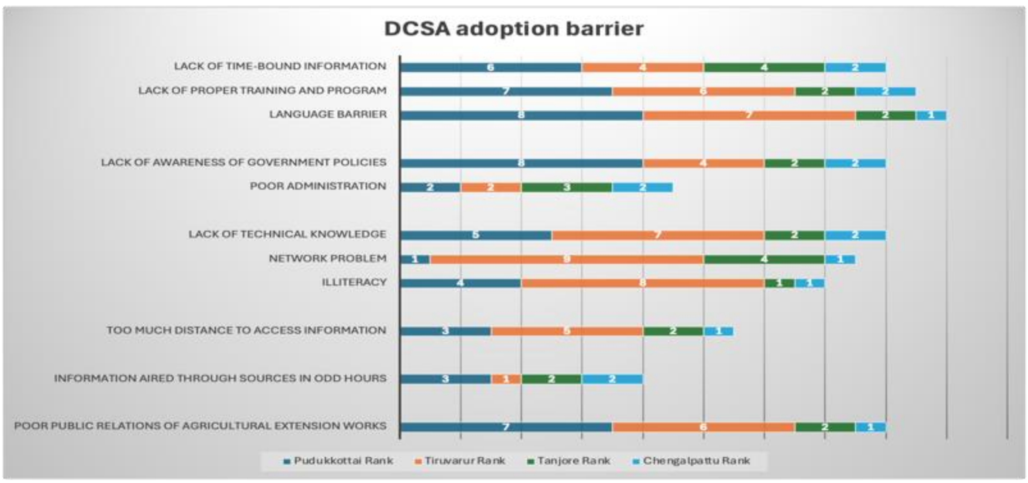


Figure 44: Barriers in accessing DCSA across four districts (research locations) in Tamil Nadu

6.5 Factors influencing farmers DCSA adoption

Table 25 exhibits the summarised dataset to provide insights into mean, standard deviation, and communalities. Mean value indicates the average rating for each of the factors. Higher mean value indicates a greater consensus among respondents. The mean values indicate the general agreement or perceived importance of specific factors by farmers. The highest mean (4.69) corresponds to the perception of climate variability (rainfall, temperature, pests), showing strong farmer awareness and agreement with ongoing climate changes. Similarly, high mean values for the use of mobile apps (4.40) and knowledge of climate-resilient digital practices (4.35) indicate a strong inclination toward using digital tools and receiving localized information through proactive outreach. These factors emphasize the usability and relevance of digital platforms in delivering agricultural support.

Standard deviation measures the variability in responses. High standard deviation values (e.g., 1.293 for awareness of specific DCSA tools) suggest differing perceptions among farmers. This variation likely arises from disparities in access to extension services, digital literacy, or infrastructure. Similarly, the standard deviation for government subsidies (1.037) and field workshops (1.092) point to inconsistent outreach or accessibility, highlighting that while some farmers find them useful, others may face barriers in benefitting from these initiatives.

Table 25: Results of descriptive analysis to evaluate the potential factors influencing farmers' DCSA adoption.

Item Name	Item Description	Mean	Standard Deviation	Communalities
ADA1	Conduct workshops and field demonstrations to educate farmers	4.04	1.092	.760
ADA2	Promote awareness among farmers through extension channels.	4.09	.941	.818
ADA3	Limited access to internet services in rural areas.	3.55	1.293	.731
ADA4	Credible information enhances farmers' trust	3.96	1.084	.758
ADA5	Farmers struggle to use smartphones due to low levels of literacy	4.35	.916	.785
AISB1	The interface is user-friendly and allows access to information with a single click.	4.40	.713	.601
AISB2	Farming activities are clearly mentioned	4.13	.642	.449
AISB3	The provided information is trustworthy.	4.34	.717	.596
AISB4	The delivery of the information is clear and straightforward	4.12	.800	.626
AISB5	The information was given in easy read format	4.32	.835	.633
AISB6	Reliable and precise information is provided	4.12	.779	.556
RCCI1	Farmers receive region-specific data based on seven agro-climatic zones.	4.69	.646	.632
RCCI2	Reservoir levels are provided for irrigation planning.	4.08	.557	.643
RCCI3	It offers alerts and advice for safeguarding crops.	4.28	.784	.622
RCCI4	Remember to maintain soil health through crop rotation and cover cropping to enhance soil fertility.	4.07	.675	.546
RCCI5	Manage pests in an environmentally friendly way.	4.16	.783	.639
IF1	Farmers know the facilities of hiring centers at economical rates	4.15	.764	.600
IF2	It provides the availability of seeds and fertilizers near location	4.20	.813	.627
IF3	It helps farmers access the crops' daily market prices to facilitate product sales	4.08	.802	.716
IF4	Farmers check the crop insurance and updates for receiving compensation	4.19	.822	.663
IF5	It ensures and tracks the extension officers visit farmers to plan and prepare for interaction	4.07	.847	.578
AGP1	The various subsidy schemes are available for farmers to help them avoid unavoidable financial burdens.	3.59	1.037	.513
AGP2	It provides a crop calendar and farmer tips based on soil and climate conditions	3.85	1.159	.510
AGP3	Daily weather forecast and advice given to the farmers to plan for cultivation	3.80	.899	.792
AGP4	The farmers receive the solution for pest infection and manage all farmers' challenges	3.82	.902	.637
AGP5	The information for the availability of seeds and fertilizer near government and private outlets	3.78	.946	.700
EAC1	The extension agency interacts with the farmers regularly	3.94	.935	.740
EAC2	The quality of the interaction with the extension officers	3.87	.937	.848
EAC3	The officers are available to assist with addressing any queries.	3.90	.955	.756
EAC4	The agency provides timely information to the farmers	3.81	.926	.723
EAC5	It provides invaluable advice and unwavering support to farmers for their agricultural endeavours.	3.83	.969	.694
FP1	The registration process is very simple	3.87	1.017	.764
FP2	It gives updates on the Market price	3.83	.934	.721
FP3	It helps me to be prepared for weather changes.	3.95	.933	.704
FP4	It helps me to get updated information on Subsidies and government schemes	3.91	.886	.723
FP5	The app provides all access in the Tamil language making it easy to use	3.94	.935	.802
FP6	It enables access to the contact information of registered farm practitioners	3.81	.893	.752
FP7	The data provided are Up-to-date	3.94	.923	.744
FP8	It is compatible with configuration mobile phones and also	3.77	1.017	.720
FP9	It helps me to identify the location of the Seeds' availability, fertilizer shops, and stock level.	3.81	.972	.738

This is based on own calculation; ADA = awareness and DCSA Adoption, AISB = agricultural information-seeking behavior, RCCI = recognition of climate change impact, IF = infrastructure facilities, AGP = Awareness of government policies, EAC = extension agency contact, FP = farmers perception.

Communality values reflect how well a factor is explained by the underlying dimensions of the analysis. High communalities are for interaction with extension officers (0.848), promotion through channels (0.818), and language accessibility (0.802). This shows that these are core factors that significantly shape farmer experience and usability. The strong representation of language and communication in the factor structure stresses the importance of culturally relevant and accessible content.

These indicate what farmers most strongly agree with as seen in table 26:

Table 26: Based on Mean Scores (Top 3 Highest Means)

Factor	Mean	Interpretation
Perceived changes in rainfall, temperature, pests	4.69	Farmers highly agree with climate variability, intergenerational knowledge & comparison.
Use of mobile apps, helplines, or websites	4.40	Widespread mobile penetration, effective helplines is a top usability factor for farmers.
Knowledge of climate-resilient digital practices	4.35	availability of localized and reliable information, and proactive outreach by extension services.

These reflect the most varied or polarized responses as seen in table 27:

Table 27: Based on Standard Deviation (Top 3 Highest SDs)

Factor	SD	Interpretation
Awareness of specific DCSA tools	1.293	Farmers' views differ widely due to differences in extension support & outreach, digital illiteracy or socioeconomic/infrastructure disparities.
Awareness of government subsidies/incentives	1.037	Perception of subsidy availability varies significantly, indicating either inconsistent delivery or awareness gaps.
Conduct workshops and field demonstrations to educate farmers	1.092	Some farmers highly value workshops, while others may have limited access or differing opinions on their effectiveness.

Communalities show how well each variable is explained by the factor model as seen in table 28:

Table 28: Highest Communalities (well-represented in factor model)

Factor	Communality	Interpretation
The quality of the interaction with the extension officers	0.848	This item is very well captured by the underlying factor structure, indicating its central role in shaping farmer experience.
Promote awareness among farmers through extension channels	0.818	Communication through extension services is a critical latent factor in the dataset.
The app provides all access in the Tamil language making it easy to use	0.802	Language accessibility is not only valued but is also statistically central to usability themes.

6.6 Adaptation Measures – Custom Table Analysis

The interview results regarding measures taken by each of farmers in districts respectively regarding adaptation to changes in rainfall patterns are summarized as below in a custom table analysis format as seen in table 29. Custom tables help to analyze the data more deeply and create a report that integrates the data into more perfect conclusions.

Table 29: Adaptation measures

Districts	**Pudukkottai**	**Thanjavur**	**Kanchipuram**	**Chengalpattu**
Measures taken to adapt to changes in rainfall patterns:				
Changing Planned Dates	13	36	14	14
Using Drought Resistant Varieties	33	14	11	0
Implemented Water Saving Techniques	5	2	4	36
Manage water supply for Rice cultivation (dry Season)				
Irrigation System	6	35	14	0
Rain Water Harvesting	13	11	10	48
Using drought Resistant Varieties	22	5	5	0

Implementing Soil Moisture Techniques -Mulching	9	1	0	2
Borewell	1	0	0	0

The data suggests that the key strategies are Drought Resistant Varieties and Rain Water Harvesting, adapting to changes in rainfall patterns and managing water supply during dry seasons. Changing Planned Dates and Implementing Soil Moisture Techniques (Mulching) are also significant, often supporting other primary measures. Irrigation Systems and Borewell are less frequently used but are still critical in specific contexts. It concludes that focusing on these interconnected measures; it is possible to develop a comprehensive and resilient strategy for agricultural adaptation and water management.

6.7 Farmers' perception about extension service

The below table 30 examines the usage of agricultural mobile applications and importantly the accessibility of extension services across four districts in Tamil Nadu—Pudukkottai, Thanjavur, Kanchipuram, and Chengalpattu. Farmers in these regions rely on a combination of digital tools such as the Uzhavan app, M-Krishi, MSSRF services, WhatsApp groups, and Plantix to access agricultural advisories. The extent to which these tools are used varies across districts, with Thanjavur showing the highest adoption (45 users) and Chengalpattu the lowest (11 users). The analysis highlights how farmers receive seasonal forecast data, interact with different sources of information—such as NGOs, private agencies, government services, and electronic media—and maintain communication with extension agencies. Notably, Thanjavur and Pudukkottai report frequent interactions with extension agencies, whereas Chengalpattu shows relatively limited engagement despite high access to government-provided services. The data provides insights into the digital divide and varying reliance on formal and informal information networks in agricultural practices.

Table 30: Farmer's usage of app and Extension Services

District	Use App	Name of the app	Access extension Services	Provide extension service	Receive forecast data of rainy season	Sources of information	Interact with extension agency
Pudukkottai	24	MSSRF services	49	NGO – 25 Private – 18 Government- 6	49	NGO – 14 Private – 17 Government- 14 Electronic Media- 4	Frequently – 22
Thanjavur	45	Uzhavan app, MSSRF services, Watsapp group, Plantix	43	NGO – 21 Private – 14 Government- 8	52	NGO – 16 Private – 10 Government- 13 Electronic Media- 4 Lead farmer- 6	Frequently – 21

Kanchipuram	28	M-Krishi, Uzhavan app	29	NGO – 8 Private – 18 Government- 3	29	NGO – 4 Private – 10 Government-9 Electronic Media- 4 Lead & peer farmer- 2	Frequently – 16
Chengalpattu	11	Uzhavan app, MSSRF services	50	Private – 5 Government- 45	10	Private – 5 Government-6 Electronic Media- 34 Lead & peer farmer- 4	Frequently – 3

The data shows that the farmers in Thanjavur and Pudukottai have the highest usage of the farmers' app in their sample size. The farmers commonly used apps such as uzhavan, MSSRF services, whatsapp group and plantix. The extension services are accessed most by Chengalpattu farmers in the sample size, followed by Pudukkottai and Thanjavur Farmers. The extension services are mainly provided by NGOs, private entities and Government. The forecasted rainfall data is received by Thanjavur Farmers in their sample data, followed by Pudukkottai farmers. The forecasted rainfall data is the information received from NGOs, private entities, Government as well as electronic media and peer farmers. The extension agency interacts with the farmers most frequently in Pudukkottai and Thanjavur. Capacity building toward improving farmers digital literacy and provisioning with accessible extension services are key for ensuring farmers have timely access to information. This, in turn, can help improve their farming practices and outcomes, particularly through the effective use of farmer-focused mobile applications.

The bar chart above on adoption at 4 different study area presents the regional variation in the adoption. Thanjavur and Pudukkottai districts had notably higher adoption levels compared to Kanchipuram and Chengalpattu districts. This increased adoption was due to the success of a community-driven bottom-up approach of extension model that was implemented in these areas. In these areas particularly local women championed as change agents and actively contributed to implementing the advisory services with farmers. The model resulted in building trust within the community villagers, which led to greater participation and better adoption of services.

The key factor attributed to the success was the establishment of an institutional building called the village-level knowledge centres, which was provision to offer regular capacity building training programs and also ensured infrastructure availability including computers and internet access so that farmers could access digital resources even without owning a personal device. Also, the digital information was contextualized to local conditions and supplemented with non-digital, easy-to-read materials, making it inclusive and accessible to all community members. This comprehensive approach enabled more equitable and inclusive access to advisory services, particularly in regions like Thanjavur, where adoption was highest.

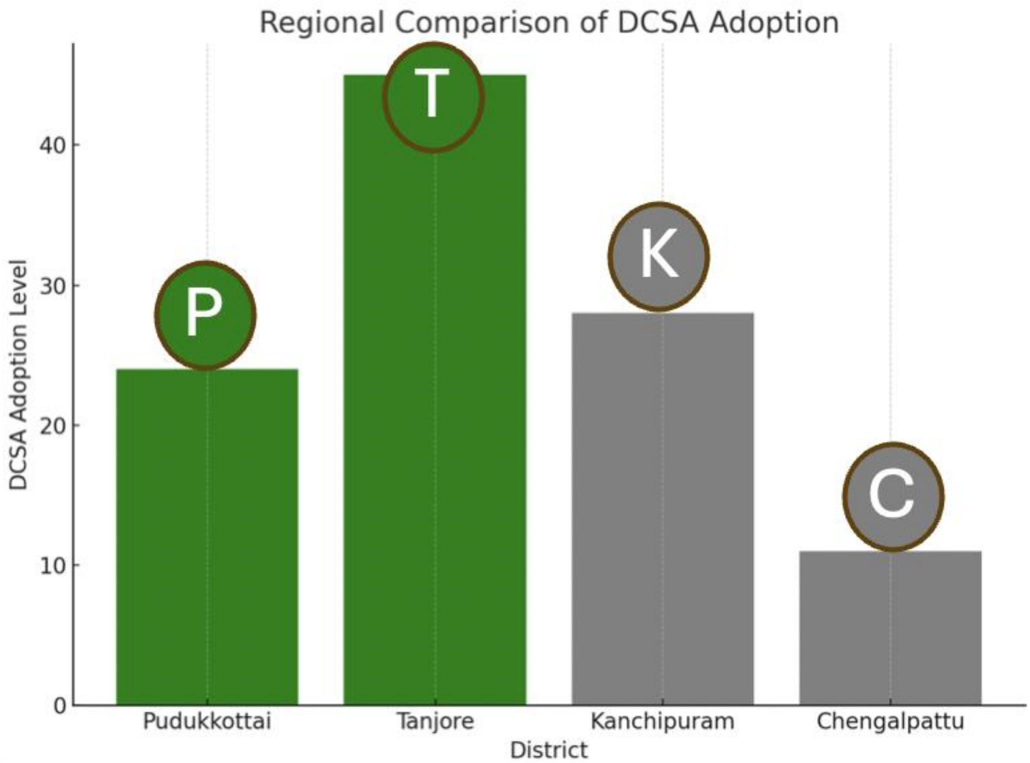


Figure 45: Regional comparison of Adoption status

The below chart reveals a clear relationship between gender balance and adoption. Districts like Thanjavur (T) and Pudukkottai (P), which have higher female, show significantly higher adoption levels. In contrast, Kanchipuram (K) and Chengalpattu (C), which exhibit higher male dominance, demonstrate lower adoption.

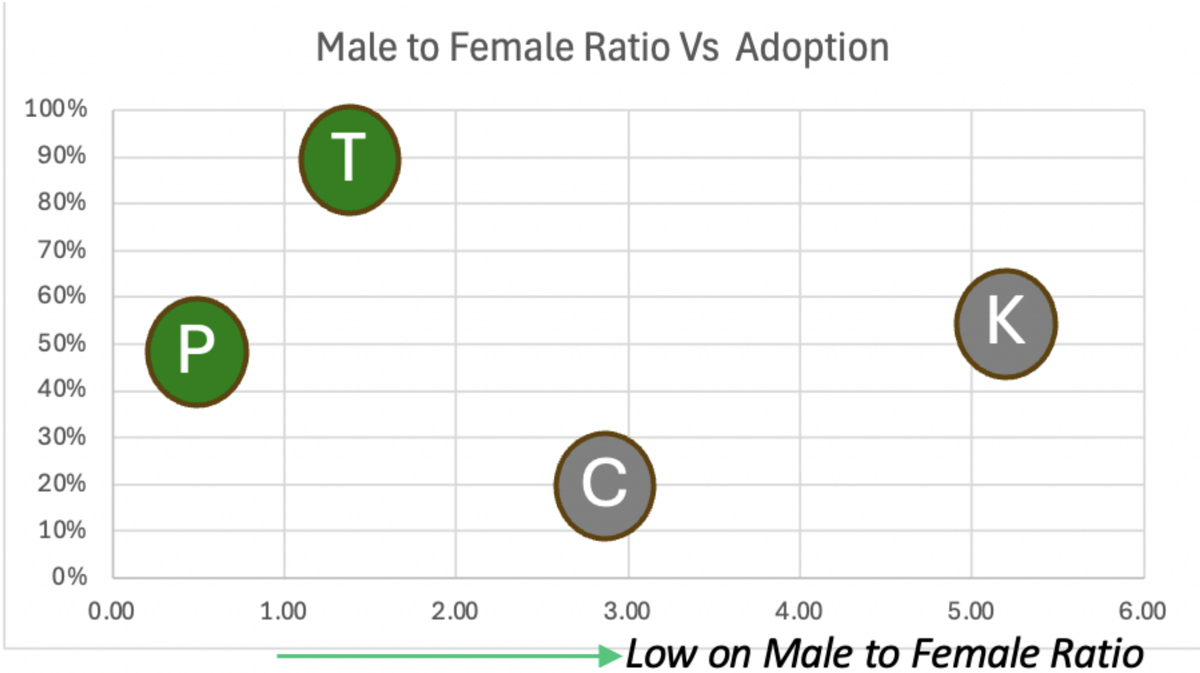


Figure 46: Male to female ratio vs adoption

Age (Above 38) vs. Adoption:

The below chart compares the percentage of older individuals (above 38 years of age) with respective adoption. In both Thanjavur (T) and Pudukkottai (P) older populations had relatively high adoption, with Thanjavur leading. Chengalpattu (C), although having an older population, shows much lower adoption, indicating that age alone is not a consistent predictor; other enabling factors play a supportive role for adoption.

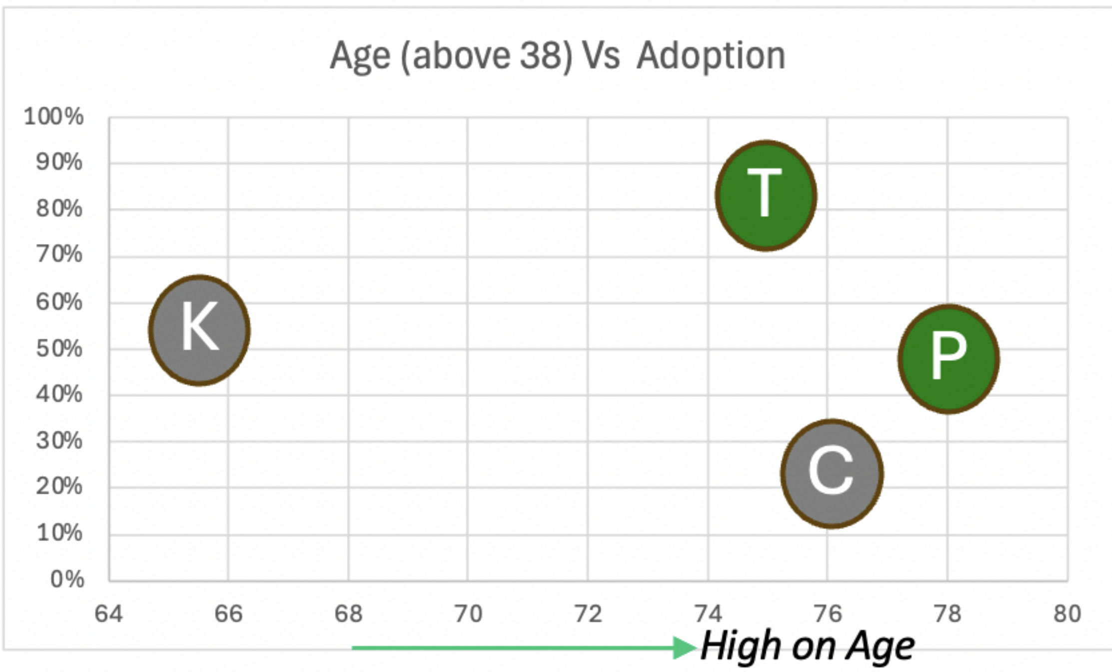


Figure 47: Age (above 38) vs adoption

Literacy Level (up to Primary Education) vs. Adoption: This chart shows an inverse trend—districts like Thanjavur (T) and Pudukkottai (P), despite having a higher proportion of people with only primary education, still report higher adoption levels. This highlights that in the sample population, literacy alone did not determine digital uptake or translate to adoption.

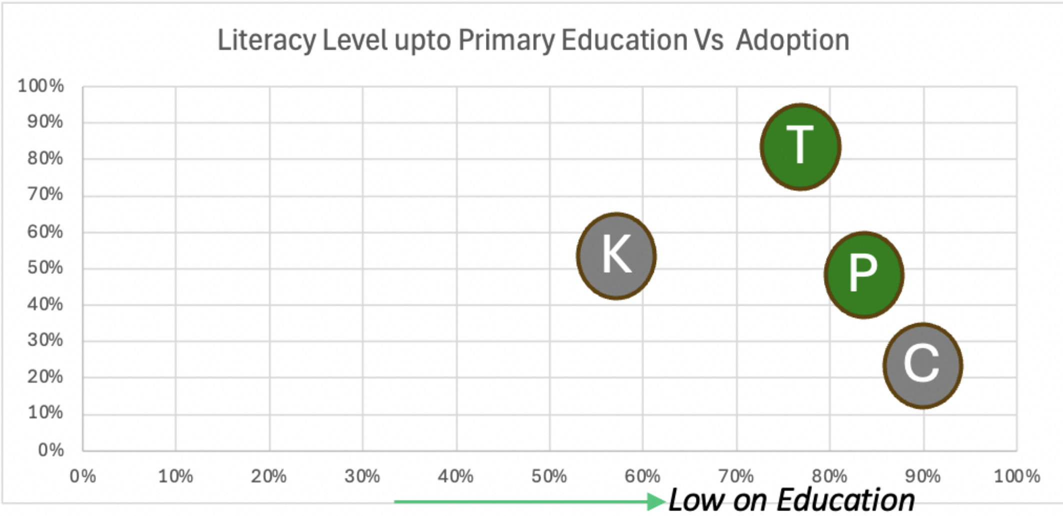


Figure 48: Education (school level or below) vs adoption

These charts indicate that social and institutional factors may play a more decisive role in adoption than demographic indicators alone. While higher education and younger populations are often assumed to facilitate digital adoption, this analysis shows otherwise. Districts like Thanjavur and Pudukkottai, despite having older populations and lower literacy levels, demonstrate better adoption, due to community-driven models, active inclusion of women, localized advisory, training, and digital infrastructure support. These findings emphasize the importance of designing inclusive, community-based digital strategies that go beyond individual capabilities and emphasize accessibility, trust-building, and locally relevant content delivery.

6.8 Regression Analysis

Regression analysis reveals the relationship between dependent and independent variables and the scenario with the interviewed respondents in each of the 4 districts. Standard coefficients range between -1 and 1.

6.8.1. Impact of Farmers' Perception in the adoption of DCSA factors in Pudukkottai

To understand the factors shaping farmers' perception of digital agricultural services, particularly in the context of DCSA adoption in Pudukottai district, a multiple linear regression analysis is conducted. The model demonstrated a strong predictive capability, with an R-value of 0.715, indicating a substantial correlation between the independent variables and the dependent variable, which is farmers' perception. The R-squared value of 0.511 suggested that approximately 51.1% of the variation in farmers' perception could be explained by the selected predictors, including extension agency contact, awareness of DCSA, infrastructure facilities, and awareness of government policies, among others. The adjusted R-squared value of 0.445 further confirms the robustness of the model, accounting for the number of predictors and the sample size.

Table 31: Model Summary- Pudukottai

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.715[a]	.511	.445	5.843
a. Predictors: (Constant), Extension agency contact, Recognition of Climate change impact, Awareness and DCSA Adoption, Awareness of Government policies, Infrastructure Facilities, Agricultural – Information seeking behavior				

The overall significance of the regression model is validated through the ANOVA test, which yielded an F-value of 7.671 and a p-value less than 0.001. This result indicates that the combination of predictors significantly contributes to explaining the variation in farmers' perceptions, confirming the suitability of the model for further interpretation of individual variable effects.

Table 32: ANOVA test- Pudukottai

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1571.254	6	261.876	7.671	.000[b]
	Residual	1502.040	44	34.137		
	Total	3073.294	50			
a. Dependent Variable: Farmers Perception						
b. Predictors: (Constant), Extension agency contact, Recognition of Climate change impact, Awareness and DCSA Adoption, Awareness of Government policies, Infrastructure Facilities, Agricultural – Information seeking behavior						

Among the predictors, awareness of government policies emerge as the most influential variable, with a standardized beta coefficient of 0.481 and a significance value of $p < 0.001$. This finding highlights that a better understanding of governmental agricultural policies and schemes is strongly associated with a more favorable perception of digital agricultural platforms. Similarly, extension agency contact, particularly through NGOs, show a significant positive effect ($\beta = 0.357$, $p = 0.006$), suggesting that farmers who receive information and support from extension agencies are more likely to form positive perceptions toward digital services. This underscores the pivotal role NGOs play in facilitating digital literacy and information dissemination in rural settings.

Table 33: Impact of Farmers' Perception in the adoption of DCSA factors in Pudukkottai

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.368	10.550		.509	.000
	Awareness and DCSA Adoption	.015	.240	.007	.062	.003
	Agricultural – Information seeking behavior	-.178	.354	-.067	-.502	.001
	Recognition of Climate change impact	-.001	.496	.000	-.003	.005
	Infrastructure Facilities	.113	.276	.052	.411	.002
	Awareness of Government policies	.926	.244	.481	3.797	.000
	Extension agency contact	.657	.230	.357	2.857	.006
a. Dependent Variable: Farmers Perception						

Picture 11: snapshots during the survey

6.8.2 Impact of Farmers' Perception in the adoption of DCSA factors in Thanjavur:

To evaluate the determinants shaping farmers' perceptions of digital agricultural information platforms in Thanjavur district, a multiple linear regression analysis is conducted using key independent variables such as extension agency contact, awareness of DCSA, government policy awareness, infrastructure, information-seeking behavior, and recognition of climate change impacts. The model yielded a strong R-value of 0.844, suggesting a high degree of correlation between the predictors and the dependent variable, which is farmers' perception. The R-squared value of 0.712 indicated that approximately 71.2% of the variance in farmers' perception is explained by these variables, which is a robust outcome for behavioral research. The adjusted R-squared value of 0.673 confirms that the model maintained its explanatory power after accounting for sample size and number of predictors.

Table 34: Model Summary- Thanjavur

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.844[a]	.712	.673	2.984
a. Predictors: (Constant), Extension agency contact, Agricultural – Information seeking behavior, Awareness and DCSA Adoption, Recognition of Climate change impact, Awareness of Government policies, Infrastructure Facilities				

The ANOVA table confirms the model's statistical significance with an F-value of 18.498 and a p-value of less than 0.001. This indicates that the overall regression model significantly predicts farmers' perception, validating the relevance of the chosen variables in explaining perception levels among Thanjavur farmers.

Table 35: ANOVA test- Thanjavur

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	988.175	6	164.696	18.498	.000[b]
	Residual	400.652	45	8.903		
	Total	1388.827	51			
a. Dependent Variable: Farmers Perception						
b. Predictors: (Constant), Extension agency contact, Agricultural – Information seeking behavior, Awareness and DCSA Adoption, Recognition of Climate change impact, Awareness of Government policies , Infrastructure Facilities						

Table 36: Impact of Farmers' Perception in the adoption of DCSA factors in Thanjavur

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	14.920	6.155		2.424	.019
	Awareness and DCSA Adoption	.088	.094	.082	.936	.000

	Agricultural – Information seeking behavior	.045	.135	.030	.332	.002
	Recognition of Climate change impact	-.124	.166	-.069	.746	.010
	Infrastructure Facilities	-.289	.199	-.141	1.454	.003
	Awareness of Government policies	.156	.150	.101	1.043	.004
	Extension agency contact	1.194	.146	.729	8.207	.000
a. Dependent Variable: Farmers Perception						

Picture 12: snapshots during the survey

6.8.3 Impact of Farmers' Perception in the adoption of DCSA factors in Kancheepuram:

To explore the factors influencing farmers’ perception of digital agricultural information in Kancheepuram district, a multiple linear regression analysis is conducted. The analysis incorporates variables such as extension agency contact (private), awareness and adoption of DCSA standards, awareness of government policies, recognition of climate change impacts, infrastructure facilities, and information-seeking behavior.

The model yields a moderate R-value of 0.495, with an R-squared of 0.245, indicating that approximately 24.5% of the variation in farmers’ perception is explained by the included predictors. However, the adjusted R-squared drops to 0.040, suggesting that the model explains only a minimal portion of the variance once adjusted for sample size and number of predictors. The standard error of the estimate is 4.028, pointing to considerable variability in responses that remains unexplained by the model.

Table 37: Model Summary- Kanchipuram

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.495[a]	.245	.040	4.028
a. Predictors: (Constant), Extension agency contact, Awareness, and DCSA Adoption, Infrastructure Facilities, Awareness of Government policies, Recognition of Climate change impact, Agricultural - Information seeking behavior				

The ANOVA results indicate that the model is not statistically significant overall, with an F-value of 1.193 and a p-value of 0.346. This implies that, collectively, the predictors do not significantly explain the variance in farmers' perceptions in this district.

Table 38: ANOVA test- Kanchipuram

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	116.163	6	19.361	1.193	.346[b]
	Residual	357.009	22	16.228		
	Total	473.172	28			
a. Dependent Variable: Farmers Perception						
b. Predictors: (Constant), Extension agency contact, Awareness and DCSA Adoption, Infrastructure Facilities, Awareness of Government policies , Recognition of Climate change impact, Agricultural - Information seeking behavior						

Further examination of the coefficients table shows that none of the individual predictors are statistically significant at the conventional 0.05 level. The predictor extension agency contact ($\beta = 0.335$, $p = 0.134$) come closest to significance, indicating a positive but not statistically conclusive effect of private agency engagement on perception. Interestingly, infrastructure facilities show a negative influence on perception ($\beta = -0.264$, $p = 0.374$), but this is also statistically insignificant, possibly pointing to unmet expectations or issues with the quality or accessibility of private infrastructure services.

Table 39: Impact of Farmers' Perception in the adoption of DCSA factors in Kanchipuram

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	36.977	11.324		3.265	.004
	Awareness and DCSA Adoption	-.095	.207	-.098	-.458	.652
	Agricultural - Information-seeking behavior	-.012	.274	-.012	-.045	.965
	Recognition of Climate change impact	.136	.338	.090	.403	.691
	Infrastructure Facilities	-.300	.330	-.264	-.907	.374
	Awareness of Government policies	.078	.272	.067	.288	.776
	Extension agency contact	.344	.221	.335	1.556	.134
a. Dependent Variable: Farmers Perception						

In conclusion, the regression model for Kancheepuram indicate a weak overall relationship between the selected factors and farmers' perception, highlighting a need for deeper exploration. It also suggests that private extension models require better integration of policy awareness, infrastructure alignment, and tailored communication to become more effective in shaping digital agricultural perceptions in this region. This will be further explored using SEM that will help studying the cumulative pathways, and indirect effects as against in regression analysis where direct effects are only evaluated.

Picture 13: snapshots during the survey

6.8.4 Impact of Farmers' Perception in the adoption of DCSA factors in Chengalpattu:

A multiple linear regression analysis is conducted to determine the extent to which various factors influence farmers’ perceptions of digital agricultural information in Chengalpattu district. The model includes variables such as extension agency contact (primarily government), awareness of DCSA adoption, information-seeking behavior, infrastructure, awareness of government policies, and recognition of climate change impacts.

The model shows a strong R-value of 0.753 and an R-squared of 0.632, indicating that approximately 63.2% of the variation in farmers' perception is explained by the selected predictors. The adjusted R-squared, however, is more modest at 0.412, suggesting that while the model performs well, some predictors contribute less effectively after adjusting for the number of variables and sample size.

Table 40: Model Summary- Chengalpattu

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.753[a]	.632	.412	2.72728
a. Predictors: (Constant), Extension Agency Contact, Awareness of DCSA adoption, Agricultural Information Seeking Behaviour, Awareness of Government Policies, Recognition of Climatic Change Impact, Infrastructure Facilities				

The ANOVA test confirms statistical significance of the model ($F = 6.728$, $p < 0.001$), meaning that the predictors collectively offer a meaningful explanation for the differences in farmers' perceptions.

Table 41: ANOVA test- Chengalpattu

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	300.244	6	50.041	6.728	.000[b]
	Residual	319.836	43	7.438		
	Total	620.080	49			
a. Dependent Variable: Farmer Perceptions						
b. Predictors: (Constant), Extension Agency Contact, Awareness of DCSA adoption, Agricultural Information Seeking Behaviour, Awareness of Government Policies, Recognition of Climatic Change Impact, Infrastructure Facilities						

Table 42: Impact of Farmers' Perception in the adoption of DCSA factors in Chengalpattu

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12.363	4.027		3.070	.004
	Awareness of DCSA adoption	.142	.094	.180	1.506	.139

	Agricultural Information Seeking Behaviour	-.019	.208	-.016	-.089	.929
	Recognition of Climatic Change Impact	.256	.324	.161	.790	.434
	Infrastructure Facilities	.043	.274	.038	.158	.875
	Awareness of Government Policies	.076	.286	.056	.264	.793
	Extension Agency Contact	.594	.270	.475	2.199	.033
a. Dependent Variable: Farmer Perceptions						

To conclude as in figure 49, case of Pudukottai, awareness of government policies and extension agency contact seems to have a strong relationship with farmers' perception. Similarly in Tiruvarur, awareness of government policies and extension agency contact has positive relationships and stands out. While in Kancheepuram, none of the independent variables demonstrate a statistically significant effect on farmers' perception. In the case of Chengalpattu, extension agency contact has a significant impact on farmers' perception while other variables does not impact significantly.

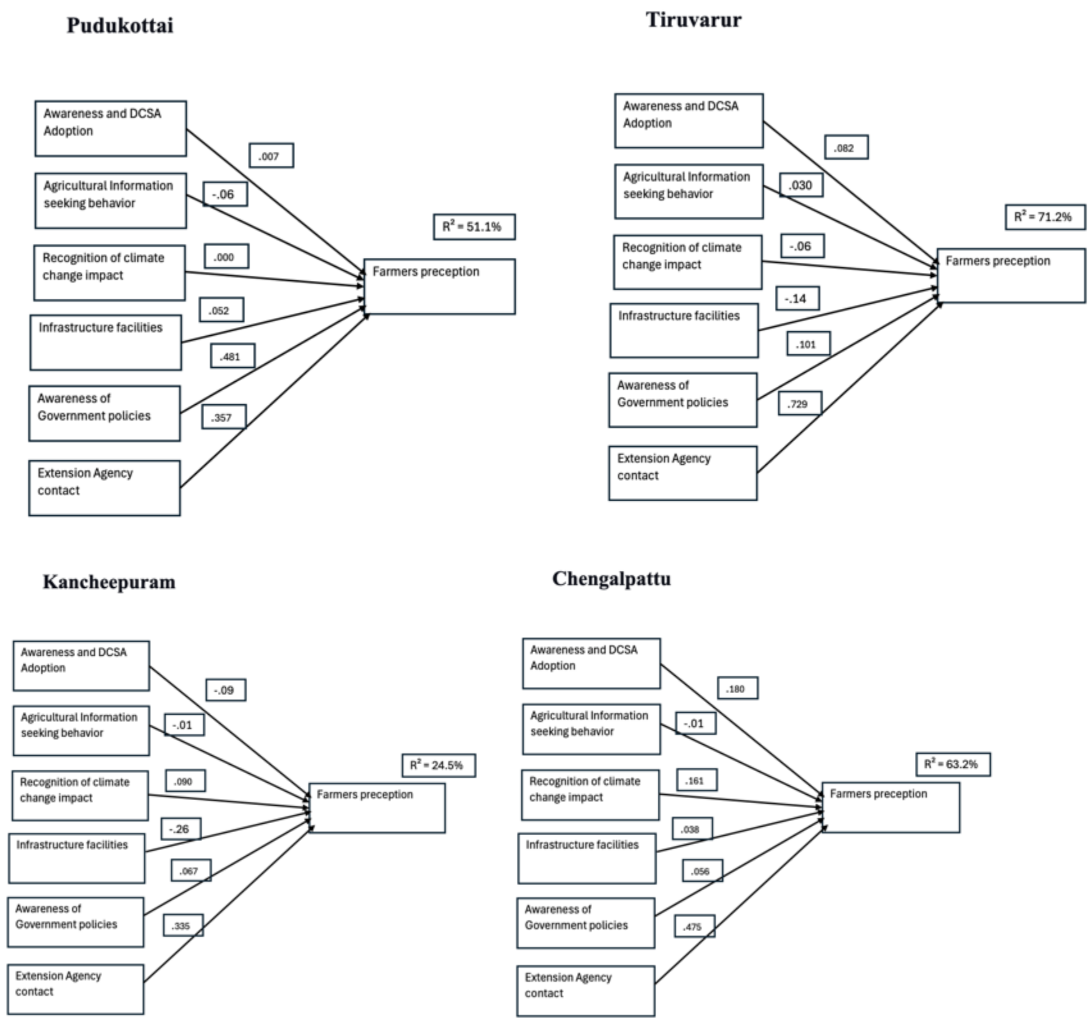


Figure 49: Multiple regression model examining the relationship between independent variables and Farmer's perception (dependent variable) across four districts (research locations) in Tamil Nadu. Numbers shown in boxes over the arrow lines are standardized regression coefficients.

Picture 14: snapshot during the survey

6.9 Exploratory Factor Analysis

From Table 43, a Cronbach's Alpha value greater than 0.6 reflects the robustness of the scales utilized within the model, indicating high reliability. The sample used in the study is deemed to be adequate for the study for applying confirmatory factor analysis (KMO = 0.875). Additionally, the Bartlett test reveals the following values ($\chi 2$ = 5113. 398, df = 780, p = 0.000), which help to verify the assumptions.

Table 43: Cronbach's Alpha coefficients of the data collection instrument

Construct*	No of questions	Cronbach's alpha
Factor 1: Awareness and DCSA adoption	5	0.916
Factor 2: Agricultural Information seeking behavior	6	0.836
Factor 3: Recognition of climate change impact	5	0.802
Factor 4: Infrastructure Facilities	5	0.837
Factor 5: Awareness of Government Policies	5	0.835
Factor 6: Extension Agency Contact	5	0.915
Factor 7: Farmer's perception	9	0.949

The factor analysis aims to analyze the complex dataset and identify the hidden data by grouping the variables. It is a statistical method that helps to reduce the data factors into different dimensions. The extraction of factors is carried out using Principal Component Analysis (PCA), and the Varimax rotation method is applied to enhance interpretability, as shown in Table 42 below. The criteria for including the factor in the analysis is, if eigen values >1. The naming convention for the related items of the factors are presented as below:

<u>Awareness and DCSA adoption(Figure 51)</u>
ADA1 Conduct workshops and field demonstrations to educate farmers
ADA2 Promote awareness among farmers through extension channels.
ADA3 Awareness of specific DCSA tools (apps, platforms).
ADA4 Credible information enhances farmers' trust in adoption
ADA5 Knowledge of climate-resilient digital practices

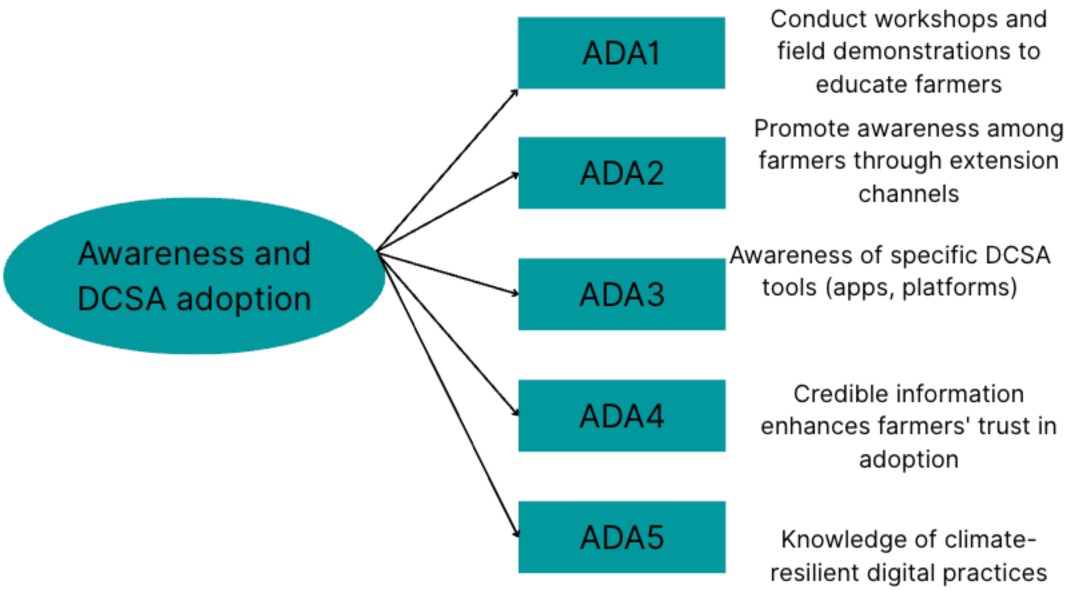


Figure 51: Indicators of Awareness and DCSA adoption

<u>Agricultural information seeking behavior(Figure 52)</u>
AISB1 Use of mobile apps, helplines, or websites
AISB 2 Participation in training sessions
AISB 3 visits to agri-dealers, agri-kiosks
AISB 4 The information is dynamic and contextualized
AISB 5 Seeking advice from peers or local leaders
AISB 6 Reliable and precise information is provided

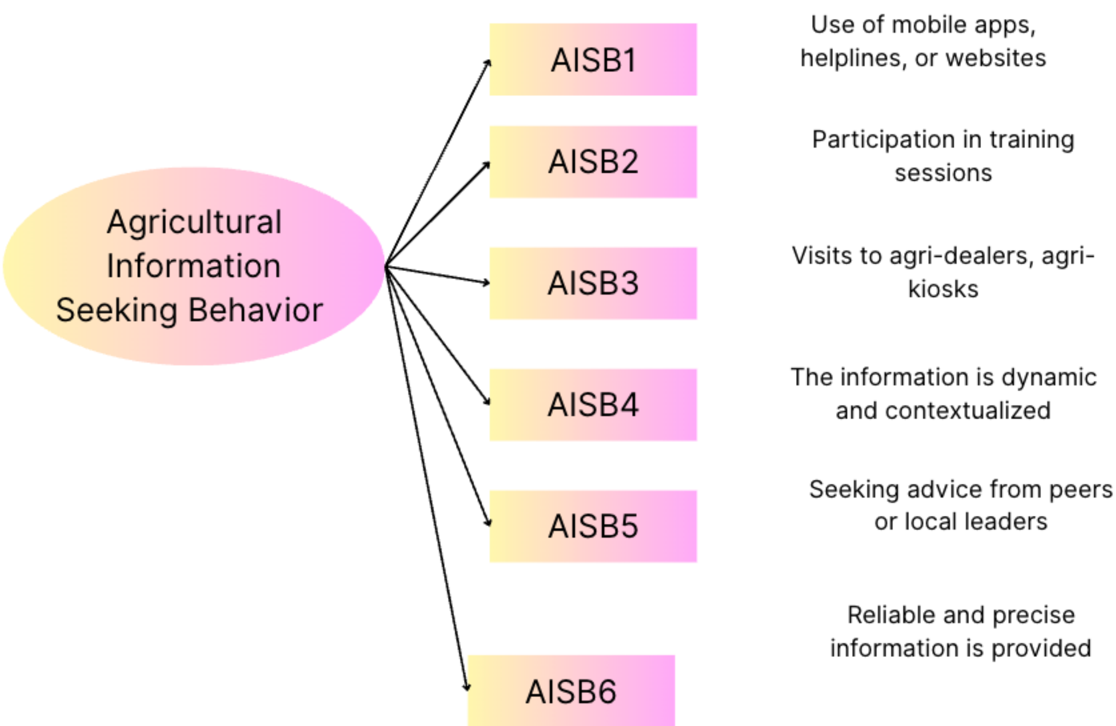


Figure 52: Indicators of Agricultural Information seeking behavior

Recognition of climate change impact(Figure 53)
RCCI1 Perceived changes in rainfall, temperature, pests
RCCI 2 Awareness of climate-induced risks to crops
RCCI 3 It offers alerts and advice for safeguarding crops.
RCCI 4 Knowledge of adaptive farming measures
RCCI 5 Manage pests in an environmentally friendly way.

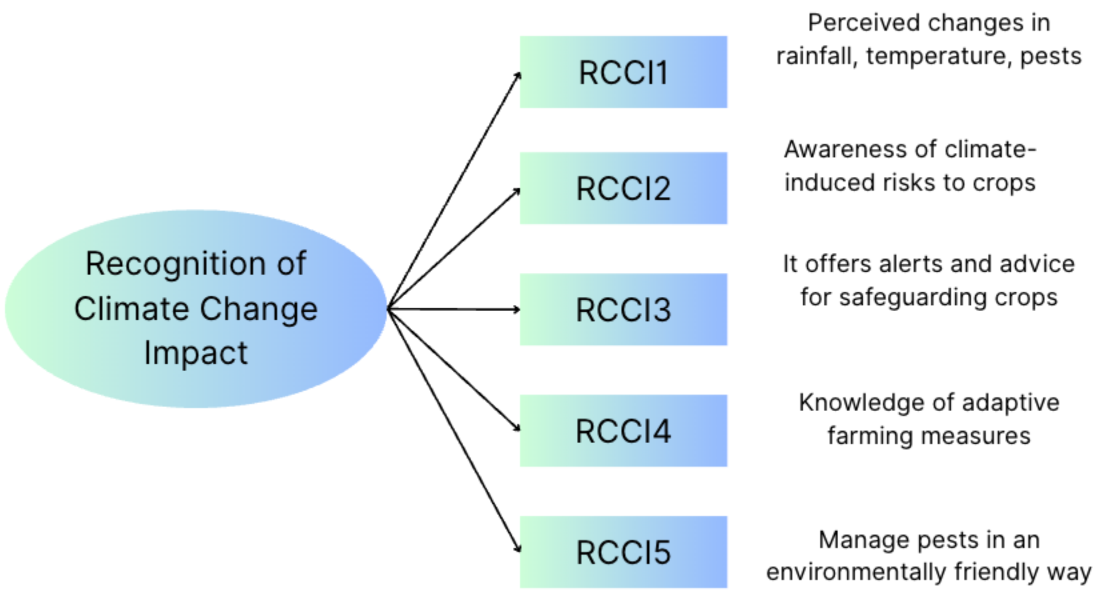


Figure 53: Indicators of Recognition of climate change impact

Infrastructure Facilities (Figure 54)
IF1 Farmers know the facilities of hiring centres at economical rates
IF 2 It provides the availability of seeds and fertilizers near location
IF 3 It helps farmers access the crops' daily market prices to facilitate product sales
IF 4 Farmers check the crop insurance and updates for receiving compensation
IF 5 Access to ICT tools and mobile connectivity

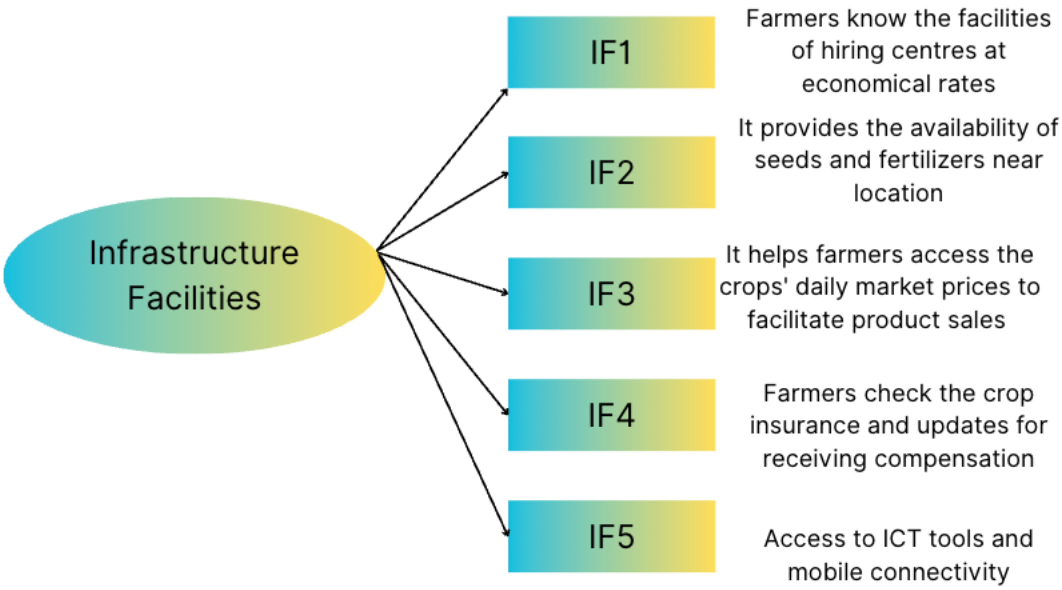


Figure 54: Indicators of Infrastructure Facilities

<u>Awareness of Government policies(Figure 55)</u>
AGP1 Awareness of government subsidies/incentives.
AGP 2 Knowledge of digital schemes (like AgriStack, eNAM) & use of govt supported digital platforms
AGP 3 Daily weather forecast, and advice given to the farmers to plan for cultivation
AGP 4 The farmers receive the solution for pest infection and manage all farmers' challenges.
AGP 5 The information for the availability of seeds and fertilizer near government and private outlets

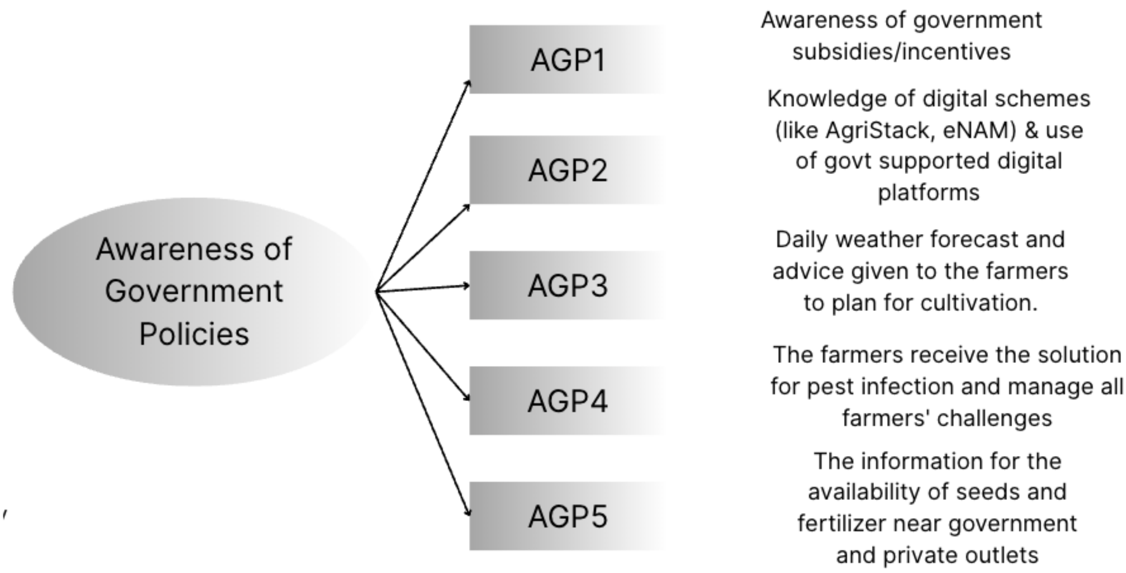


Figure 55: Indicators of Awareness of government policies

Extension Agency contact(Figure 56)

EAC1 The extension agency interacts with the farmers regularly.

EAC 2 Trust in information from NGOs/public/private sources

EAC 3 Exposure to digital tools via extension agents.

EAC 4 The agency provides timely information to the farmers

EAC 5 It provides invaluable advice and unwavering support to farmers for their agricultural endeavours.

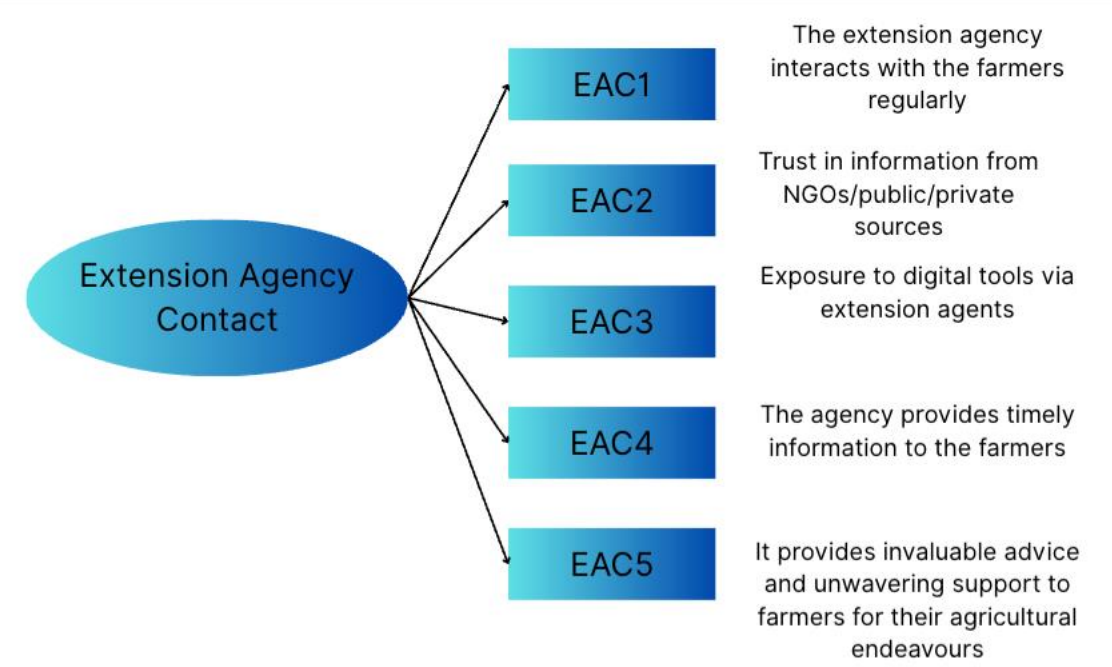


Figure 56: Indicators of Extension Agency Contact

Farmers perception(Figure 57)

FP1 Perceived usefulness of digital services

FP 2 It gives updates on the Market price

FP 3 It helps me to be prepared for weather changes.

FP 4 It helps me to get updated information on Subsidies and government schemes

FP 5 The app provides all access in the Tamil language making it easy to use

FP 6 Perceived improvement in productivity

FP 7 Willingness to adopt digital practices

FP 8 It is compatible with configuration mobile phones

FP 9 Perceived reliability of digital information

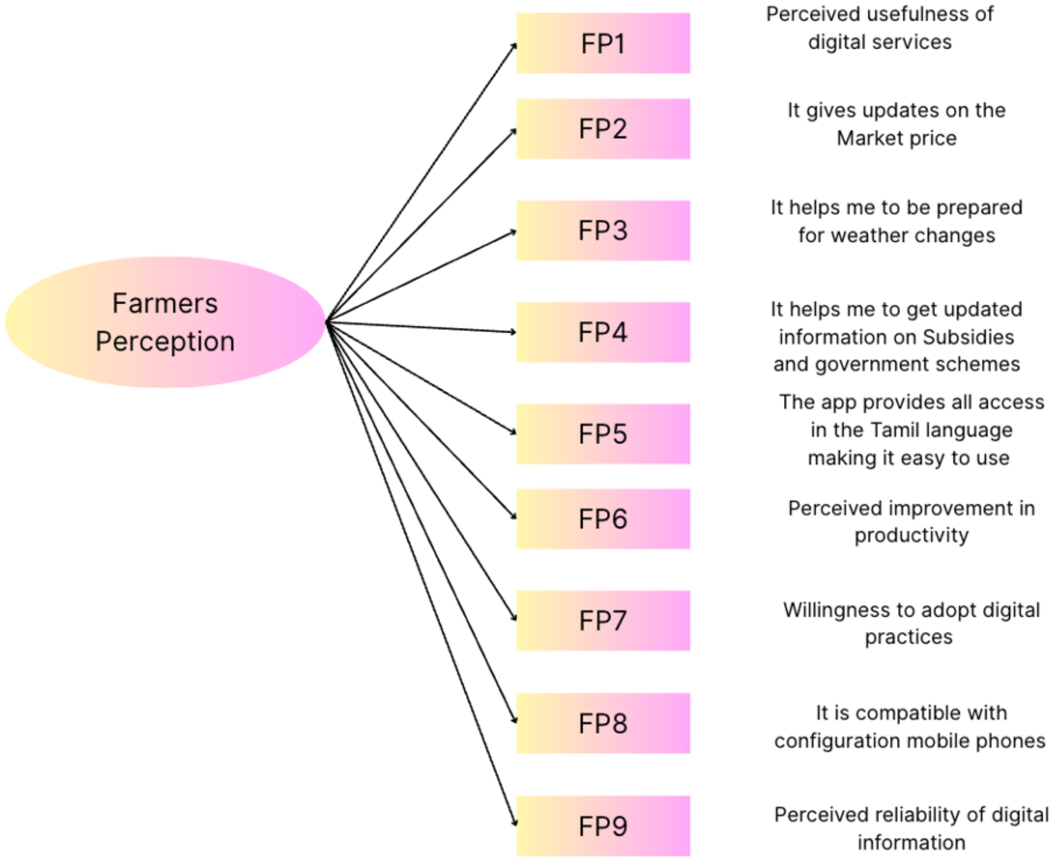


Figure 57: Indicators of Farmers Perception

Table 44: Principal Component Analysis.

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	11.252	28.130	28.130	11.252	28.130	28.130	8.609	21.523	21.523
2	5.818	14.544	42.675	5.818	14.544	42.675	3.914	9.785	31.308
3	3.883	9.707	52.382	3.883	9.707	52.382	3.445	8.612	39.920
4	1.880	4.701	57.083	1.880	4.701	57.083	3.359	8.398	48.318
5	1.722	4.305	61.388	1.722	4.305	61.388	2.748	6.870	55.188
6	1.370	3.425	64.813	1.370	3.425	64.813	2.689	6.721	61.909
7	1.235	3.088	67.901	1.235	3.088	67.901	2.397	5.991	67.901
8	.964	2.411	70.312						
9	.854	2.135	72.447						
10	.810	2.025	74.472						
11	.730	1.825	76.297						
12	.710	1.775	78.072						
13	.680	1.699	79.770						
14	.623	1.556	81.327						
15	.607	1.519	82.846						
16	.563	1.408	84.254						
17	.535	1.337	85.590						
18	.493	1.232	86.822						
19	.459	1.148	87.970						
20	.427	1.067	89.037						
21	.387	.966	90.003						
22	.374	.934	90.938						
23	.349	.872	91.810						
24	.318	.794	92.604						
25	.289	.723	93.326						
26	.277	.692	94.019						
27	.271	.677	94.696						
28	.240	.601	95.296						
29	.235	.587	95.883						
30	.211	.526	96.409						
31	.200	.500	96.910						
32	.187	.466	97.376						
33	.175	.437	97.813						
34	.153	.382	98.195						
35	.142	.354	98.549						
36	.137	.342	98.891						
37	.136	.339	99.231						
38	.123	.309	99.539						
39	.097	.244	99.783						
40	.087	.217	100.000						

Table 45 displays the results of the exploratory factor analysis along with the matrix of the component coefficients generated and their respective loading factors. The seven components included in the survey questionnaire are identified and confirmed, resulting in seven factors: (1) farmers' perception, (2) awareness and DCSA adoption, (3) agricultural information-seeking behavior, (4) infrastructure facilities, (5) recognition of climate change impact, (6) awareness of government policies, and (7) extension agency contact.

As observed in the last row of the table 43, the cumulative factor loading is 67.90%, i.e., the 7 factors extracted, account for 67.90% of the accumulated variance for the answers (Factor 1 = 28.13%, Factor 2 = 14.54, Factor 3 = 9.71%, Factor 4 = 4.70%, Factor 5 = 4.30%, Factor 6 = 3.43%, Factor 7 = 3.09%). The components generated in the analysis reveal that the questions are properly grouped in the original constructs.

Table 45: Exploratory factor analysis with the matrix of the coefficients and factors(components) with respective factor loadings.

	Components						
	1	2	3	4	5	6	7
FP5	.882						
FP6	.835						
FP1	.834						
FP7	.825						
FP8	.815						
FP9	.815						
FP3	.814						
FP4	.778						
FP2	.773						
ADA2		.894					
ADA5		.883					
ADA4		.870					
ADA1		.863					
ADA3		.837					
AISB3			.745				
AISB4			.742				
AISB5			.726				
AISB1			.716				
AISB6			.681				
AISB2			.650				
IF3				.805			
IF2				.745			
IF4				.741			
IF1				.687			
IF5				.631			
RCCI2					.767		
RCCI1					.747		
RCCI3					.679		
RCCI4					.657		
RCCI5					.560		
AGP3						.778	

AGP5						.626	
AGP2						.614	
AGP1						.575	
AGP4						.502	
EAC2							.730
EAC5							.637
EAC1							.611
EAC4							.586
EAC3							.593
Eigenvalue	11.252	5.818	3.883	1.880	1.722	1.370	1.235
% O explained variance	28.13	14.54	9.71	4.70	4.30	3.43	3.09

The extraction method used was Principal component Analysis and Rotation Method (varimax with Kaiser Normalization). The rotation converged in 7 iterations.

For instance, variables FP5 to FP9 load strongly on Component 1, suggesting they represent a common underlying factor related to Farmers' Perceptions. Similarly, ADA variables cluster on Component 2, indicating a distinct factor related to another aspect of the study.

The rotation method redistributes the explained variance, ensuring that the component provides a clearer and more balanced representation of the data structure. This aids in understanding the relationships between variables and the factors they represent, supporting robust and reliable factor interpretation. Overall, the rotated matrix demonstrates the effectiveness of the PCA and Varimax rotation in uncovering the underlying structure of the dataset.

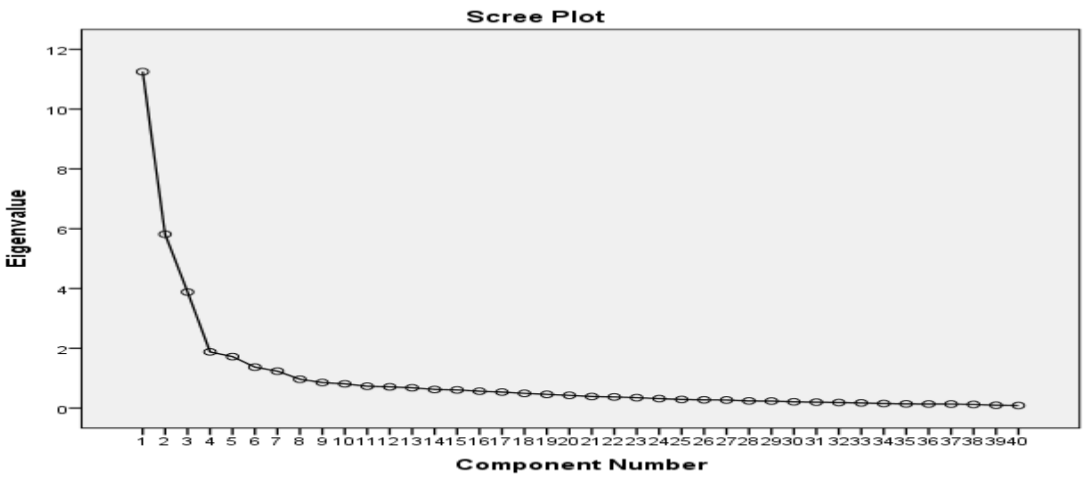


Figure 58: Scree Plot

The scree plot as in figure 58 represents the number of factors to retain based on the eigenvalues and helps identify the elbow point of these factors in descending order from the start to the end of the component factors. The scree plot aids in simplifying complex data for further analysis to ensure a model that fits the data well.

Socio-economic factors such as monthly income, farmer landholding, and farmers' experience were analyzed comparing to five latent constructs: awareness and DCSA adoption, agricultural information-seeking behavior, recognition of climate change impact, infrastructure facilities, and awareness of government policies. This helped to explore the relationship between these factors and the five constructs.

Monthly income had a strong influence on farmers' recognition of climate change impacts, suggesting that higher-income groups are more aware of environmental risks and adaptation measures. It also had a slightly moderate effect on agricultural information-seeking behavior. However, income had not impacted on constructs such as infrastructure access, awareness of government policies, and awareness & DCSA adoption, indicating that financial resources were not enough for broader engagement with digital agriculture.

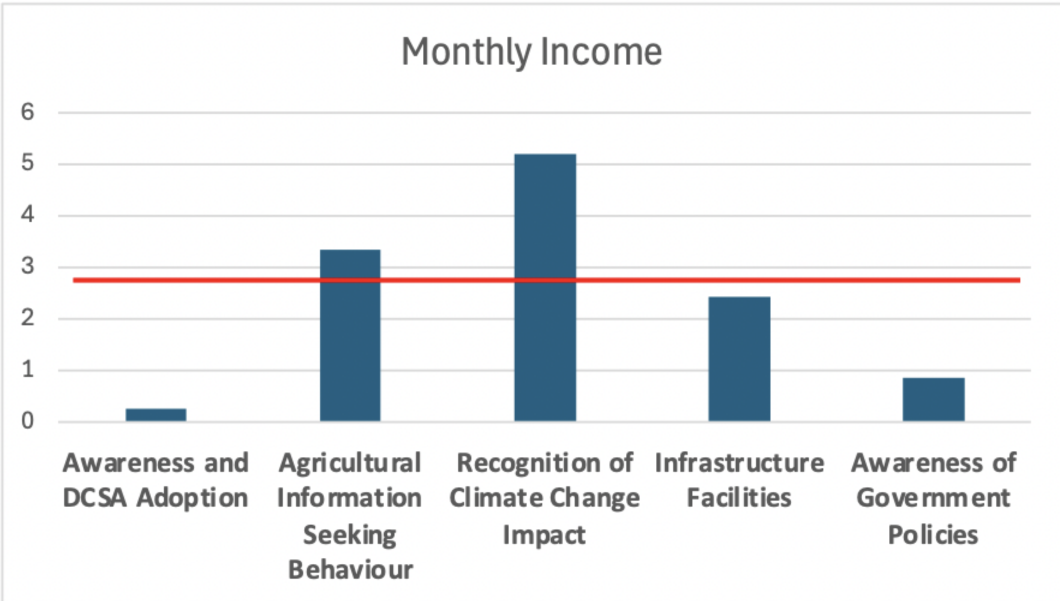


Figure 59: Relationship of farmers monthly income with the constructs

Landholding size was a significant driver of awareness of government policies, likely because larger landholders are more exposed to institutional mechanisms and benefit schemes. It had not impacted other constructs such as awareness and DCSA adoption, agricultural information seeking behavior, recognition of climate change impact and infrastructure facilities.

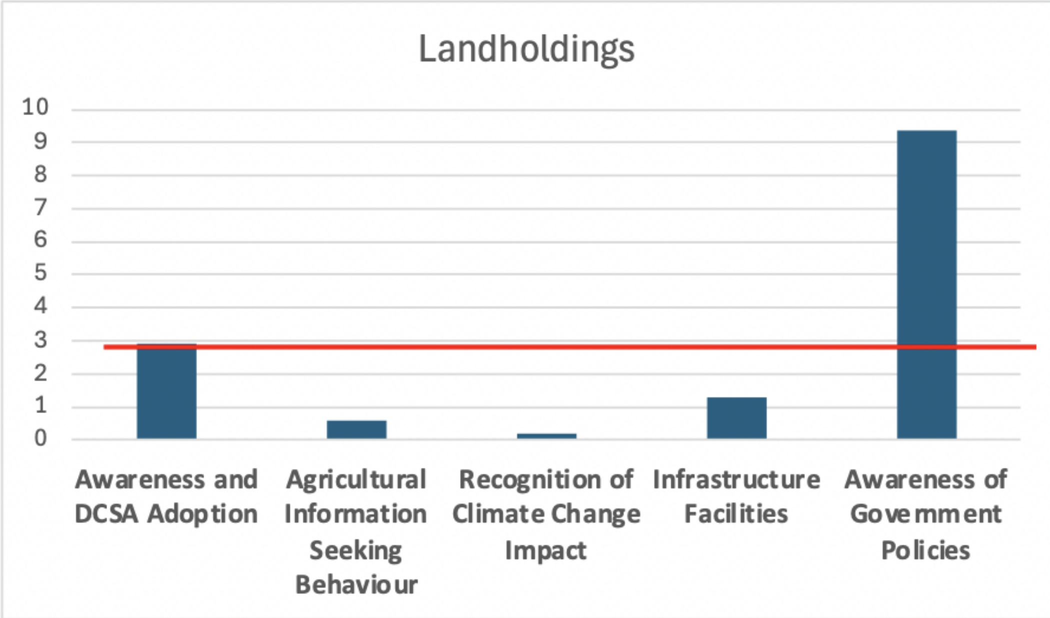


Figure 60: Relationship of farmers' landholdings with the constructs

Farming experience moderately influenced awareness of government policies, as seasoned farmers are more likely to interact with institutions over time. It had a limited role in shaping other factors. This implies that while experience may aid in understanding administrative processes, it did not translate into proactive climate-resilient behavior or other factors in the studied area.

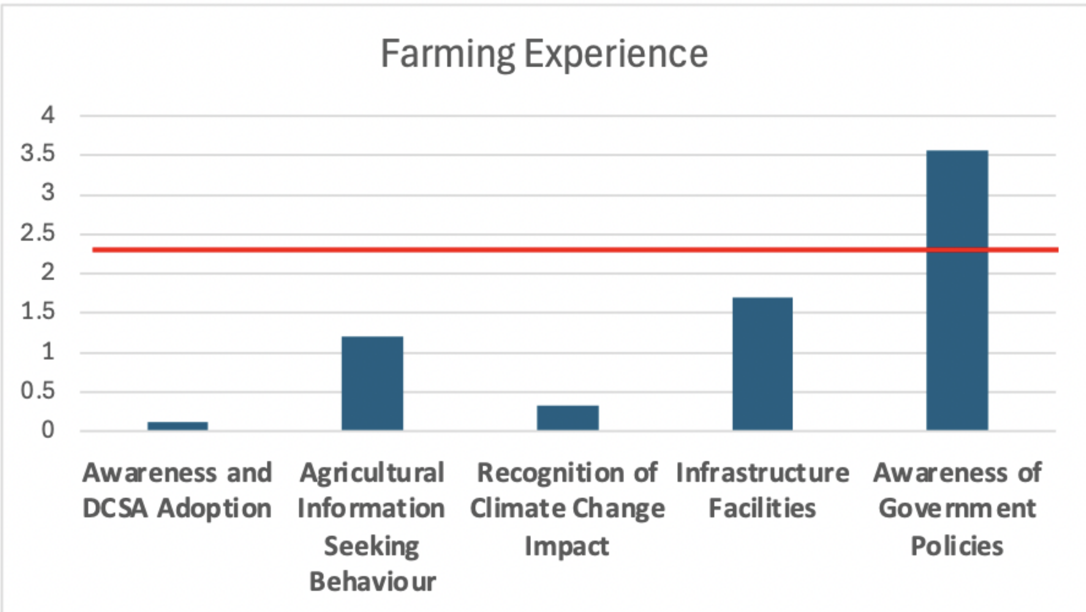


Figure 61: Relationship of farming experience with the constructs

6.10 Confirmatory Factor Analysis

Confirmatory Factor Analysis (CFA) is essential for validating measurement models by ensuring that observed variables accurately represent the intended latent constructs. This analytical approach improves the reliability and validity of measurements, leading to more precise and trustworthy outcomes. CFA offers a rigorous methodology for validating theories and models based on theoretical frameworks or previous empirical research. Furthermore, evaluating model fit helps identify discrepancies between the proposed model and the empirical data, thereby fostering enhanced model refinement and increasing accuracy.

Confirmatory Factor Analysis on Awareness and DCSA Adoption:

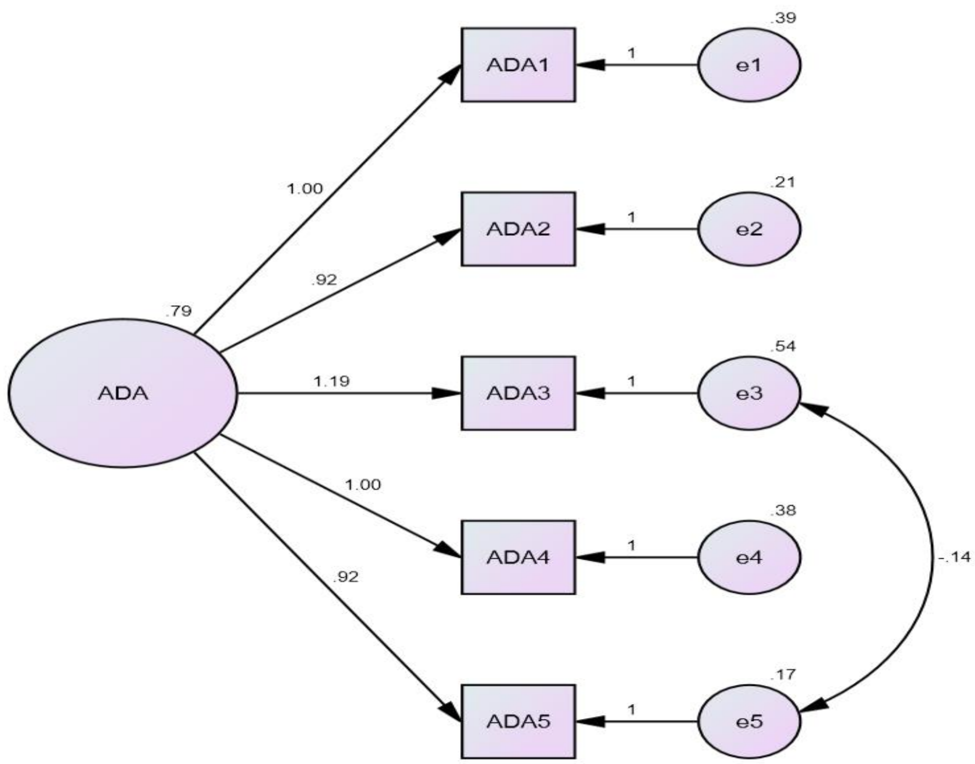


Figure 62: Confirmatory Factor Analysis on Awareness and DCSA Adoption

Table 46: CFA fit indices table on Awareness and DCSA Adoption

Indices	Abbreviation	Obtained Value	Recommended criteria
Reliability test	Cronbach's Alpha	0.916	>7 good fit
P Value		0.542	>0.05 model fit
Normed Chi-square	χ^2 /df	0.774	$1 < \chi^2$ /df < 3
Goodness-of-fit index	GFI	0.993	>0.90
Adjusted GFI	AGFI	0.975	>0.80
Normed fit index	NFI	0.995	>0.90
Comparative fit index	CFI	1.000	>0.90
Tucker–Lewis index	TLI	1.003	>0.90
Root mean square error of approximation	RMSEA	0.000	<0.05 good fit < 0.08 acceptable fit

The reliability test indicates that the measurements are consistent and dependable. The p-value of 0.542 exceeds 0.05, suggesting that there is no significant difference between the observed data and the model predictions, indicating a good model fit. The chi-square value is 0.774, slightly below the ideal range, yet it still signifies a good fit with low complexity. The Goodness of Fit Index (GFI) is 0.993, meaning the model accounts for 99.3% of the variance in the observed data, which is excellent. The Adjusted Goodness of Fit Index (AGFI) is 0.975, demonstrating an excellent fit, considering model complexity. The Normed Fit Index (NFI) stands at 0.995, suggesting that the model fits very well compared to a basic model. The Comparative Fit Index (CFI) registers at 1.000, indicating that the model fits the data perfectly in comparison to an independent model. The Tucker-Lewis Index (TLI) is 1.003, showing that the model is strong and well-defined. Finally, the Root Mean Square Error of Approximation (RMSEA) is 0.000, indicating that the model closely aligns with the observed data, presenting no errors.

Table 47: Estimate table for CFA on Awareness and DCSA Adoption
Source: SPSS Output for Primary Data

			Estimate	S.E.	C.R.	P
ADA1	<---	ADA	1.000			
ADA2	<---	ADA	.921	.064	14.475	***
ADA3	<---	ADA	1.188	.094	12.692	***
ADA4	<---	ADA	.997	.076	13.151	***
ADA5	<---	ADA	.916	.063	14.505	***

All ADA indicators (ADA1 to ADA5) show strong and statistically significant loadings on the ADA construct, confirming their effectiveness as measures of the underlying latent variable. The high critical ratios and significant p-values further validate the reliability of these relationships.

Confirmatory Factor Analysis on Agricultural Information Seeking Behaviour:

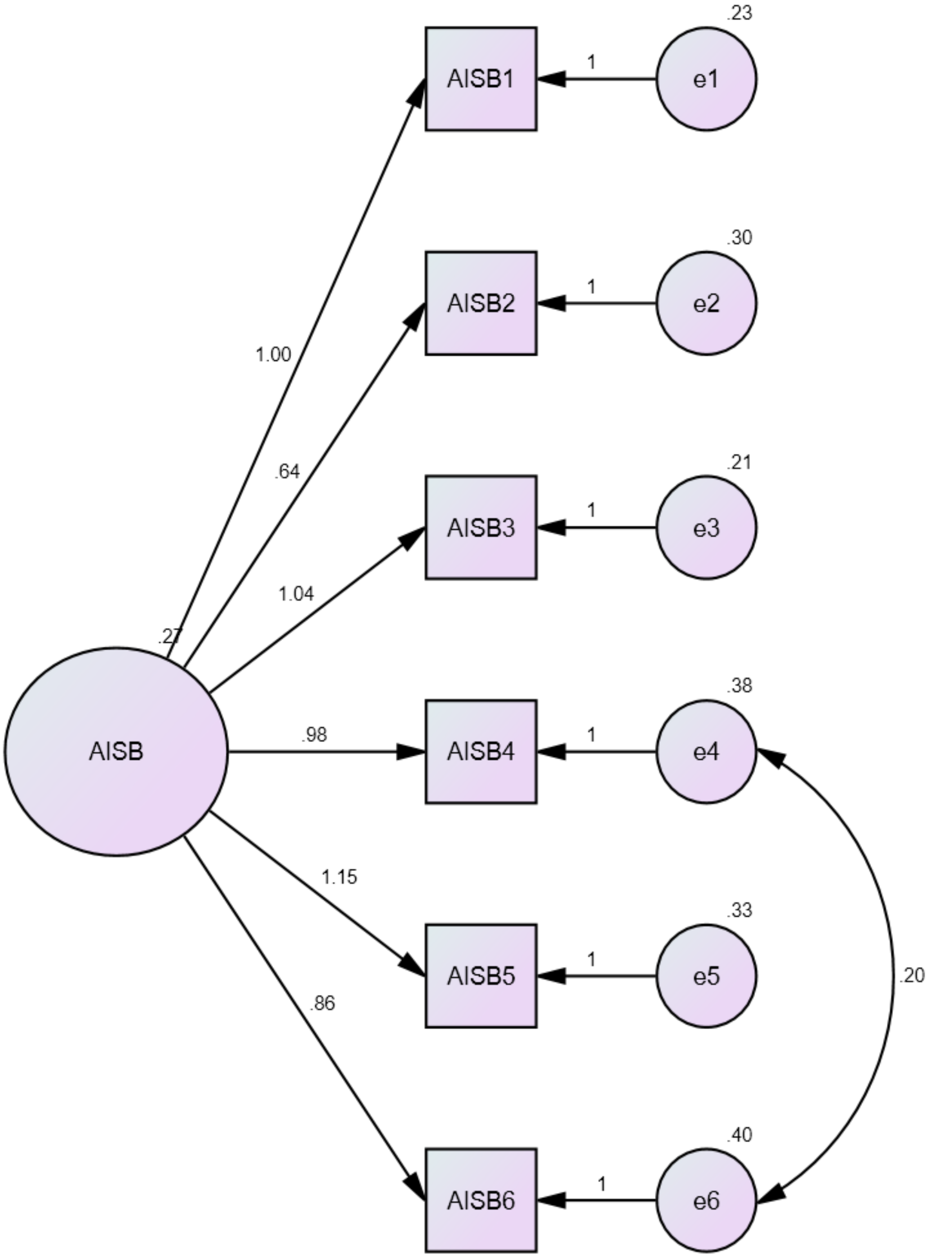


Figure 63: Confirmatory Factor Analysis on Agricultural Information Seeking Behaviour

Table 48: CFA fit indices table on Agricultural Information Seeking Behaviour
Source: SPSS AMOS Output

Indices	Abbreviation	Obtained Value	Recommended criteria
Reliability test	Cronbach's Alpha	0.836	>7 good fit
P Value		0.555	>0.05 model fit
Normed Chi-square	χ^2 /df	1.342	$1 < \chi^2$ /df < 3
Goodness-of-fit index	GFI	0.990	>0.90
Adjusted GFI	AGFI	0.969	>0.80
Normed fit index	NFI	0.986	>0.90
Comparative fit index	CFI	1.003	>0.90
Tucker–Lewis index	TLI	1.006	>0.90
Root mean square error of approximation	RMSEA	0.000	<0.05 good fit < 0.08 acceptable fit

A value greater than 0.7 indicates a good fit, suggesting that the items within the test are consistent and effectively measure the same construct. A P-value exceeding 0.05 suggests that the model fits the data well, indicating no significant difference between the observed and expected covariance matrices. A value ranging between 1 and 3 is considered acceptable, reflecting a reasonable fit of the model to the data. A GFI value greater than 0.90 indicates a good fit, demonstrating that the model adequately represents the observed data.

An AGFI value exceeding 0.80 suggests a good fit by adjusting the GFI based on the degrees of freedom used in the model. An NFI greater than 0.90 indicates a good fit between the model and the sample data. A CFI value over 0.90 suggests a good model fit compared to a baseline model, demonstrating an improvement in fit. A TLI value greater than 0.90 shows an adequate fit of the model, considering the complexity of the model structure. An RMSEA value less than 0.06 indicates a good fit, with values up to 0.08 still considered acceptable.

Table 49: Estimate table for CFA on Agricultural Information Seeking Behaviour
Source: SPSS Output for Primary Data

			Estimate	S.E.	C.R.	P
AISB1	<---	AISB	1.000			
AISB2	<---	AISB	.633	.100	6.345	***
AISB3	<---	AISB	1.055	.116	9.082	***
AISB4	<---	AISB	.959	.125	7.654	***
AISB5	<---	AISB	1.105	.132	8.383	***
AISB6	<---	AISB	.773	.122	6.313	***

All AISB indicators (AISB1 to AISB6) exhibit statistically significant loadings on the AISB construct, thus confirming their effectiveness as accurate measures of the underlying latent variable. The high critical ratios and significant p-values further indicate that these relationships are both robust and reliable.

Confirmatory Factor Analysis on Recognition of Climate Change Impact:

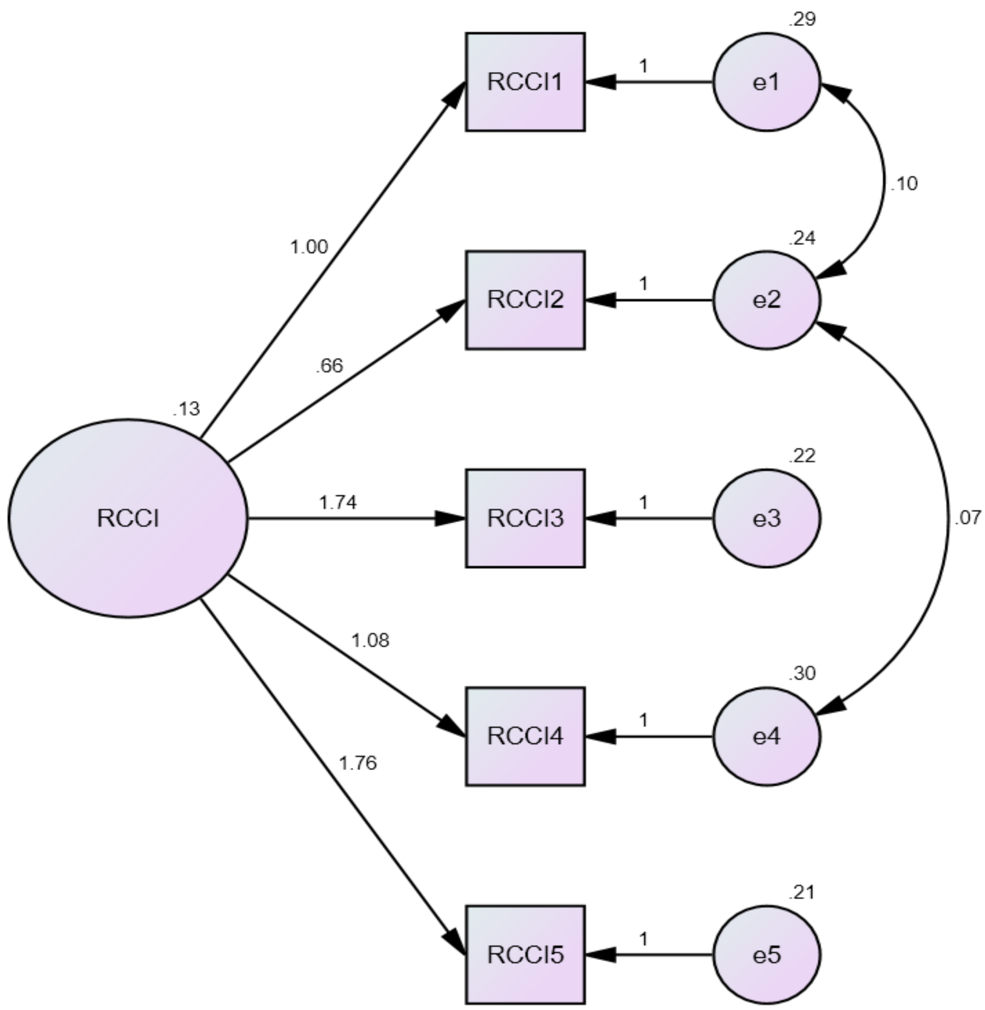


Figure 64: Confirmatory Factor Analysis on Recognition of Climate Change Impact

Table 50: CFA fit indices table on Recognition of Climate Change Impact
Source : SPSS AMOS Output

Indices	Abbreviation	Obtained Value	Recommended criteria
Reliability test	Cronbach's Alpha	0.802	>7 good fit
P Value		0.08	>0.05 model fit
Normed Chi-square	χ^2 /df	2.684	$1 < \chi^2$ /df < 3
Goodness-of-fit index	GFI	0.983	>0.90
Adjusted GFI	AGFI	0.913	>0.80
Normed fit index	NFI	0.973	>0.90
Comparative fit index	CFI	0.982	>0.90
Tucker–Lewis index	TLI	0.983	>0.90
Root mean square error of approximation	RMSEA	0.045	<0.05 good fit < 0.08 acceptable fit

A value exceeding 0.7 indicates a good fit, demonstrating that the items within the test exhibit a satisfactory level of internal consistency. A value greater than 0.05 suggests an adequate model fit, implying that the null hypothesis can be retained, meaning there are no significant discrepancies between the observed and expected correlations. A ratio greater than 1 and less than 3 is considered acceptable, representing an appropriate balance between model complexity and fit. A GFI value greater than 0.90 signifies a good fit, indicating that the model explains a substantial portion of the variance in the data.

A value exceeding 0.80 is favorable, as it adjusts for the number of parameters in the model, thereby offering a more conservative assessment of fit. An NFI value greater than 0.90 is seen as good, signaling a strong overall fit of the model compared to a baseline model. A CFI above 0.90 suggests excellent model fit, demonstrating a significant improvement over the baseline model. A TLI value greater than 0.90 indicates a strong fit, accounting for model complexity. A value less than 0.06 reflects a good fit, representing the error of approximation in the population.

Table 51: Estimate table for CFA on Recognition of Climate Change Impact
Source: SPSS Output for Primary Data

			Estimate	S.E.	C.R.	P
RCCI1	<---	RCCI	1.000			

			Estimate	S.E.	C.R.	P
RCCI2	<---	RCCI	.664	.116	5.750	***
RCCI3	<---	RCCI	1.738	.254	6.855	***
RCCI4	<---	RCCI	1.076	.187	5.764	***
RCCI5	<---	RCCI	1.757	.256	6.864	***

All indicators are statistically significant and serve as reliable measures of the RCCI construct. This confirms their robustness and effectiveness in assessing the underlying latent variable.

Confirmatory Factor Analysis on Infrastructure Facilities:

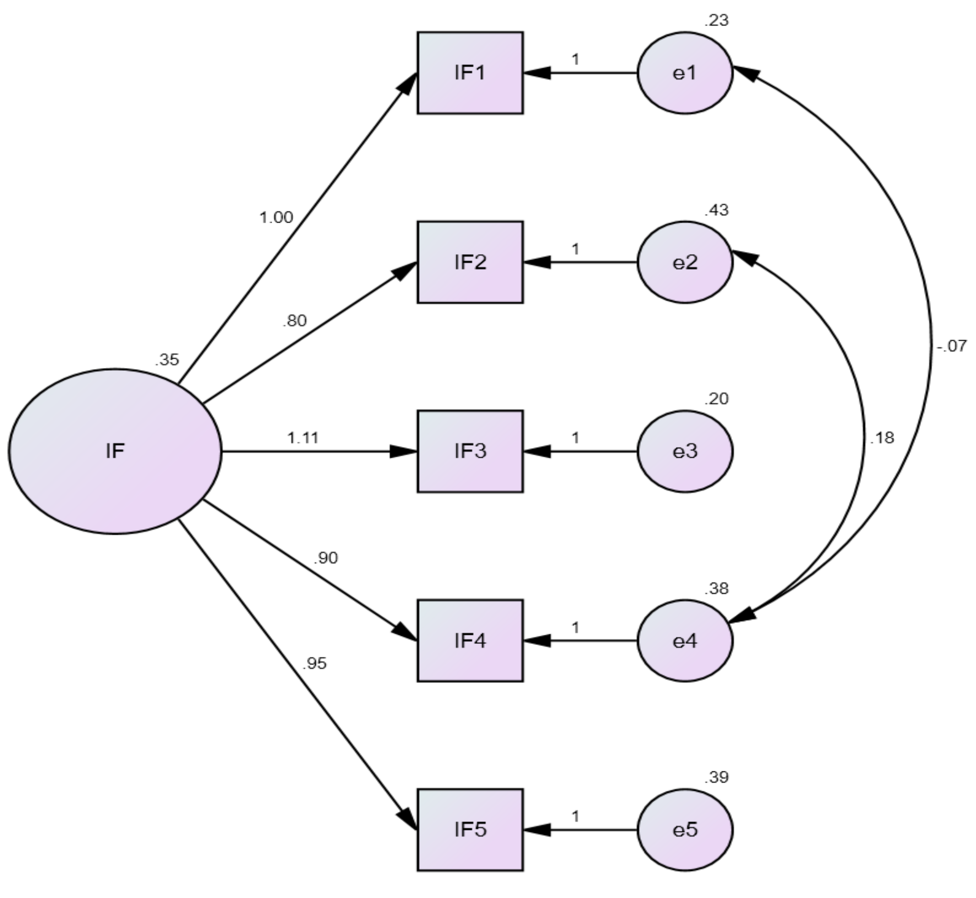


Figure 65: Confirmatory Factor Analysis on Infrastructure Facilities

Table 52: CFA fit indices table on Infrastructure Facilities

Indices	Abbreviation	Obtained Value	Recommended criteria
Reliability test	Cronbach's Alpha	0.837	>7 good fit
P Value		0.913	>0.05 model fit
Normed Chi-square	χ^2 /df	0.176	$1 < \chi^2 /df < 3$
Goodness-of-fit index	GFI	0.999	>0.90
Adjusted GFI	AGFI	0.994	>0.80
Normed fit index	NFI	0.999	>0.90
Comparative fit index	CFI	1.000	>0.90
Tucker–Lewis index	TLI	1.024	>0.90
Root mean square error of approximation	RMSEA	0.000	<0.05 good fit < 0.08 acceptable fit

The obtained value of the reliability test is 0.837, indicating a good fit since it exceeds the recommended threshold of 0.7. The P Value recorded at 0.913 is significantly greater than the critical value of 0.05, suggesting that the model fits well. The GFI obtained is 0.999, demonstrating an excellent fit for the model. An AGFI value of 0.994 indicates a good fit. The NFI is 0.999, above the acceptable limit, signifying a strong model fit. A CFI value of 1.000 is indicative of a perfect fit. The TLI score is 1.024, affirming a good model fit. The RMSEA is recorded at less than the critical value of 0.05, indicating an excellent fit for the model.

Table 53: Estimate table for CFA on Infrastructure Facilities

Source: SPSS Output for Primary Data

			Estimate	S.E.	C.R.	P
IF1	<---	IF	1.000			
IF2	<---	IF	.801	.109	7.352	***
IF3	<---	IF	1.112	.113	9.861	***
IF4	<---	IF	.903	.120	7.501	***
IF5	<---	IF	.954	.113	8.468	***

All five indicators (IF1 to IF5) demonstrate strong statistical significance, confirming their reliability as effective measures of the Infrastructure Facilities construct. The analysis reveals that each indicator exhibits high critical ratios, substantiating their effectiveness in capturing the essence of the latent variable. This robust statistical evidence highlights the importance of these indicators in providing accurate and trustworthy measurements, reinforcing their role in the assessment of infrastructure facilities.

Confirmatory Factor Analysis on Awareness of Government Policies:

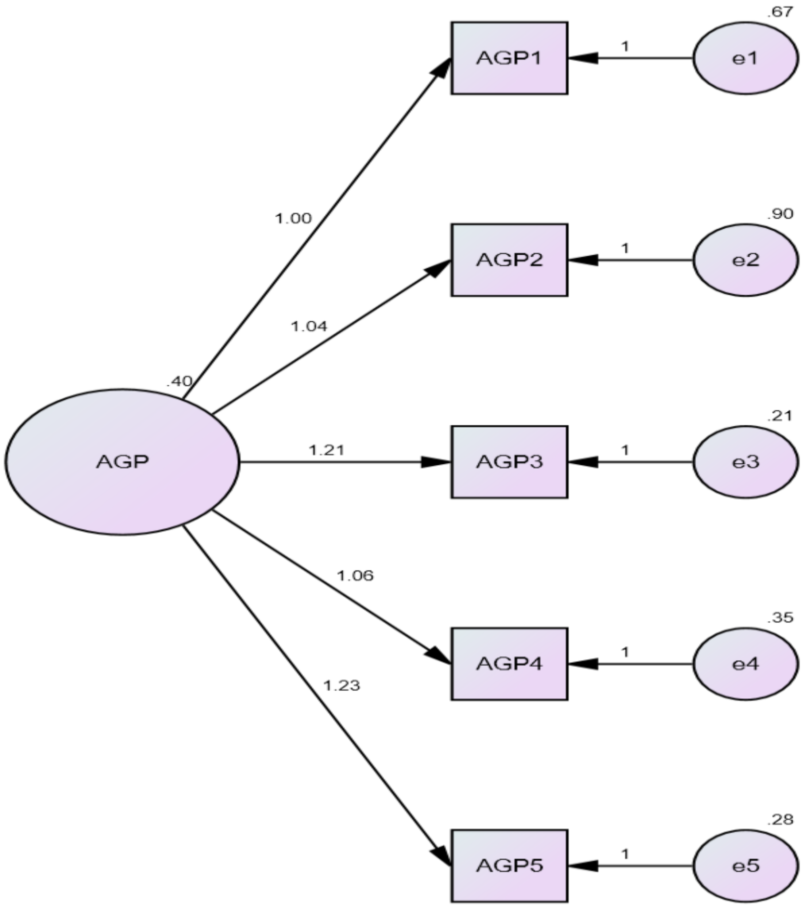


Figure 66: Confirmatory Factor Analysis on Awareness of Government Policies

Table 54: CFA fit indices table on Awareness of Government Policies

Indices	Abbreviation	Obtained Value	Recommended criteria
Reliability test	Cronbach's Alpha	0.835	>7 good fit
P Value		0.184	>0.05 model fit
Normed Chi-square	χ^2 /df	1.505	$1 < \chi^2 /df < 3$
Goodness-of-fit index	GFI	0.984	>0.90
Adjusted GFI	AGFI	0.951	>0.80
Normed fit index	NFI	0.980	>0.90
Comparative fit index	CFI	0.993	>0.90
Tucker–Lewis index	TLI	0.986	>0.90
Root mean square error of approximation	RMSEA	0.053	<0.05 good fit < 0.08 acceptable fit

The fit indices obtained from the Confirmatory Factor Analysis (CFA) on Awareness of Government Policies demonstrate strong reliability and fit. The Reliability Test, indicated by Cronbach's Alpha, yielded a value of 0.835, reflecting good internal consistency. The p-value is 0.184, which is greater than 0.05, suggesting an acceptable model fit. The Normed Chi-square (χ^2/df) value stood at 1.505, falling between 1 and 3, signifying a good fit.

The Goodness-of-Fit Index (GFI) was 0.984, indicating an excellent fit, while the Adjusted GFI (AGFI) was 0.951, further confirming this quality. The Normed Fit Index (NFI) recorded a value of 0.980, depicting a good fit. The Comparative Fit Index (CFI) reached 0.993, suggesting an excellent fit, and the Tucker–Lewis Index (TLI) stood at 0.986, also demonstrating an excellent fit. Finally, the Root Mean Square Error of Approximation (RMSEA) was 0.053, below the threshold of 0.05 for a good fit, and below 0.08 is considered acceptable, placing this value within the desirable range.

Table 55: Estimate table for CFA on Awareness of Government Policies
Source: SPSS Output for Primary Data

			Estimate	S.E.	C.R.	P
AGP1	<---	AGP	1.000			
AGP2	<---	AGP	1.039	.160	6.475	***
AGP3	<---	AGP	1.207	.140	8.593	***
AGP4	<---	AGP	1.061	.134	7.948	***
AGP5	<---	AGP	1.227	.145	8.447	***

All the indicators, identified as AGP1 through AGP5, demonstrate statistical significance and serve as reliable measures for the construct of Awareness of Government Policies. The analysis reveals high critical ratios alongside significant p-values, which together affirm the strength and dependability of these indicators in accurately capturing the essence of the underlying latent variable. This robust performance underscores their effectiveness in evaluating public awareness regarding government policies.

Confirmatory Factor Analysis on Extension Agency Contact:

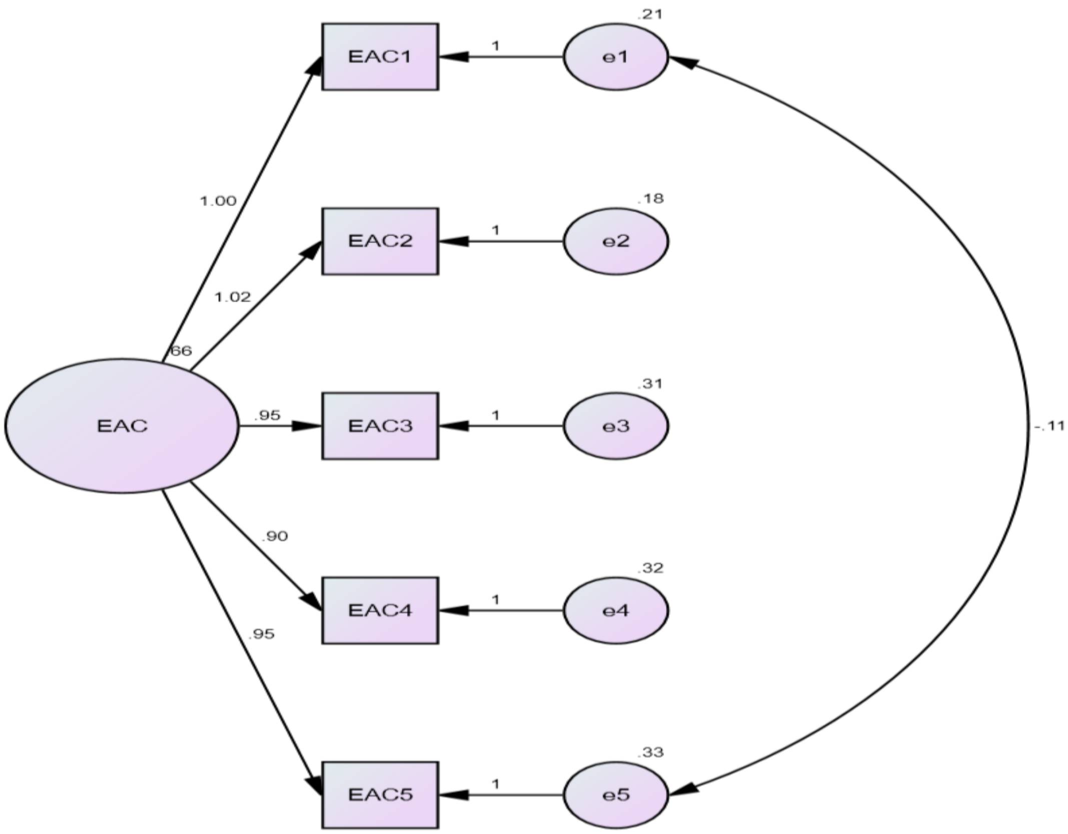


Figure 67: Confirmatory Factor Analysis on Extension Agency Contact

Table 56: CFA fit indices table on Extension Agency Contact
Source : SPSS AMOS Output

Indices	Abbreviation	Obtained Value	Recommended criteria
Reliability test	Cronbach's Alpha	0.915	>7 good fit
P Value		0.121	>0.05 model fit
Normed Chi-square	χ^2 /df	1.823	$1 < \chi^2$ /df < 3
Goodness-of-fit index	GFI	0.985	>0.90
Adjusted GFI	AGFI	0.943	>0.80
Normed fit index	NFI	0.988	>0.90
Comparative fit index	CFI	0.995	>0.90
Tucker–Lewis index	TLI	0.987	>0.90
Root mean square error of approximation	RMSEA	0.068	<0.05 good fit < 0.08 acceptable fit

The model demonstrates a high level of reliability, particularly with a Cronbach's Alpha of 0.915, which is well above the recommended threshold of 0.70. The P-value of 0.121 suggests no significant deviation from the model fit, as it exceeds the 0.05 criterion. The Normed Chi-square value of 1.823 comfortably falls within the accepted range of 1 to 3, supporting the adequacy of the model fit. Goodness-of-fit indices, the GFI and AGFI values (0.985 and 0.943, respectively) exceed the suggested benchmarks, indicating a strong fit and a good model to the data.

The NFI, CFI, and TLI values (0.988, 0.995, and 0.987) all exceed the 0.90 threshold, reinforcing the conclusion that the model provides an excellent fit for the observed data. The RMSEA value of 0.068 is below the ideal threshold of 0.05, further supporting the idea of an appropriate model fit and validating the data by demonstrating its reliability.

Table 57: Estimate table for CFA on Extension Agency Contact
Source: SPSS Output for Primary Data

			Estimate	S.E.	C.R.	P
EAC1	<---	EAC	1.000			
EAC2	<---	EAC	1.023	.064	16.058	***
EAC3	<---	EAC	.950	.069	13.719	***
EAC4	<---	EAC	.896	.068	13.128	***
EAC5	<---	EAC	.952	.084	11.344	***

This table shows the estimated parameters related to the Extension Agency Contact factor. Each row represents a different aspect of the EAC being examined, and the values indicate the strength of the relationship between the observed variables and the EAC construct.

Confirmatory Factor Analysis on Farmers Perception:

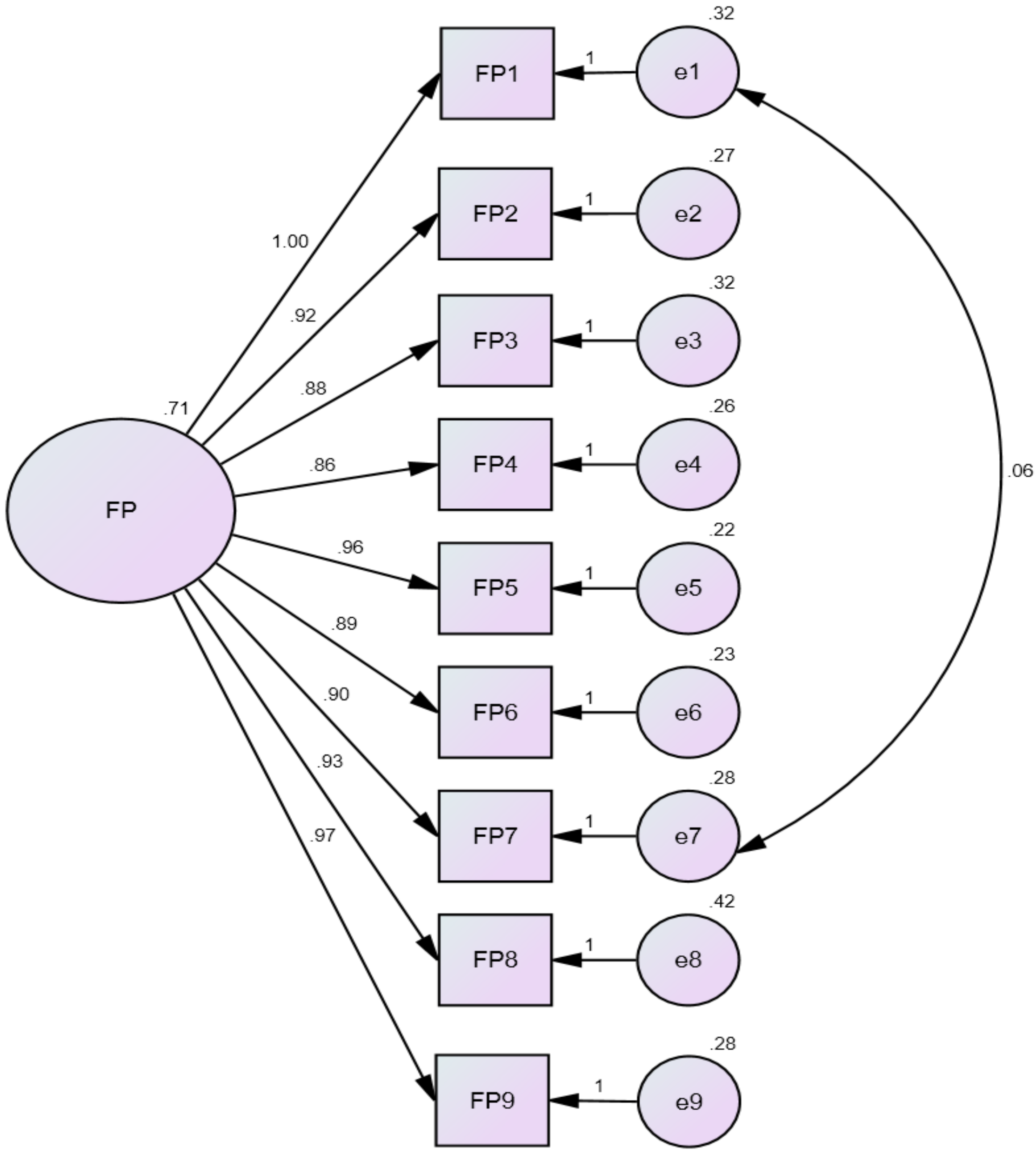


Figure 68: Confirmatory Factor Analysis on Farmers' Perception

Table 58: CFA fit indices table on Farmers Perception
Source: SPSS AMOS Output

Indices	Abbreviation	Obtained Value	Recommended criteria
Reliability test	Cronbach's Alpha	0.949	>7 good fit
P Value		0.254	>0.05 model fit
Normed Chi-square	χ^2 /df	1.192	$1 < \chi^2 /df < 3$
Goodness-of-fit index	GFI	0.974	>0.90
Adjusted GFI	AGFI	0.939	>0.80
Normed fit index	NFI	0.984	>0.90
Comparative fit index	CFI	0.997	>0.90
Tucker–Lewis index	TLI	0.995	>0.90
Root mean square error of approximation	RMSEA	0.033	<0.05 good fit < 0.08 acceptable fit

A Cronbach value of 0.949 suggests an excellent level of internal consistency among the measured items. A P value greater than 0.05 indicates that the model fits the data well, affirming its adequacy. A chi-square value of 1.192 falls well within the acceptable range, suggesting a good model fit. A GFI value greater than 0.90 is considered a sign of good fit; with a value of 0.974, the model demonstrates a strong fit with the data. An AGFI value exceeding 0.80 indicates a good fit, and the obtained value of 0.939 suggests a robust fit, effectively adjusting for model complexity.

The NFI should be above 0.90 to indicate a good fit; at 0.984, this model shows an excellent fit to the data. A CFI value greater than 0.90 is indicative of a good model. The value of 0.997 signals an exceptional fit compared to the baseline model. A TLI exceeding 0.90 indicates a strong model fit, with the obtained value of 0.995 confirming a superior fit to simpler models. A RMSEA value below 0.05 is considered indicative of a good fit; with a value of 0.033, this model is well-positioned, demonstrating a close fit to the population covariance matrix.

The table below encompasses a comprehensive list of indicators, referred to as FP1 to FP9, identified as statistically significant and reliable measures for assessing the Farmers' Perception construct. Each indicator has undergone rigorous statistical analysis, revealing high critical ratios alongside significance in p-values. These findings serve robustness and dependability of the indicators in effectively measuring the underlying latent variable associated with farmers' perceptions.

Table 59: Estimate table for CFA on Farmers' Perception
Source: SPSS Output for Primary Data

			Estimate	S.E.	C.R.	P
FP1	<---	FP	1.000			
FP2	<---	FP	1.017	.078	13.107	***
FP3	<---	FP	.901	.068	13.234	***
FP4	<---	FP	.867	.060	14.334	***
FP5	<---	FP	1.082	.077	14.057	***
FP6	<---	FP	.955	.073	13.027	***
FP7	<---	FP	.917	.062	14.801	***
FP8	<---	FP	1.027	.085	12.105	***
FP9	<---	FP	1.016	.079	12.856	***

Confirmatory Factor Analysis on initial measurement model with covariance:

The table below presents the fit indices from the initial measurement model, including reliability and various goodness-of-fit metrics.

Table 60: CFA fit indices table on initial measurement model with covariance
Source: SPSS AMOS Output

Indices	Abbreviation	Obtained Value	Recommended criteria
Reliability test	Cronbach's Alpha	0.890	>7 good fit
P Value		0.204	>0.05 model fit
Normed Chi-square	χ^2 /df	1.032	$1 < \chi^2 /\text{df} < 3$
Goodness-of-fit index	GFI	0.991	>0.90
Adjusted GFI	AGFI	0.990	>0.80
Normed fit index	NFI	0.910	>0.90
Comparative fit index	CFI	0.993	>0.90
Tucker–Lewis index	TLI	0.992	>0.90
Root mean square error of approximation	RMSEA	0.016	<0.05 good fit < 0.08 acceptable fit

The table shows a value greater than 0.70, indicating that the constructs represented by the measurement model possess high internal consistency. A higher Cronbach's Alpha reflects the robustness of the scales used within the model. A P value greater than 0.05

indicates a non-significant difference between the observed covariance matrix and the model-implied covariance matrix, suggesting that the model fits the data adequately. A higher P value is preferable as it supports the goodness of fit of the model.

The ratio of the chi-square statistic to the degrees of freedom falls within the ideal range of 1 to 3. Values in this interval suggest that the model provides a reasonably good approximation of the data, thus confirming the model's suitability. A GFI value of 0.991 exceeds the conventional benchmark of 0.90, indicating an almost perfect fit between the specified model and the observed data.

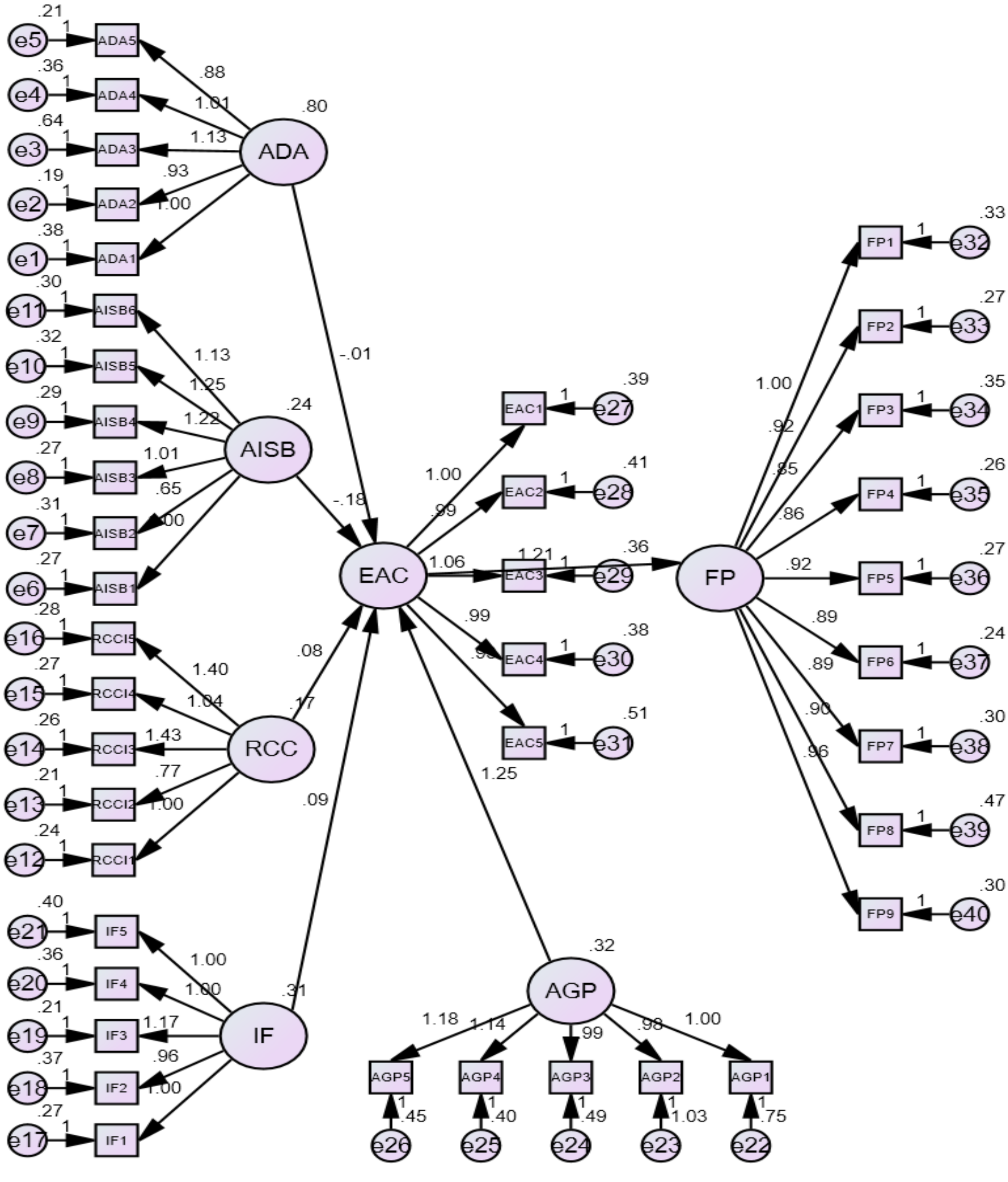


Figure 69: Initial measurement model with covariance

With an AGFI of 0.990, this index, which adjusts for the number of parameters in the model, also exceeds the threshold of 0.80, confirming that the model is robust and adequately fits the data while considering model complexity. An NFI value above 0.90 indicates that the specified model fits the data substantially better than a baseline model supporting the model's overall adequacy.

The CFI assesses the model's fit compared to an independent baseline model. A CFI value near 1.00, such as 0.993, reflects a strong comparative fit to describe the data. The TLI value above 0.90 indicates an excellent fit, emphasizing the model's ability to represent the data effectively without overfitting. RMSEA measures the discrepancy between the model's implied covariance matrix and the observed covariance matrix. A value less than 0.05 indicates a close fit of the model to the data, suggesting that the model has a high degree of accuracy in its representation.

Table 61: Estimate table for CFA on initial measurement model with covariance
Source: SPSS Output for Primary Data

			Estimate	S.E.	C.R.	P
EAC	<---	AISB	-.180	.064	-2.813	***
EAC	<---	ADA	-.009	.032	-.268	***
EAC	<---	RCC	.076	.074	1.026	***
EAC	<---	IF	.094	.054	1.733	***
EAC	<---	AGP	1.249	.168	7.424	***
FP	<---	EAC	1.206	.101	11.968	***
ADA1	<---	ADA	1.000			
ADA2	<---	ADA	.930	.064	14.523	***
ADA3	<---	ADA	1.128	.093	12.113	***
ADA4	<---	ADA	1.005	.076	13.222	***
ADA5	<---	ADA	.885	.063	14.042	***
AISB1	<---	AISB	1.000			
AISB2	<---	AISB	.654	.110	5.960	***
AISB3	<---	AISB	1.014	.127	8.004	***
AISB4	<---	AISB	1.216	.143	8.480	***
AISB5	<---	AISB	1.250	.149	8.386	***
AISB6	<---	AISB	1.125	.138	8.139	***
RCCI1	<---	RCC	1.000			
RCCI2	<---	RCC	.769	.123	6.270	***
RCCI3	<---	RCC	1.434	.188	7.646	***
RCCI4	<---	RCC	1.040	.152	6.822	***
RCCI5	<---	RCC	1.399	.185	7.552	***
IF1	<---	IF	1.000			
IF2	<---	IF	.959	.118	8.161	***

			Estimate	S.E.	C.R.	P
IF3	<---	IF	1.170	.120	9.785	***
IF4	<---	IF	1.003	.119	8.426	***
IF5	<---	IF	1.001	.123	8.167	***
AGP1	<---	AGP	1.000			
AGP2	<---	AGP	.980	.179	5.488	***
AGP3	<---	AGP	.989	.150	6.612	***
AGP4	<---	AGP	1.139	.158	7.204	***
AGP5	<---	AGP	1.177	.165	7.140	***
EAC1	<---	EAC	1.000			
EAC2	<---	EAC	.985	.094	10.445	***
EAC3	<---	EAC	1.061	.096	11.114	***
EAC4	<---	EAC	.989	.093	10.634	***
EAC5	<---	EAC	.934	.098	9.488	***
FP1	<---	FP	1.000			
FP2	<---	FP	.923	.066	14.065	***
FP3	<---	FP	.854	.068	12.537	***
FP4	<---	FP	.859	.063	13.648	***
FP5	<---	FP	.922	.066	14.014	***
FP6	<---	FP	.886	.063	14.151	***
FP7	<---	FP	.885	.066	13.421	***
FP8	<---	FP	.896	.076	11.865	***
FP9	<---	FP	.956	.069	13.952	***

All path coefficients and factor loadings are statistically significant, demonstrating strong support for the hypothesized relationships proposed in the model. They estimate robust and meaningful connections between the latent variables and their respective indicators.

6.11 Analyzing Institutional framework through Structural Equation Modeling

NGO:

In the institutional Structural Equation Modeling (SEM) framework as presented in fig 70, the Non-Governmental Organizations (NGOs) was the distinct extension agency type. The model demonstrates that “Extension Agency Contact – NGO” has a meaningful direct influence on Farmers' Perception (path coefficient = 6.48). Importantly, the construct “Extension Agency Contact – NGO” exhibits an R^2 value of 15.46%. And this variance can be moderately explained by its predictors namely, Agricultural Information Seeking Behavior and Awareness of Government Policies, which have direct effects. This indicates that farmers who actively seek agricultural information are more likely to engage with NGO services, and awareness of government policies may further encourage such engagement by legitimizing NGO roles. The R^2 value for Farmers' Perception (16.32%) is explained by all these factors shaping it.

The SEM framework also highlights significant covariances among three core constructs: Agricultural Information Seeking Behavior, Recognition of Climate Change Impact, and Infrastructure Facilities. The numerical values over the bidirectional arrows indicate the covariance strength. This signifies how these factors coexist or co-evolve amongst each other. Notably, Agricultural Information Seeking Behavior shows meaningful covariance with both Recognition of Climate Change Impact (2.88) and Infrastructure Facilities (9.09), suggesting that farmers who actively seek agricultural information are generally more attuned to climate change impacts and better connected to physical or service infrastructure. The covariance between AISB and Infrastructure Facilities is 9.09, a relatively strong value, indicates a interdependence between farmers who actively seek agricultural information are also the ones well connected to infrastructural access or development. This implies that infrastructure such as irrigation, weather forecasting services, or digital infrastructure significantly shape how farmers perceive and respond to climate variability. Finally, these associations reinforce the idea that awareness, perception, and structural capacity are mutually reinforcing dimensions in the context of institutional and behavioral adaptation.

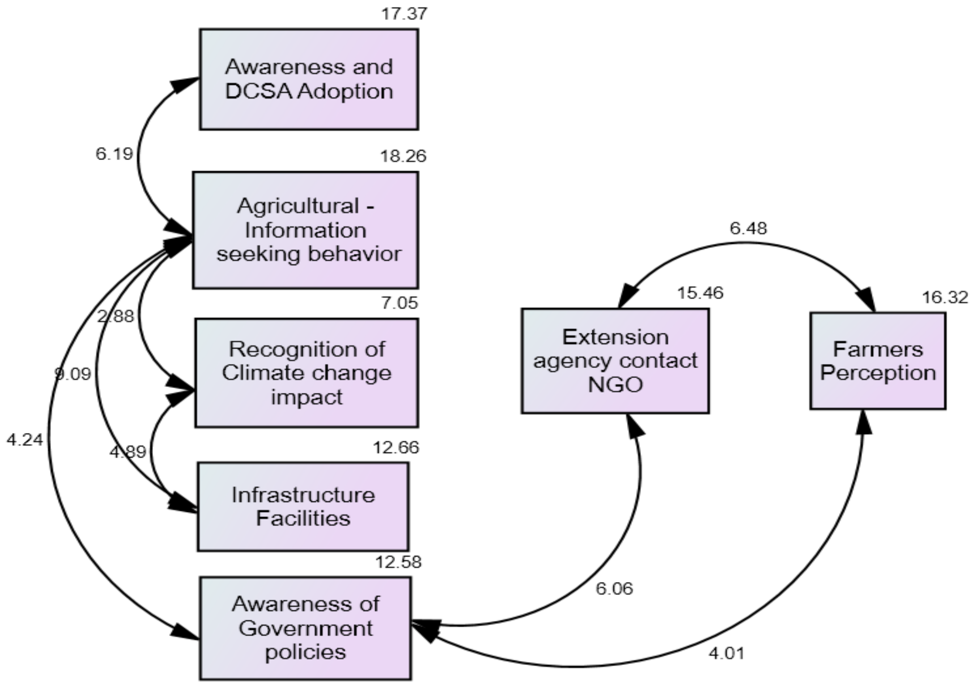


Figure. 70. Understanding Farmer Perceptions on DCSA Adoption Through NGO Interventions
Source: SPSS AMOS output

Table 62: CFA fit indices table on Path Analysis on NGO
Source SPSS AMOS Output

Indices	Abbreviation	Obtained Value	Recommended criteria
P Value		0.751	>0.05 model fit
Normed Chi-square	χ^2 /df	0.715	$1 < \chi^2$ /df < 3
Goodness-of-fit index	GFI	0.923	>0.90
Adjusted GFI	AGFI	0.834	>0.80
Normed fit index	NFI	0.967	>0.90
Comparative fit index	CFI	0.999	>0.90
Tucker–Lewis index	TLI	0.998	>0.90
Root mean square error of approximation	RMSEA	0.000	<0.05 good fit < 0.08 acceptable fit

Private agencies:

The Institutional Structural Equation Modeling (SEM) framework presented in fig 71, integrates private sector actors as distinct agricultural extension service providers. This offers insights into how farmers interact with institutional structures. The R^2 value for Awareness and DCSA Adoption is 17.37%, indicating that the model explains 17.37% of the variance in this construct. Similarly Agricultural Information Seeking Behavior → R^2 = 16.22% and Farmers' Perception → R^2 = 16.32%. These values do not reflect the influence from those constructs, but rather the influence on them. Path Coefficients (e.g., Infrastructure Facilities ➡ Awareness of Government Policies = –3.94), indicate standardized regression weights (beta coefficients) or Standardized Path Coefficients or Beta Weights (β). It represents the direction and strength of influence between two variables.They can be positive (supportive) or negative (inhibitory). Notably, the model reveals that Private Extension Agency Contact is strongly influenced by Awareness of Government Policies (path coefficient = 4.23), with the construct achieving an R^2 value of 14.73%. This suggests that a moderate portion of farmers' engagement with private extension services can be explained by their awareness of policy frameworks. This signifies that there exists a complementary, rather than substitutive, relationship between state and private extension actors. The model also shows that Private Extension Contact significantly contributes to shaping Farmers' Perception (path coefficient = 5.37, R^2 = 16.32%), emphasizing the role of private institutions in impacting farmers and the ways they interpret and respond to agricultural and environmental challenges.

A significant thing observed is the negative path coefficient between Infrastructure Facilities and Awareness of Government Policies (β = –3.94). It implies that improved access to infrastructure inadvertently reduce farmers' reliance on or exposure to formal policy frameworks; possibly due to greater market orientation or stronger dependence on non-governmental service providers in well-developed regions. This finding has policy significance, suggesting that government communication strategies must remain targeted even in infrastructure-rich areas to maintain policy visibility and impact.

It was found that few mutual covariances, such as between Agricultural Information Seeking Behavior and Recognition of Climate Change Impact (7.28), and between Recognition of Climate Change Impact and Infrastructure Facilities (3.11). Overall, the model highlights that private sector-led extension systems are influential institutional actors, especially when farmers already possess infrastructural access and program awareness.

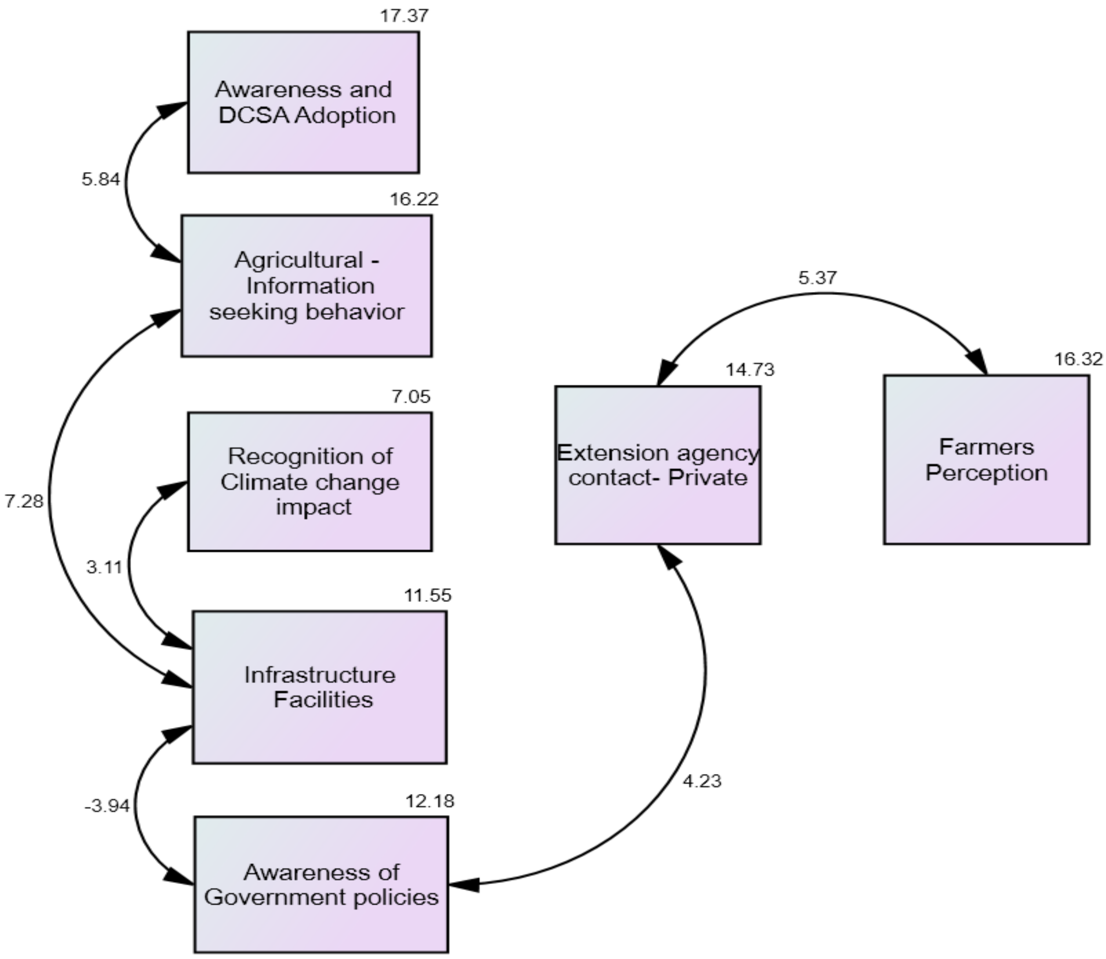


Figure . 71. Understanding Farmer Perceptions on DCSA Adoption through private Interventions

Source: SPSS AMOS output

Table 63: CFA fit indices table on Path Analysis on Private Agencies
Source: SPSS AMOS Output

Indices	Abbreviation	Obtained Value	Recommended criteria
P Value		0.696	>0.05 model fit
Normed Chi-square	χ^2 /df	0.785	1 < χ^2 /df < 3
Goodness-of-fit index	GFI	0.901	>0.90
Adjusted GFI	AGFI	0.805	>0.80
Normed fit index	NFI	0.990	>0.90
Comparative fit index	CFI	0.999	>0.90
Tucker–Lewis index	TLI	0.998	>0.90
Root mean square error of approximation	RMSEA	0.000	<0.05 good fit < 0.08 acceptable fit

Government:

In this model, Government Extension Agency Contact serves as a key intermediary construct, with an R^2 value of 7.12%, indicating that its engagement is modestly explained by contributing variables, most notably Recognition of Climatic Change Impact (path coefficient = 1.51) and Infrastructure Facilities (4.40). These relationships suggest that farmers who recognize the effects of climate change and have access to infrastructure are more likely to interact with government agencies.

In this SEM framework, Farmer Perceptions are directly shaped by Awareness of Government Policies, as evidenced by a path coefficient of 3.65 and an R^2 value of 12.40%, indicating that policy awareness explains a meaningful portion of how farmers perceive and respond to their agricultural environment. This underscores the importance of not only the availability of institutional support but also the visibility and clarity of policy communication to the farming community. Contrary to initial expectations, Government Extension Agency Contact does not directly influence Farmer Perceptions in the model. This suggests that public extension services do not significantly shape farmers' attitudes unless supported by a strong understanding of the policies they are meant to implement highlighting a critical area for policy-action alignment.

The model also presents important covariances among the constructs. For instance, Agricultural Information Seeking Behavior showed a strong relationships with Recognition of Climatic Change Impact (4.50), and Awareness of DCSA Adoption with IF (2.59). This implies that proactive information seeking farmers are more likely to be aware of climate change impacts and are also the ones who are ready to adopt DCSA services.

Although the SEM framework does not include a direct path between Recognition of Climatic Change Impact and Infrastructure Facilities, the model reveals a substantial covariance value of 7.29 between the two constructs. The high covariance points out to a strong empirical association, suggesting that farmers who are more aware of climate change impacts are also likely to have better access to infrastructure, or vice versa. This relationship is driven by underlying contextual factors such as regional development, institutional support systems, or exposure to external interventions that simultaneously enhance both climate awareness and infrastructural availability. It higlights the importance of recognizing that institutional elements influence each other indirectly or through unobserved mechanisms, which are crucial for designing holistic policy and extension strategies.

The final influence on Farmers' Perception is modest (12.40), implying that the government extension system plays more of a supportive or background role in influencing digital adoption compared to private or NGO`s. The weaker association also reflects gaps in service personalization, digital readiness, or outreach intensity in public systems. On the other hand, the presence of steady covariances among constructs (e.g., between Awareness of DCSA and Government Policies at 2.59) suggests that policy-level knowledge and infrastructure access still interplay to indirectly shape public engagement pathways.

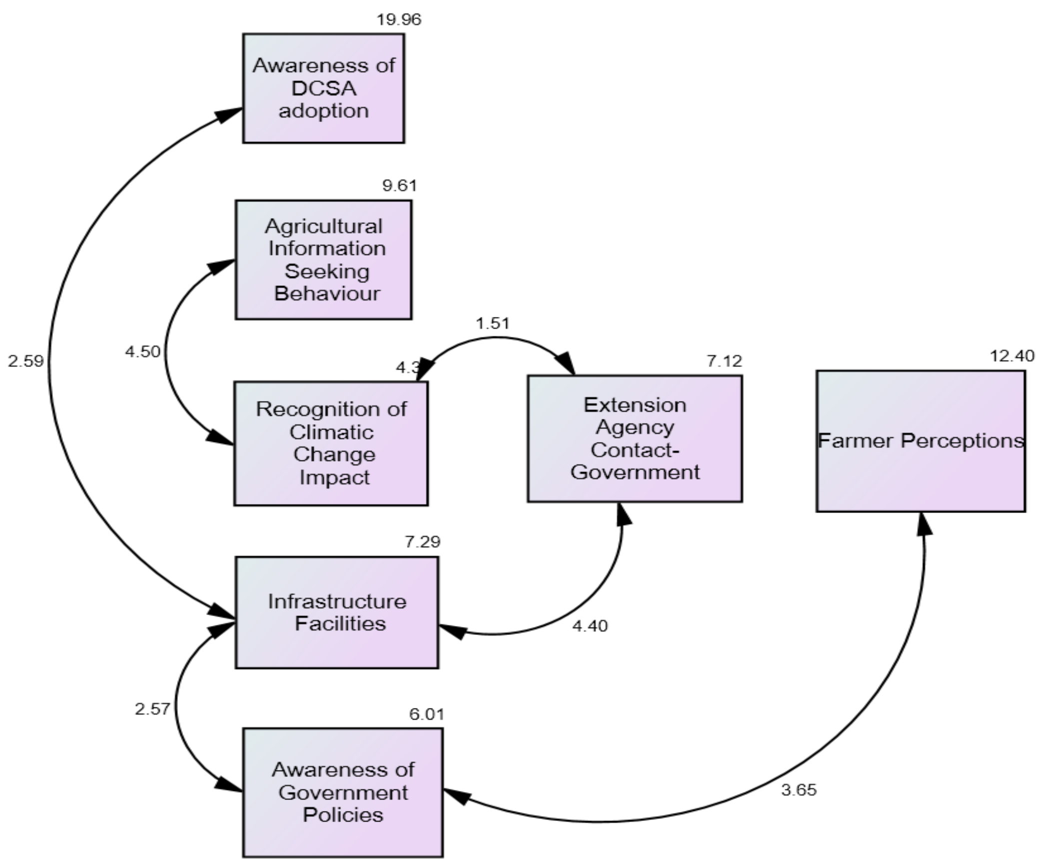


Figure. 72. Understanding Farmer Perceptions on DCSA Adoption through government interventions

Table 64: CFA fit indices table on Path Analysis on Government
Source: SPSS AMOS Output

Indices	Abbreviation	Obtained Value	Recommended criteria
P Value		0.712	>0.05 model fit
Normed Chi-square	χ^2 /df	0.736	$1 < \chi^2 /df < 3$
Goodness-of-fit index	GFI	0.951	>0.90
Adjusted GFI	AGFI	0.852	>0.80
Normed fit index	NFI	0.971	>0.90
Comparative fit index	CFI	0.915	>0.90
Tucker–Lewis index	TLI	0.988	>0.90
Root mean square error of approximation	RMSEA	0.002	<0.05 good fit < 0.08 acceptable fit

CHAPTER 7: DISCUSSION

The analysis of average scores revealed three key themes that resonate deeply with farmers: awareness of climate variability, utilization of mobile-based information services, and understanding of climate-resilient digital practices. The extremely high level of agreement regarding climate-related changes (mean = 4.69) highlights farmers' keen sensitivity to environmental changes, especially related to rainfall, temperature, and pest behavior. Furthermore, the strong acceptance of mobile applications and helplines (mean = 4.40) demonstrates the increasing usability and reach of digital channels in rural areas, aided by mobile access and intuitive interfaces. (Aravindh Kumar et al., 2020; Nandhini & Rohini, 2022) Additionally, farmers' favorable reaction to localized, reliable digital information (mean = 4.35) emphasizes the significance of not only content availability but also its contextual relevance. (Chandrasekaran, 2020; Abraham, 2020)

On the other hand, examining the standard deviations showcased some interesting polarization, especially when it comes to awareness of specific DCSA tools, government subsidies, and how effective training or field demonstrations are perceived to be. The significant variation in these responses highlights differences in outreach efforts, access to digital infrastructure, and trust in institutional sources. These differences often arise from varying levels of extension support, socioeconomic factors, and geographic accessibility. (Akudugu et al., 2023; Dwomoh et al., 2023) This really points to the importance of adopting a more inclusive and consistent approach to sharing information.

7.1 Synthesis of findings for different agro-ecological zones

Regression analyses across four districts revealed a regionally differentiated view of the key influences on DCSA perception.

Pudukottai:

In Pudukottai, awareness of government policies and NGO contact came out as the strongest positive predictors. Farmers showed trust and satisfaction with the NGO extension agency contact. This was mainly due to two reasons: farmers were happy with the effective pest resolution provided by the VKC plant clinic. Additionally, the timing and different formats of advisory information, such as digital and non-digital formats, made accessing agricultural information easier for them. The farmers who participated in the survey were primarily women farmers compared to men. Farmers had increased policy literacy due to NGO-led interventions. This play a pivotal role in shaping favorable perceptions amidst farmers. However, information-seeking behavior showed a negative influence. This could be largely attributed to the fact that the farmers perceived DCSA ecosystem was fragmentation or felt they were overload with information networks.

One of the successful case among the farmers interviewed is a farmer who transitioned from mere awareness to full adoption of digital advisory services with structured support. Initially, he was restrained to use or learn to use digital advisory services as he was constrained by time and a demanding daily schedule with his farm work. The farmer acknowledged not having the time or resources to independently learn or engage with digital tools. However, with consistent support from the NGO team, and the local change who championed the agricultural information dissemination, this individual was gradually introduced to agricultural advisories through audio messages, WhatsApp updates, video trainings, and in-person demonstrations. These step-by-step interventions helped bridge the gap between awareness and practical adoption. The turning point in the farmer's mindset came after a critical event, i.e. extended droughts during 2018, which made him realize the importance of timely and relevant advisory information.

Thanjavur:

In Thanjavur, the highest perception scores were driven by strong NGO engagement ($\beta = 0.729$). The implication of this farmers value of participatory and trust-based extension. Socio-economic demographic analysis revealed that men and women farmer had near equal participation. While awareness of DCSA and government policies remained positive contributors, infrastructure and climate change awareness paradoxically showed negative relationships. This may be attributed to unmet expectations or heightened risk sensitivity without corresponding support, emphasizing the need to align awareness-building with practical infrastructure support. Farmers had high awareness of digital schemes and government supported platforms. They were inclined to organic ways of farming. There was significant dissatisfaction about water needs not met as the irrigation from the Mettur dam over the recent years have not been enough. They were also discontent about inadequate storage facilities resulting enormous post-harvest losses.

A smallholding paddy farmer shared how blended advisory ecosystems that combined digital tools with personalized extension helped him build resilience and also make informed agricultural decisions. Despite not having a smartphone, he said he was able to stay updated on agricultural information through regular voice messages sent by the NGO. With the help of his daughter, he accesses these messages and received timely guidance on crop health, climate updates, and best practices.

What sets this farmers journey apart is the consistent support he received from NGO extension officers, who maintain personal contact through frequent field visits. These visits also accommodated use cases such as soil testing, seed replacement awareness (vidhai parimatram), and training in organic manuring practices. He mentioned all of these supports have contributed to better yield and sustainable practices on his farm.

In a period of time, he was also exposed to digital advisory services such as the Uzhavan app, Plantix, YouTube farming channels, and WhatsApp groups. However, he notes that while these platforms are informative, they often lack dynamic or localized content, especially regarding pesticide management, organic farming techniques, and fertilizer recommendations. Moreover, he quoted concerns around privacy and repetition of content while using platforms like YouTube for learning new farming practices.

To navigate weather variability, particularly unpredictable monsoons and droughts, the farmer relied on a mix of All India Radio, Rice Research center, Kisan Cal center, scientific call centers of Tamil Nadu Agriculture University's (available from 7 a.m. to 7 p.m.), and NGO's highly accurate climate voice advisories, which according to him is 90% precise. However, he highlights a critical need: weather forecasts should be available at least 10 days in advance to allow meaningful agricultural planning. The current 72-hour updates, though helpful, often arrive too late to mitigate crop risk.

An active member of a Farmer Producer Organization (FPO), another farmer participates in Zoom-based training sessions, joins discussions through WhatsApp and YouTube, and learns from peer farmers. His trust in fellow farmers' lived experience and NGO's hands-on guidance shapes his practical decisions more than top-down digital extension advisory approach. He believes that practical observation, verified through personal trials or trusted advice, holds more weight than theoretical inputs alone. His story underscores a powerful insight: combining ICT tools with human-centered, participatory advisory approaches like NGO's locally embedded support bridges the digital divide.

Kancheepuram:

In Kancheepuram, the model was not statistically significant, reflecting weak institutional traction and a lack of cohesive extension engagement. This was decided to be analyzed further using structural equation modeling in the hope that we could find interrelated or indirect effects that might exist. But in general the field observations showed farmers increased satisfaction with extension agency due to provision of improved market and consumer connectivity services. Since farmers here were predominantly supported by the private extension agency contact though they found the bridging of farmers with market related information and consumers were beneficial for them, they had to pay if they were to receive such localized services after the project pilot period. The financial sustainability of such initiative was something not effective for small/marginal farmers.

A smallholder farmer who cultivated crops like paddy and groundnut said he faced limited access to timely agricultural advice and weather-related information. Because of this he mentioned he had struggled with low yields and input inefficiencies. After enrolling in the mKRISHI program, the farmer began receiving timely voice messages and personalized advisories in the regional language, which is Tamil. These messages included weather forecasts, pest alerts, and information on optimal times for sowing and fertilizer application. He also had access to range of video content to learn on farming practices and participated in community-based training sessions.

One of the critical benefits was his shift to climate-resilient practices after understanding the changing monsoon patterns through weather alerts. He mentioned with this knowledge he adjusted his sowing schedule and irrigation timing, which helped him avoid crop loss.

Chengalpattu:

In Chengalpattu, the government extension contact was the only significant influencer of farmers' perception. Farmers said the extension agency effectively helped solve farmers' queries. But they were met infrequently. While other factors such as DCSA awareness and infrastructure were present, their impacts were statistically weak, indicating a need for improved communication, clearer policy articulation, and stronger delivery systems. The most voiced concern in this study area was that high socioeconomic status equaled better contact with extension agents, which in turn translated to higher access to agricultural information.(Dwomoh et al., 2023; Ferdinand et al., 2021b) Farmers in general relied on the guidance of peers and progressive farmers as their reliable source of agricultural information. (Anabel et al., 2018) With proximity to urban markets, part-time farmers who were making a dual income existed in the sampled population. (Jabbar et al., 2023)

A farmer mentioned how the Uzhavan app significantly enhanced his decision-making in crop protection and financial access. Despite limited formal training, he tried the app as he was curious about its AI-based pest and disease identification feature, which learnt from a fellow farmer. This feature allowed him to quickly detect crop issues by uploading photos through his smartphone. This real-time support helped him apply appropriate countermeasures in advance, and helped to reduce crop damage. Importantly his reliance and dependency on the local agricultural input pesticide dealer was reduced.

Additionally, the direct input subsidy scheme, integrated through the app, enabled him to apply directly for financial assistance without the need to visit local offices or depend on middlemen. He received timely notifications on eligibility, application deadlines, and disbursement status. He said he could also know when the extension agent would visit him as he could refer to the schedule from the app.

7.2 Results of analytical framework validation

Awareness and DCSA Adoption:

It has been prominently observed during the interviews with farmers that awareness of DCSA services has not translated into DCSA adoption. Farmers who were aware were not motivated to use them because they did not perceive them as having direct benefits and were skeptical about the ease of user navigation. All these factors point to barriers that exist towards adoption: an institutional void that can facilitate adoption, access to infrastructure, and other challenges. Conversely, in places where awareness translated into adoption, it was enabled by factors such as ease of use and format of the advisory, receipt of the advisory at a convenient time, and the availability of an agricultural specialist or community representative who eased and facilitated the adoption process. Ease of use and format of the advisory refer to voice advisories provided at a convenient time to farmers' registered mobile numbers. Non-digital formats of advisories were contextualized and available specific to the location. These were the factors that were strongly and consistently cited by the farmers affiliated with MSSRF-VKC in pudukottai and tanjavur, which was lagging in government extension support.

In case of Kancheepuram farmers who were mostly affiliated with private systems, the main reason for adoption is the contextualized advisories based on real-time weather alerts. The important factor that eased adoption, even among low-literate farmers, was the provision of a voice-based interactive voice response system.

All five indicators, including conducting workshops and field demonstrations to educate farmers(ADA1), promoting awareness among farmers through extension channels(ADA2), awareness of specific DCSA tools (apps, platforms) (ADA3), credible information enhancing farmers' trust in adoption(ADA4), and knowledge of climate-resilient digital practices(ADA5), significantly contributed to the awareness and DCSA adoption construct. Each of the five observed indicators (ADA1 to ADA5) played a substantial role in the latent construct, evidenced by strong standardized factor loadings ranging from 0.79 to 1.19. However, among these, awareness of specific DCSA tools (apps, platforms) was especially significant, boasting the highest loading of 1.19. This factor was pivotal in shaping farmers' awareness and adoption behaviors. It indicates that the government should implement necessary promotional measures for the available DCSA services, which could markedly increase adoption rates. The error variances associated with the indicators were relatively low, demonstrating the reliability of the measures, with ADA5 (knowledge of climate-resilient digital practices) exhibiting the lowest unexplained variance at 0.17. Notably, a small negative correlation (-0.14) was observed between the error terms of ADA3 and ADA5. This suggests that there could be potential in respondents' interpretations, a complementary relationship or there could exist shared external influences, such as digital illiteracy, mobile phone accessibility issues, and internet access challenges. This reflects a convergence in how farmers perceive digital tools and climate-resilient practices, possibly due to integrated extension campaigns or bundled policy initiatives. (Balasundram et al., 2023; Jabbar et al., 2022b) Policymakers should recognize this linkage and design holistic awareness programs that simultaneously promote tool-specific knowledge alongside broader climate-smart digital literacy, thereby enhancing the efficacy of adoption strategies.

<u>Agricultural Information Seeking Behaviour</u>:

Farmers in the appropriate ecosystem, with consistent institutional support, were motivated to learn and seek agricultural information. They even registered for training related to organic farming to build resilience against climate change and adopt new agricultural technologies in general. However, most of them rely on their inherited knowledge passed down through generations or prefer the more convenient option of learning from their peers. Regarding the study, it was difficult to compare the differences in adoption by agroecological zone. What distinguished the adoption was the institutional support. Digital illiteracy never hindered the farmers in their agricultural information-seeking behavior. This was evident when the village knowledge center (MSSRF) was in easily accessible areas for villagers, providing basic ICT infrastructure and having a trained individual in ICT to assist villagers who were illiterate or faced digital literacy challenges. Women also increasingly utilized advisory services when supported by female change agents from the same community. Socio-economic or caste issues were reported as insignificant by the interviewed farmers in this context. (Boateng et al., 2024)

In the case of Kancheepuram farmers, who were mostly affiliated with private systems, their agricultural information-seeking behavior was motivated by the quick response time for the queries they asked, either through voice messages, SMS, or photo queries. They reported In the case of Kancheepuram farmers, who were mostly connected to private systems, their agricultural information-seeking behavior was driven by the quick response time for the queries they submitted, whether through voice messages, SMS, or photo queries. They reported receiving responses within 3 to 6 hours. In contrast, farmers in Chengalpattu noted that they were contacted by extension agents once a month, whereas those in Kancheepuram were met with weekly. Meanwhile, farmers in Pudukottai and Tanjavur were supported by Village Knowledge Centers, an institutional setup where they could seek advice from experts on a daily basis. The downtime for receiving any response to their queries through the DCSA service typically takes 1 or 2 days. They were contacted by extension agents once a month, while in Kancheepuram they met weekly. Those in Pudukottai and Tanjavur were facilitated through Village Knowledge Centers, where they could receive advice from experts on a daily basis. The downtime for receiving any response to their queries through the DCSA service usually takes one or two days.

All indicators related to agricultural information-seeking behavior, such as the use of mobile apps, helplines, or websites (AISB1), participation in training sessions (AISB2), visits to agri-dealers and agri-kiosks (AISB3), the dynamic and contextualized nature of information (AISB4), seeking advice from peers or local leaders (AISB5), and the provision of reliable and precise information (AISB6), were significant and made substantial contributions to the construct. The standardized factor loadings range from 0.64 to 1.15, with AISB5 (seeking advice from peers or local leaders) and AISB4 (clear and straightforward information delivery) highlighting their strong contributions. A positive correlation of 0.20 is observed between the error terms of AISB4 and AISB6; this implies a link and synergy between dynamic and contextualized information and the reliability and precision of information. These insights emphasize that the key to effective agricultural advisories is localization or contextuality combined with simplicity and reliability.

For policymakers, this means they have to design integrated communication strategies that deliver timely, localized, and technically accurate content—such as mobile advisories and region-specific weather and crop alerts. Messages could also be co-developed with trusted local intermediaries. Such approaches can strengthen both the perceived utility and trustworthiness of agricultural information services. (Krishna & Naik, 2020; Kumar & Karthikeyan, 2020)

Recognition of Climate Change Impact:

In the case of Kancheepuram farmers, the contextualized advisories, especially regarding real-time weather data, helped the farmers recognize climate risks and motivated them to develop adaptation strategies. In Tanjavur, farmers became increasingly aware of rising pest-related issues and were registering to receive certification in organic farming methods. In Chengalpattu, farmers mostly acknowledged climate change and felt its impact. However, few recognized that DCSA could be an adaptive measure in response. During interviews with farmers, we inquired about the adaptation strategies they preferred. For instance, Pudukkottai, which is a relatively drought-prone district, showed a higher adoption of drought-resistant varieties, followed by rainwater harvesting. In Chengalpattu, many farmers implemented rainwater harvesting along with water-saving techniques. The region indicated that farmers were significantly responsive to water management initiatives. In Thanjavur, a traditional rice belt with established irrigation systems, the emphasis is clearly on adjusting planting dates and relying on irrigation rather than modifying crops. This suggests an effort to maintain cropping intensity by adjusting timing rather than crop type. Lastly, in Kancheepuram, we received relatively moderate responses across all options we provided. This could indicate that farmers perceived comparatively moderate exposure to risk. There was no singular dominant adaptive strategy. From our data, we understand that farmers' recognition of climate change and its impact was greatly shaped by geographic and agroecological contexts. This also influenced their types of adaptive behaviors. All these underscore the importance of designing localized climate-resilient strategies. Adaptation measures should align with regional vulnerabilities, consider water access levels, and other farming practices.

Perceived changes in rainfall, temperature, pests (RCCI 1), awareness of climate-induced risks to crops (RCCI 2), it offers alerts and advice for safeguarding crops (RCCI 3), knowledge of adaptive farming measures (RCCI 4), and managing pests in an environmentally friendly way (RCCI 5) are the indicators related to the recognition of climate change impact construct. All the indicators significantly contributed to the construct. The loadings ranged from 0.66 to 1.76. This means that all the indicators providing different dimensions still meaningfully contributed to the construct. Of all the indicators, the two with high loadings were: it offers alerts and advice for safeguarding crops (RCCI 3) and managing pests in an environmentally friendly way (RCCI 5). This emphasizes the importance of action-oriented or significant practical aspects related to the recognition of climate change and its impact.

The error correlations were identified between perceived changes in rainfall, temperature, and pests (RCCI 1) as well as awareness of climate-induced risks to crops (RCCI 2). This suggests that farmers' firsthand observations of changing environmental conditions are closely linked to their awareness of potential threats to agriculture. Additionally, correlations were observed between awareness of climate-induced risks to crops (RCCI 2) and knowledge of adaptive farming measures (RCCI 4). This implies that recognition of risks is connected to a willingness or readiness to adopt adaptation strategies. These findings underscore that experiential learning could serve as an effective countermeasure solution.

From a policy standpoint, the findings highlight the importance of integrated awareness and capacity-building programs. Initiatives should not only communicate the risks posed by climate change but also demonstrate actionable, locally relevant adaptive farming practices. By grounding extension efforts in farmers' lived experiences of climate variability, policymakers can more effectively promote evidence-based adaptation strategies, thereby enhancing the resilience of agricultural communities. (Andrieu et al., 2017; Dinesh et al., 2018)

Infrastructure Facilities:

In Pudukottai and Tanjavur, farmers felt that the institutional infrastructure, in the form of village knowledge centers with ICT facilities, where access to information across any stage of the agricultural value chain was readily available, helped them. In Kancheepuram, farmers affiliated with the private extension felt that the specific DCSA service offered by them worked on any handset and also in low-bandwidth areas. This contrasted with the Chengalpattu farmers, who stated they were mandated to use an Android mobile phone with very good internet connectivity for the key DCSA service offered by the government.

Farmers know of the facilities at hiring centers for economical rates (IF1), They provide access to seeds and fertilizers near their location (IF2), This helps farmers obtain daily market prices for crops to facilitate product sales (IF3), Farmers check crop insurance and updates to receive compensation (IF4), and Access to ICT tools and mobile connectivity (IF5), all these indicators meaningfully contribute to the construction of infrastructure facilities. The factor loadings ranged from 0.80 to 1.11. The access to daily market prices for crops to facilitate product sales (IF3) and access to ICT tools and mobile connectivity (IF5) showed high loadings among all the indicators. This implies that digital and market-linked infrastructure is perceived as particularly valuable.

A negative minor error correlation was identified. Farmers are aware of the facilities at hiring centers for economical rates (IF1), and they check crop insurance and updates to receive compensation (IF4). This suggests a disconnect between physical service access and institutional risk-mitigation mechanisms. This mismatch could stem from the gap between awareness levels and accessibility challenges. (Akudugu et al., 2023; Quarshie et al., 2023)Additionally, correlations were observed between their access to seeds and fertilizers near their location (IF2) and the fact that farmers check crop insurance and updates to receive compensation (IF4). Farmers who perceive strong infrastructural support are also more likely to be aware of or benefit from institutional services like insurance. These findings indicate that farmers need better support through integrated infrastructure and services. (Karthikeyan, 2017; Dibbern et al., 2024) To assist them more effectively, policies should enhance local access to services, implement straightforward awareness campaigns about crop insurance, and establish one-stop centers (like digital kiosks) where farmers can obtain both farming inputs and insurance information. This approach can make services more beneficial, help farmers better prepare for risks, and ensure equitable access for all.

Awareness of Government Policies:

In Kancheepuram, farmers affiliated with the private extension acknowledged that the specific DCSA service they offered also provided many updates and knowledge about a range of other government schemes, which helped them stay informed. The same was true for farmers in Pudukottai and Thanjavur, who were affiliated with NGO extension systems. Farmers in Chengalpattu were able to access government policies and schemes through a specific module from within the DCSA service app itself.

Awareness of government subsidies and incentives (AGP1), knowledge of digital schemes (such as AgriStack and eNAM), and use of government-supported digital platforms (AGP 2); the daily weather forecast and advice provided to farmers for planning cultivation (AGP 3); solutions for pest infections and management of farmers' challenges (AGP 4); and information on the availability of seeds and fertilizers at government and private outlets (AGP 5) all significantly contributed to the awareness of government policies construct. The factor loadings ranged from 1.00 to 1.23. The daily weather forecast and advice provided to farmers for planning cultivation (AGP 3) and information on the availability of seeds and fertilizers at government and private outlets (AGP 5) had high loadings. The implication of this is that farmers strongly prefer actionable information that helps them with daily decision making and farming decisions. (Kumar & Karthikeyan, 2020)

However, awareness of government subsidies and incentives (AGP1) and the use of government-supported digital platforms (AGP2) had higher error levels. This indicates that although we recognize these as important aspects, farmers' awareness of them is inconsistent, suggesting that their usage may also be unreliable. Our understanding from field interviews is that this inconsistency results from issues like low digital skills, inadequate outreach or promotional activities, and a lack of clear communication from the government. Additionally, in the case of subsidies and incentives, there were no proper selection mechanisms, leading to the same farmer being chosen repeatedly. This was noted by other farmers who were relatively of lower socio-economic status or caste.

This highlights the need for better ways to share policy information and incorporate equitable selection mechanisms. Simply sending one-way messages is not enough. Instead, the government should focus on straightforward, localized awareness efforts like mobile messages, training sessions, and support from local organizations or NGOs like MSSRF-VKC, as seen in our study. Sharing this policy information through trusted channels, such as extension workers, community representatives, village information centers, and farmer groups, can make policies more accessible and beneficial for all farmers. (Abraham, 2022; Palanisamy & Bharadwaj, 2018)

Extension Agency contact

The extension agency interacts regularly with farmers(EAC1), fosters trust in information from NGOs, public, and private sources(EAC 2), promotes exposure to digital tools through extension agents(EAC 3), and provides timely information to farmers(EAC 4), and Extension agency offers invaluable advice and unwavering support for their agricultural endeavors(EAC 5), all indicators significantly contribute to the construct of extension agency contacts. All five indicators, had loadings ranging from 0.66 to 1.02. The strongest loadings was observed for fosters trust in information from NGOs, public, and private sources(EAC 2), and promotes exposure to digital tools through extension agents(EAC 3). This highlights the critical role of credibility dimension in DCSA facilitation. Notably, a negative correlation (-0.11) was observed between the error terms of extension agency interacts regularly with farmers(EAC1), and invaluable advice and unwavering support for their agricultural endeavors(EAC 5). This suggests that frequent interaction alone did not always translate into farmers perception where they considered support as valuable. This could mean that farmers viewed the contact as procedural or generic, rather than tailored and solution-oriented. Such findings indicate the we need a shift in policy to focus more on quality than of extension engagement. Policymakers should invest in training extension agents not only as technical advisors but also as trusted facilitators, capable of delivering context-specific, actionable insights. Integrating trust-building strategies, promoting multi-channel communication (including digital outreach), and establishing farmer feedback loops can help ensure that extension services are both accessible and meaningful to the diverse needs of farming communities. (Carbonell, 2016; Sindakis & Showkat, 2024)

Farmers perception

The perceived usefulness of digital services (FP1) includes providing updates on market prices (FP2), helping me prepare for weather changes (FP3), and offering updated information on subsidies and government schemes (FP4). The app provides complete access in the Tamil language, making it easy to use (FP5). Perceived improvements in productivity (FP6), willingness to adopt digital practices (FP7), compatibility with mobile phone configurations (FP8), and perceived reliability of digital information (FP9) all significantly contribute to farmers' perception construct, all nine indicators demonstrating strong standardized factor loadings ranging from 0.86 to 0.97. They contributed well to the farmers perception latent construct. Among these, perceptions of usefulness, reliability, and productivity enhancement are especially influential. A positive correlation (0.06) is observed between the error terms of perceived usefulness of digital services (FP1) and willingness to adopt digital practices (FP7). This validates our understanding from DOI theory that there exists a link between farmers' belief in the usefulness of digital services and their willingness to adopt such practices, even after accounting for the shared variance explained by the latent factor. This suggests that usefulness and adoption intent is shaped by overlapping, experience-based judgments, farmers who find digital tools practically beneficial are also more open to integrating them into routine farming decisions. (Everett M. Rogers, 2003; Evan T. Straub, 2009) From a policy standpoint, this highlights the importance of demonstrating tangible value through user-centric digital interventions. Policymakers could prioritize experiential learning opportunities, such as hands-on demonstrations, digital literacy workshops, and testimonials from peer farmers to foster both belief in and readiness for adoption. Building this bridge between perceived value and behavioral intention is essential for scaling advisory services equitably and sustainably.

Structural Model test:

The test of the structural model that assessed the factors influencing the adoption of Digital Climate-Smart Agriculture (DCSA) practices and effectiveness of institutions tested five latent variables—Awareness and DCSA Adoption (ADA), Agricultural Information-Seeking Behaviour (AISB), Recognition of Climate Change Impact (RCCI), Infrastructure Facilities (IF), and Awareness of Government Programs (AGP)—on Extension Agency Connect (EAC), which in turn predict Farmers' Perception (FP) of DCSA tools. Extension Agency Connect (EAC), acted as the mediating variable.

Among the predictors of EAC, AGP has the strongest and statistically significant positive effect (Estimate = 1.249, S.E. = 0.168, C.R. = 7.424, $p < 0.001$), indicating that farmer awareness of government subsidies, digital schemes, and access to advisory services strongly enhances engagement with extension agencies. The broader implication of this is as below:

IF (Estimate = 0.094, C.R. = 1.733, $p < 0.001$) also showed a modest but significant positive effect, underscoring the importance of accessible infrastructure like market information, insurance, and ICT tools. In contrast, AISB has a statistically significant negative influence on EAC (Estimate = –0.180, C.R. = –2.813, $p < 0.001$), suggesting that farmers engaging in information-seeking independently may rely less on institutional extension support, or potentially experience information overload or confusion from decentralized sources.

Interestingly, ADA (Estimate = –0.009, C.R. = –0.268, $p < 0.001$) shows a negligible and negative path to EAC, which could imply that general awareness does not automatically translate to interaction with extension agencies unless accompanied by institutional support or actionable benefits. There is a disconnect between awareness and action, emphasizing the need for institutional follow-through, personalized outreach, and support systems to convert awareness into meaningful extension engagement. (Quarshie et al., 2023)

RCCI (Estimate = 0.076, C.R. = 1.026, $p < 0.001$), though positive, has a relatively weak and marginally significant effect, indicating that while awareness of climate-induced risks is necessary, it does not independently drive farmers toward engagement unless facilitated by programs or platforms that offer clear adaptation measures.

The path from EAC to FP was highly significant and strong (Estimate = 1.206, C.R. = 11.968, $p < 0.001$), confirming that farmers' interaction and trust in extension agencies directly shape their perceptions of the usefulness, reliability, and accessibility of digital agricultural services. This validated that EAC played a prime role as a central mediating variable linking background factors to the perceived value and potential adoption of DCSA tools.

At the measurement level, all factor loadings were significant ($p < 0.001$), supporting the reliability and validity of the observed indicators. For example, within ADA, ADA3 (awareness of specific tools) and ADA4 (credible information) have high loadings (1.128 and 1.005, respectively), emphasizing their importance. Within AISB, AISB4 to AISB6 show particularly high loadings (>1.1), suggesting that dynamic, contextualized, and reliable information sources are critical components of this behavior. RCCI indicators like RCCI3 and RCCI5 have very strong loadings (1.434 and 1.399), reinforcing the importance of actionable risk communication. Similarly, AGP4 and AGP5 had high loadings (>1.1), indicating that timely advice and seed/fertilizer availability information from public/private outlets was important within awareness of government programs.

The indicators related to FP also loaded significantly and consistently, with FP9 (perceived reliability) and FP6 (improved productivity) having some of the highest values, emphasizing that they were the most important things farmers value most in digital solutions.

To conclude, the implications of the analytical framework validation are discussed briefly. It provides foresight into which indicators stood out under the respective constructs. The adoption of digital advisory services is often constrained by several external barriers, including digital illiteracy, limited internet connectivity, and lack of access to digital devices. These challenges disproportionately affect rural communities, limiting their ability to fully engage with and benefit from digital tools. (Jarial, 2022; Sharma et al., 2022).

However, the perceived usefulness of digital advisories, particularly when they offer timely information on input availability and market prices, emerged as a strong influential factor for adoption. Such market-oriented insights enable farmers to make more informed production and marketing decisions, aligning with their economic interests.

Importantly, awareness and knowledge about digital tools were often shaped by social networks, including peers, local leaders, and community-based methods of outreach as compared to top-down extension methods. This underscores the value of community-oriented approaches in driving adoption.

At the same time, it indicated that the current digital ecosystem in agriculture was fragmented. It also resulted in overlapping information and confusion among end-users, reducing the overall effectiveness of the services. This was captured by the AISB factor which was negative.

Finally, contact with agricultural extension agencies emerged as a significant predictor of adoption. Farmers who interact regularly with extension workers are likelier to adopt digital tools. This suggests that strengthening extension services can play a key role in enhancing digital inclusion in agriculture, bridging the digital divide.

7.3 Comparative Insight: Public vs. Private vs. NGO Institutional SEM Models

The comparative analysis of the Institutional SEM models, each centered around a different extension agency type: Government (Public), Private, and Non-Governmental Organizations (NGOs), offers insight into how institutional actors mediate the relationship between enabling conditions and farmers' perceptions of DCSA technologies.

The results have been categorized under the four subsections: Institution-Wise Influence on Farmers' Perception, Responsiveness to Enabling Factors (e.g., Policy Awareness, Infrastructure), Role of Recognition of Climate Change Impact, and Inter-Construct Relationships and Model Synergies.

1. <u>Institution-Wise Influence on Farmers' Perception:</u> NGO and Private models show more direct and effective influence; in contrast, the Government operates more indirectly via policy awareness.

- ♦ Government Extension Contact had an indirect influence on farmers’ perceptions, primarily mediated through Awareness of Government Policies ($\beta = 3.65$), which explains 12.40% (R^2) of the variance. The model did not establish a direct link between government extension and perception, indicating a more policy-mediated pathway.

- ♦ Private Extension Contact had a direct effect on Farmer Perception ($\beta = 5.37$), resulting in a higher explanatory power ($R^2 = 16.32\%$). This underscored the efficiency and targeted engagement of private agencies in shaping perceptions through service delivery.

- ♦ The NGO Extension Contact had the strongest direct influence ($\beta = 6.48$) on Farmer Perception, with $R^2 = 16.32\%$, similar to private extension. This reflects NGOs' strong community connection, participatory methods, and tailored messaging, making them highly effective in changing farmers' worldviews.

2. <u>Responsiveness to Enabling Factors</u> : NGOs respond to farmer behavior and awareness, private contact hinges on policy synergy, and government extension relies more on institutional infrastructure and contextual awareness.

- ♦ The Government Contact is greatly influenced by our Infrastructure Facilities ($\beta = 4.40$) and our growing Recognition of Climate Change Impact ($\beta = 1.51$). This shows how much we rely on well-organized environments and our awareness of these important issues.

- ♦ Private Contact is significantly shaped by the Awareness of Government Policies ($\beta = 4.23$), indicating a positive connection between the two. Interestingly, there is a negative trend from Infrastructure to Policy Awareness ($\beta = –3.94$), which suggests that people in well-resourced areas may not see policies as clearly as others.

- ♦ NGO Contact is highly responsive to Agricultural Information Seeking Behavior ($\beta = 4.24$) through Awareness of government policies ($\beta = 6.06$), showing that NGOs are tapped into proactive, policy-literate farmer segments.

3. <u>Role of Recognition of Climate Change Impact:</u> Recognition of climate change acts like a cognitive trigger across all models, and directly shapes government engagement, influencing behavioral adaptation in NGO and private models.

- In the Government Model, it directly influences Extension Agency Contact (β = 1.51) and strongly covaries with Infrastructure (7.29). It serves a bridging role by linking awareness to institutional engagement.
- In Private Model: Influences Infrastructure (β = 3.11) and co-varies with Information Seeking (β = 7.28), suggesting it reinforces infrastructure demand and behavioral adaptation indirectly.
- In the NGO Model, it indirectly strengthens the pathway to NGO contact through Information Seeking Behavior, which is influenced by climate recognition (β = 2.88).

Understanding the impact of climate change varies depending on the model we look at. In the NGO and Private Models, RCCI showed a moderate level of recognition (both at 7.05. In the government model, it contributed a low proportion of variance; on the other hand, it had a direct influence on the government extension agency contact.

4. Inter-Construct Relationships and Model Synergies:

- Throughout all three SEM frameworks—government, private, and NGO : a clear and strong connection exists between Recognition of Climate Change Impact (RCCI) and Agricultural Information Seeking Behavior (AISB). This implies that there exists a close relationship between these variables. The direct path coefficients from the government model (β = 4.50), private model (β = 7.28 through IF), and NGO model (β = 2.88) highlighted a strong behavioral link across all these institutional types. This suggests that farmers who understand and accept the effects of climate variability are more likely to pursue agricultural knowledge and advisory services. The consistency and strength of this connection indicate that awareness of climate change serves as a significant motivator for farmer participation, presenting an important leverage point for creating effective information dissemination strategies. Regardless of the institutional delivery method, enhancing farmers' awareness of climate-related risks could greatly improve their proactive search for solutions, innovations, and institutional support.
- Infrastructure Facilities are most interlinked in the Government model, affecting both government policy awareness and Extension Contact.
- Private model displays stronger feedback loops between awareness, behavior, and service uptake. On the contrary, there exists a risk of policy detachment in well-infrastructured regions.
- NGO model close synergies between information seeking, government policy understanding, recognition of climate change impact and infrastructure facilities.

7.4 Evidence-driven recommendations

- Leverage NGO extension as a primary DCSA conduit: NGO extension contact emerged in the data analysis as the most significant predictor of farmers' positive perceptions. The women-led, community-driven, bottom-up structure was effective, and therefore, formal partnerships should be established. This will enhance effective advisory rollouts and alleviate issues where farmers have low trust in government extension agency contacts or where infrastructure gaps exist. Also, in enabling them to act as first responders to improve digital literacy, climate risk awareness, and participatory planning. The community-driven and local change agent approach could enable people to access DCSA, addressing access issues seamlessly. The participatory planning methods were effective in improving not only DCSA access but also climate risk awareness. (Boateng et al., 2024; Abraham, 2022)

- Convert awareness into action through structured demonstrations: Analyzing the five latent constructs on their effect on farmers' perception, it was found that awareness and DCSA adoption had a modest influence. Also, from the field interviews, it is understood that Awareness alone did not lead to adoption in most cases. Translating awareness into action is essential. Adoption could be facilitated through conducting field or community demonstrations. This should happen at all three levels: institutional, community, and individual. To explain the functionality of key advisory service, like the Uzhavan app, such community demonstrations could be held. This is anticipated to bridge the knowledge-action gap. Diversified approach based on the user base has to be planned with special effort to reach women farmers.(Akudugu et al., 2023; Jabbar et al., 2022a)
- Rebuild trust in the information ecosystem through curated platforms (Agristack): The analysis of the latent construct revealed that agricultural information-seeking behavior negatively affected farmers' perceptions. This was due to the many advisory services, some offered by the state government and a some by the central government. These factors could have caused confusion or information overload among farmers. Importantly services need to be promoted well. For instance, farmers should be encouraged to register into platforms such as agristack, focused facilitation efforts need to be carried out. This will help farmers receive localized, relevant, and season-specific advisory content. (Krishna & Naik, 2020; Abraham, 2022)

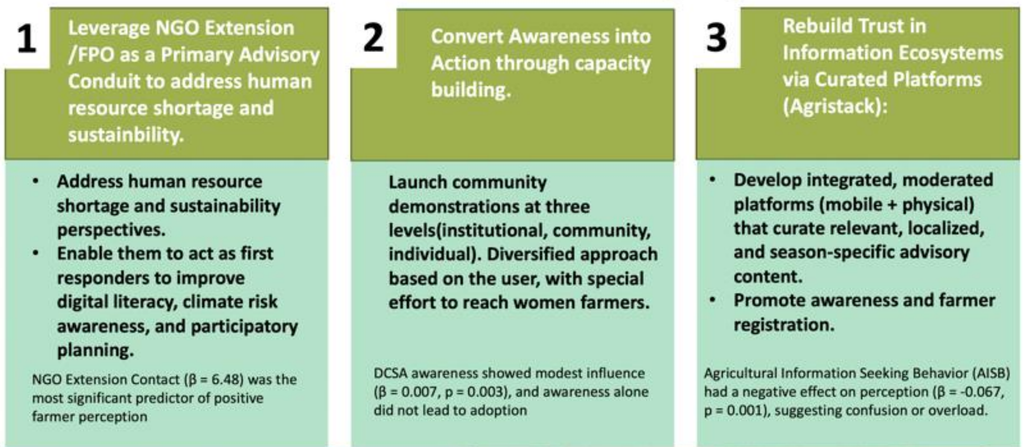


Figure 73: Recommendations-1

- Mandate institutional building, ICT infrastructural support at village level: Institutional building with infrastructural support at the village level implemented in collaboration with panchayat level government could be the key. Promoting already existing Krishi vigyan Kendras that are meant to conduct farm trails, frontline demonstrations or trainings will help farmers. These services are not known to many farmers or they do not use it because of less promotion efforts. (Karthikeyan, 2017.; Ingram et al., 2022)

- Improve extension quality over quantity: A negative correlation was observed between frequency of visit and quality. This signifies that the current metrics of measuring the number of visit over a period will not be enough but rather value qualitative metrics such as how much of farmers problem was solved and satisfaction level of farmers. Public extension agents should be trained through training programs solution-oriented ways of solving farmers problems and also two-way engagement methods. There should be a mechanism incorporated to capture periodic feedback. A voice SMS inbuilt monitoring system can help serve the process. (Abraham, 2020; Abraham, 2022)

- Re-integrate public extension through policy anchoring: Farmers' perception was significantly shaped by policy awareness compared to direct extension agency contact. Therefore it is suggested that government extension outreach around beneficial schemes for farmers such as crop insurance, eNam, and others. Make policy updates part of weekly whatsapp videos or Interactive Voice Response calls by extension agents. For this purpose and larger reach it could be targeted to deliever even to devices that require less mobile data. Men/women farmers have be to selected carefully. (Abraham, 2022; Palanisamy & Bharadwaj, 2018)

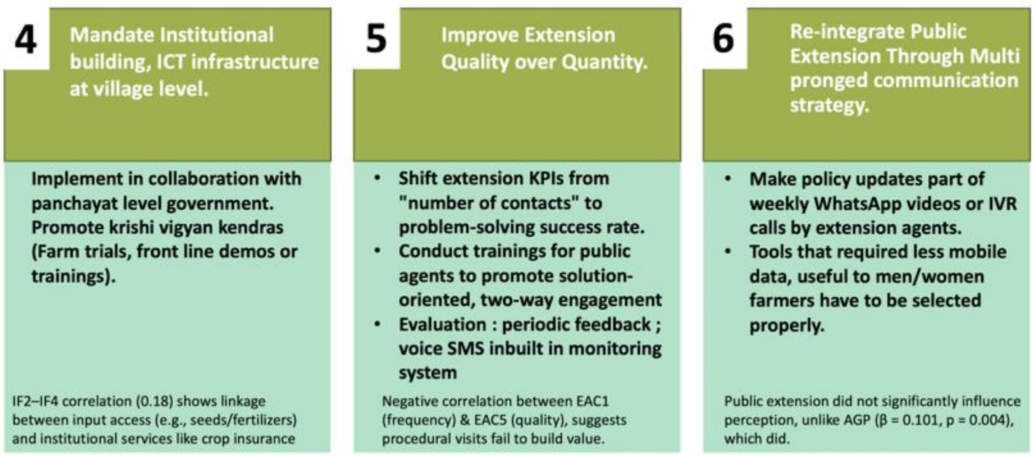


Figure 74: Recommendations-2

Academic contribution:

The academic contribution of research is visualized at three levels: theoretical, empirical, and policy.

Theoretical:

- Extension of Rogers' Diffusion of Innovation theory to the context of advisory services: The study was enriched by applying Rogers' Diffusion of Innovation theory, the five key attributes of technology adoption, i.e., relative advantage, compatibility, complexity, trialability, and observability, to the adoption of advisory tools in two different settings of climate-vulnerable agricultural communities.

- Operationalizing DPSIR for digital agricultural information: A conceptual framework to materialize effective dissemination of digital agricultural information was visualized using DPSIR framework. The central problems and pressures analysing the drivers, pressures, state, impacts, barriers, and propositions related to advisory services in the agricultural context was presented on the same.

- The hybrid theoretical framing by combining the DPSIR and DOI, the research linked individual level adoption behaviour with structural-environmental constraints.

Empirical:

- Multidimension assessment of adoption drivers: The study empirically validated diverse factors such as recognition of climate change and impact, awareness and DCSA adoption, agricultural information seeking behaviour, infrastructure facilities, and awareness of government policies and their linkage to institutional support in shaping the adoption behaviour of farmers.

- Evidence on institutional heterogeneity and its mediating role: By comparing the NGO, public and private extension models, the study provides insights into how institution facilitates in shaping farmers perception regarding advisory services.

- District level variation and ground-level barriers to adoption: The data set of 200 farmers from diverse agroecological setting informed context specific policy.

Policy:

- Emphasized the need for policy strategies toward digital inclusion of small-scale and marginal farmers, based on empirical adoption patterns

- Proposed recommendation for effective dissemination of digital agricultural information services or advisories.

Table 64: Academic contribution of the study

Category	Existing Research	Academic contribution of this research
Theoretical	Global studies on effectiveness of digitalization of climate smart agricultural services exist, need to understand factors facilitate adoption – house hold survey (van Wijk et al., 2020) Digital agricultural information systems are assessed but rarely within a framework in the study area. (Kumar & Karthikeyan, 2020) (Mathuabirami et al., 2019)	Conceptualized a framework based on potentials, drivers, barriers and gaps of digitalization of climate-smart agricultural services Extension of Rogers Diffusion of Innovation theory to the context of advisory services in rural Tamil Nadu Operationalizing DPSIR for digital agricultural information linking individual level adoption behavior with structural-environmental constraints
Empirical	Studies exist on assessing varied knowledge level of farmers to advisory access, yet lack of socio technical analysis (Kungumaselvan et al., 2022) Farmer's perception difference across the districts in the state has been studied but institutional heterogeneity has not been analyzed. (Abraham, 2020) (Prasad et al., 2020) (Abraham, 2022)	Developed a framework to analyse factors shaping farmers perception and institutional effectiveness in disseminating digital agricultural information Multidimension assessment of adoption drivers Evidence on institutional heterogeneity and its mediating role District level variation and ground-level barriers to adoption
Policy	Only few studies focus localization and two-way engagement model for farmers (Ingram et al., 2022) Lack of consideration on differential digital access based on literacy and gender (Mathuabirami et al., 2019) (Rani et al., 2022)	Proposed actionable policy recommendation for digital inclusion and equitable access of information Proposed recommendation for effective dissemination of digital agricultural information services or advisories.

CHAPTER 8: CONCLUSION

The concluding chapter of this thesis presents the core of the research, research contributions, limitations of the research, and future study scope.

8.1 Summary of Key Findings

1. **The global and national literature review highlights the need for Climate Smart Agriculture (CSA) in general, and more specifically to the coastal region of India, particularly in the state of Tamil Nadu. There has been a 20% increase in rainfall, a 20 cm rise in sea level, and a 10% increase in cyclone speed in Tamil Nadu over the past 20 years. These various climate stresses create a necessity for CSA. Since 2015, the government of India has initiated the Digital India mission, and in 2021, it launched the Digital Public Infrastructure (Agristack) specifically to provide tailored advisories and data-driven services to farmers. All these policies, as well as climate change regimes, have enhanced the importance of digitalization of climate-smart agricultural services in Tamil Nadu.**

Due to the adverse effects of climate change, the agricultural sector in India faces multifaceted challenges such as increasing temperatures, erratic rainfall, rising droughts, and declining soil fertility. These pose several implications for the nation's food security, the livelihoods of the rural population, and the sustainability of the farming system. Climate-smart agriculture (CSA) is a key solution in this scenario, as it integrates adaptive and mitigation strategies to enhance productivity, reduce greenhouse gas emissions, and build resilience in food systems. (Andrieu et al., 2017; Dinesh et al., 2018; Khatri-Chhetri et al., 2016) The need for climate smart agriculture becomes even more important in the coastal regions of India which are highly vulnerable to the adverse impact of climate change. Farming in the coastal region is impacted due to sea level increase, saline water intrusion, frequent cyclones, and vagaries of monsoon. Implementing CSA in the coastal region helps protect the fragile ecosystems providing sustainability in the long-term. Tamil Nadu is the southernmost coastal state in India has been facing several disruption in the agricultural sector due to 20% increase in rainfall, 20cm rise in sea level, a 10% increase in cyclone speed over the past 20 years. Approximately 90% of the farmers in the state account to marginal and small-scale farmers collectively. The varying climate stressors mandate the implementation of CSA to develop climate resilience amongst farmers, especially small-scale farmers, in the state of Tamil Nadu.

The Government of India has been promoting digital initiatives to transform various sectors, including agriculture. In 2015, the Digital India campaign was launched to enhance online infrastructure and increase internet connectivity, aiming to make government services more accessible to citizens, especially in rural areas. In 2021, the government introduced the Digital Agriculture Mission, which includes the development of AgriStack, a comprehensive digital public infrastructure designed to provide tailored advisories and data-driven services to farmers. (Sindakis & Showkat, 2024; Krishna & Naik, 2020) Agristack has several key components such as farmers registry, geo-referenced village maps, and crop sown registry. The components aim to make agricultural service delivery effective and accessible.

The increasing importance placed on national digital policies and global climate change frameworks has underscored the need for digitalization and climate-smart agricultural services in Tamil Nadu. These initiatives are crucial for delivering timely, location-specific advisories and support to small-scale farmers. (Balasundram et al., 2023; Li et al., 2022)

2. **In Tamil Nadu, there are eight digital agricultural information services for farmers, offered by both the state and central governments. Among these, the Uzhavan application, provided by the Tamil Nadu state government (initiated in 2018), is notably promoted, with an average of 18% of farmers registered. Registration levels vary by district, with Tiruvannamalai having the highest at 30% and Nilgiris the lowest at 5%. The varying levels of adoption is attributed to: 1) the availability of institutional or extension support, 2) district level digital divide, 3) literacy level and age, and 4) economic conditions of the farmers. The primary obstacles identified in the key farmer interviews (n=50) and key informant surveys(n=12) include: 1) lack of contextualized information, 2) low awareness, and 3) lack of digital literacy.**

In Tamil Nadu, the integration of digital technology into agriculture has been actively pursued by both the state and central governments through a range of digital agricultural information services. A total of eight such services are currently available to farmers, aiming to improve access to timely, relevant, and localized information. A few examples are Gramin Krishi Mausam Sewa, e-velanamai, eNam, Agmarknet, and the TNAU agritech portal. These platforms support various functions, including weather updates, market prices, crop advisory, pest and disease alerts, input availability, and government scheme details.

Among these services, the Uzhavan mobile application stands out as a flagship initiative of the Tamil Nadu state government. It was launched in 2018 by the Department of Agriculture, Uzhavan (meaning “farmer” in Tamil) was designed to bridge the information gap between the government and the farming community. The app offers a wide range of services in Tamil and English, making it accessible and farmer-friendly. Key features include weather forecasts, details of crop insurance, subsidy programs, crop-specific advisories, information on seed and fertilizer availability, and a facility for booking farm machinery.

Despite its comprehensive features, only around 18% of farmers in Tamil Nadu are registered on the Uzhavan platform. This limited adoption highlights several underlying challenges, especially in rural areas. Registration levels vary by district, with Tiruvannamalai having the highest at 30% and Nilgiris the lowest at 5%. The varying levels of adoption could be attributed to the challenges, such as digital literacy, smartphone accessibility, connectivity issues in rural areas, low promotional efforts by the government, an absence of an offline mode in the application, mandating the farmers to consume internet at all times, and difficulty in navigating the application. (Aravindh Kumar et al., 2020; Jarial, 2022; Sharma et al., 2022)

Given the context, a reconnaissance survey was conducted with 50 farmers using rural participatory approaches. The results were validated with stakeholder interviews involving 12 domain specialists. The study aimed to understand farmers' perceptions of digitalization in climate-smart agriculture (DCSA), guided by the Diffusion of Innovation (DOI) theory. It was targeted to understand how farmers perceive technological attributes and related barriers to adoption. Following this farmers were categorized as innovators to laggards. A total of 50 participants were selected through snowball sampling from two contrasting locations: Chengalpattu in Tamil Nadu (Type A: top-down, government-led extension approach) and Embalam in Puducherry (Type B: MS Swaminathan research Foundation – Village Knowledge Center, a bottom-up, community-driven with women as a local change agent).

Data collection was carried out through four Focus Group Discussions (FGDs), two at each site with approximately 12 participants per session, and a semi-structured survey of 50 individual interviews. The FGDs involved open-ended questions aligned with five technological attributes from the DOI framework, aiming to gather insights into climate perception, information needs, and perceived barriers. The semi-structured surveys captured demographic information and data related to DCSA adoption.

The study employed factor analysis for data analysis. Radar charts were used to interpret findings from both the qualitative (FGDs) and quantitative (surveys) methods and to make a comparative analysis of the farmers interviewed at the two study locations. This mixed-methods approach enabled a comprehensive understanding of the differences in perception and adoption patterns across varied institutional setups. Farmers associated with MSSRF Village Knowledge Center showed a significantly higher proportion of early adopters and active users of digital tools. The key reasons farmers found as barrier toward DCSA adoption were 1) lack of contextualized information, 2) low awareness, and 3) lack of digital literacy. (Akudugu et al., 2023; Quarshie et al., 2023)

3. **An analytical framework with 5 key constructs: 1) policy awareness, 2) information-seeking behavior, 3) infrastructure access, 4) climate impact recognition, and 5) Digital Climate Smart Agriculture (DCSA) awareness was created based on a literature review and key farmer interviews. This was linked to three types of institutional supports: public, private, and NGO (non-government organizations) to analyze their influence on farmer perception and adoption. The study utilized a structured questionnaire with 64 variables [e.g., knowledge**

of climate resilient digital practices, dynamic and contextualized information, knowledge of adaptive farming measures, etc.] across 200 farmers from four study areas (Tiruvarur, Pudukottai, Chengalpattu, and Kancheepuram), which were selected based on varying levels of DCSA registration (very low to high) and representation of distinct agroecological zones. Data analysis was conducted using confirmatory factor analysis and structural equation modeling.

Based on the insights from the literature review, reconnaissance interview, and stakeholder interview, an analytical framework was constructed It had five key constructs namely policy awareness, agricultural information seeking behaviour, infrastructure access, climate impact recognition, and digital climate smart agriculture (DCSA) awareness. (Jabbar et al., 2022a; Jabbar et al., 2022b) Each of the five latent constructs had minimum of five to maximum of nine indicators associated with it individually. For instance latent construct policy awareness related to awareness of government subsidies/incentives, knowledge of digital schemes (like agristack, eNam) and use of government supported digital platforms, daily weather forecast and advise given to the farmers to plan for cultivation, farmers received the solution for pest infection, information for availability of seeds and fertilizers near government and private outlets. The latent construct namely farmers perception included variables or indicators such as perceived usefulness of digital services, receive updated market price, to be prepared for weather changes, to get updated information on subsidies and government schemes, app provides all access in tamil language making it easy to use, perceived improvement in productivity, willingness to adopt digital practices, compatible with mobile phone configurations, perceived reliability of digital information . The questionnaire had captured various information in the form of categories and on likert scale. In addition to information on demographics, farming practices, ICT/DCSA usage, extension services, advisory service impact and cost; on a likert scale on basis of the five latent constructs 41 individial questions were composed. Total a set of questionnaire comprised of 64 data points which were administered to 200 farmers. This was linked to three types of institutional supports: public, private, and NGO (non-government organizations) to analyze their influence on farmer perception and adoption.

The survey was conducted across diverse agro-climatic zones of Tamil Nadu to assess the adoption of Digital Climate-Smart Agriculture (DCSA) services. The selected districts: Thanjavur, Pudukkottai, Kancheepuram, and Chengalpattu were strategically chosen based on varying levels of DCSA adoption and institutional support. Thanjavur, located in the Cauvery Delta Zone, showed a high adoption rate and was supported by NGO-led initiatives. In contrast, Pudukkottai exhibited medium adoption in a water-stressed southern zone, while Kancheepuram and Chengalpattu, part of the North-East Monsoon zone, showed low adoption levels under private and public institutional models respectively.

District-wise Uzhavan app registration data revealed substantial variation, with top-performing districts like Tiruvannamalai and Salem registering over 100,000 farmers, while Chengalpattu and Kancheepuram lagged significantly behind. (Nandhini & Rohini, 2022) Sample sizes were consistent across all locations (50 farmers each), ensuring uniformity in data collection. Data analysis was conducted using confirmatory factor analysis and structural equation modeling.

4. **Confirmatory factor analysis revealed that top five factors influencing DCSA adoption are: 1) recognition of climate change impact (manage pests in an environmentally friendly way) 28%, 2) farmers' awareness of specific DCSA tools such as mobile apps and digital platforms 24%, 3) infrastructure facilities (access to daily market prices) 23%, 4) agricultural information-seeking behaviour (advice from peers or local leaders) 20.3%; and 5) farmers' perception (perceived reliability of digital information) 12%. This implies that effective DCSA intervention must prioritize practical relevance by leveraging peer and local leader influences to build trust in agricultural digital advisories. Extension Agency Contact (EAC) strongly predicted farmers' perception of DCSA tools, explaining about 30% of its variance.**

Research findings indicate that manage pests in an environmentally friendly way contributed to 28% of recognition of climate change impact, farmers' awareness of specific DCSA tools such as mobile apps and digital platforms 24%, access to daily market prices contributed to infrastructure facilities by 23%, advice from peers or local leaders contributed to agricultural information-seeking behaviour by 20.3%, perceived reliability of digital information contributed to farmers' perception by 12%. With respect to awareness and DCSA adoption, the negative correlation between ADA3 & ADA5, indicates shared external influences such as digital illiteracy, accessibility issues to mobile phones or digital platforms, and internet access issues. Similarly, regarding agricultural information seeking behavior a positive correlation between AISB4 & AISB6, pointed out to synergy between clarity and credibility in their information-seeking experiences. Regarding recognition of climate change and impact a positive correlation was observed between RCCI1&RCCI2, perceptual link between environmental changes and crop threats and a positive correlation between RCCI2&RCCI4, highlighted that awareness of climate risk results openness to adaptive farming. Regarding infrastructure facilities, a negative correlation was found between IF1 & IF4, highlighting a disconnect in how farmers relate physical service access and institutional risk-mitigation mechanisms and a positive correlation between IF2 & IF4, revealed perceived input support links to greater awareness of institutional services. Findings on awareness of government policies pointed to high error variance between AGP1 & AGP2, knowledge of digital and financial schemes exist, but awareness and utilization gap remains inconsistent. Regarding extension agency contact, a negative correlation between EAC1 & EAC5, indicated frequent interaction alone does not always translate into a perception of valuable support. This may point out to the fact that current information provided could be procedural, generic, emphasizing that farmers value quality over quantity. Insights on farmers perception pointed out to a positive correlation between FP1 & FP7, implying a pperceived usefulness of digital tools aligns with readiness to adopt them. (Abraham, 2022; Krishna & Naik, 2020)

Finally, the structural model tested the effects of five latent variables: the collective effect of awareness and DCSA adoption, agricultural information seeking behavior, recognition of climate change impact, infrastructure facilities on extension agency contact and in turn on how they shape farmers perception. Extension Agency Contact (EAC) strongly predicted farmers' perception of DCSA tools, explaining about 30% of its variance.

5. **The key determinants validated through Structural Equation Modeling showed that government-led extension did not directly impact farmers' perceptions. Agricultural information-seeking behavior and awareness of government programs were modestly influenced by: 1) NGO-led extension services (6.5%), 2) availability and accessibility to infrastructure (4.4%) and 3) climate change recognition (1.5%). Private extension contact also played a strong role, primarily influenced by government policy awareness.**

The model demonstrates that "Extension Agency Contact – NGO" has a meaningful direct influence on Farmers' Perception (6.48). The construct "Extension Agency Contact - NGO" was moderately explained by its predictors namely, Agricultural Information Seeking Bbehavior & Awareness of Government Policies. Covariances among Agricultural Information Seeking Behaviour, Recogntion of Climate Change Impact and Infrastructure Facilties indicate that awareness, perception, and structural capacity are mutually reinforcing dimensions in the context of institutional and behavioral adaptation. Grassroots presence, participatory approaches, and localized trust, can serve as a powerful institutional conduit to foster digital adoption in climate-resilient farming.(Boateng et al., 2024; Abraham, 2022)

Findings show that private extension contact significantly contributes to shaping Farmers Perception; Awareness and DCSA Adoption, Agricultural Information Seeking Behaviour, Awareness of Government Policies contributed to meaningful variance. Private Extension Agency Contact seems to be strongly influenced by Awareness of Government Policies, implication of this is it plays more of a complementary rather than a substitutive relationship between state and private extension actors. Infrastructure Facilities and Awareness of Government Policies ($\beta = -3.94$)., implies when infrastructure is relatively well-developed, farmers are relying more on market or private-sector services, reduced dependence on or awareness of government interventions. Government communication strategies must remain targeted even in infrastructure-rich areas to maintain policy visibility and impact. Covariance between Agricultural Information Seeking Behaviour, Infrastructure Facilities, and awareness of government policies points to systemic nature of farmer behavior, where cognitive, environmental, and structural elements interact to shape engagement with extension systems (private).

Government Extension Agency Contact served as a key intermediary construct, indicating that its engagement is modestly explained by contributing variables, such as Recognition of Climate Change Impact (path 1.51) and Infrastructure Facilities (4.40). Farmer Perceptions are directly shaped by Awareness of Government Policies. Contrary to initial expectations, Government Extension Agency Contact did not directly influence Farmer Perceptions in the model. Covariance between awareness and DCSA adoption, infrastructure facilities, and awareness of government policies pointed to the importance of viewing institutional interactions not as linear interventions but as interconnected systems. Final influence on Farmers Perception was modest ,implying government extension support played more of a supportive or background role, reflecting the gaps in service personalization, digital readiness, and the outreach intensity rendered by the public system.

6. **Combining the above findings with analysis of Digital Public Infrastructure policy and other policies related to climate smart agriculture suggest five following policy priorities:1) Institutionalize GO-NGO Partnerships leveraging their grassroots networks to enhance reach, trust, and local relevance, 2) Mainstream Community-based Demonstrations to promote hands-on learning and facilitate behaviour change through contextual engagement, 3) Redesign and Integrate Digital Platforms into a centralized system that consolidates essential advisories such as weather updates, pest alerts, subsidy details, and market information, available through digital and offline channels, 4) Establish Integrated Agri-Service Hubs at the village or block level to co-locate services like digital assistance, input provision, insurance facilitation, and market linkages, ensuring efficient and comprehensive support for farmers, and 5) Implement Targeted Digital Literacy Campaigns focusing on building digital skills across diverse literacy levels and ensuring inclusive access to DCSA tools and services, thereby bridging the digital divide in agriculture.**

A conceptual framework to materialize effective dissemination of digital agricultural information
is visualized as below in the Figure 75. This framework captures the central problems and pressures analyzing the drivers, pressures, state, impacts, barriers, and propositions related to advisory services in the agricultural context. (Campuzano et al., 2023)

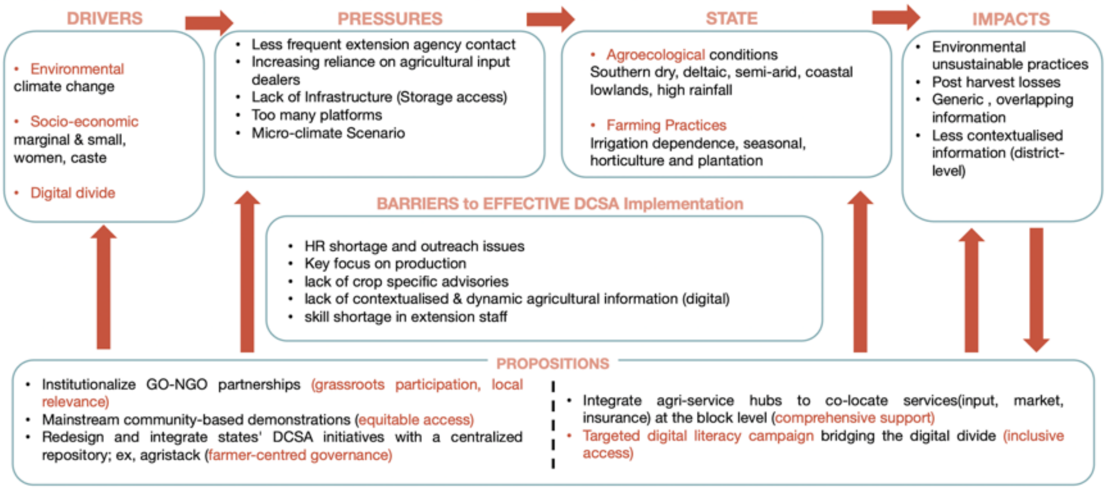


Figure 75: Conceptual framework to materialize effective dissemination of digital agricultural information

8.2 Research Contributions

This research provides an informed perspective on DCSA adoption by exploring how environmental and institutional elements influence farmers' participation in digital climate-smart agricultural practices. It highlights the significance of farmer-focused, grassroots extension methods to enhance digital uptake at the local level. By utilizing Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modelling (SEM), a novel adoption framework is suggested, which builds on the Diffusion of Innovation theory while integrating institutional factors. The study establishes a vital interdisciplinary link between digital technologies, climate resilience, and rural agricultural progress. The results offer meaningful insights for shaping policies, guiding academic research, and facilitating practical applications. This study emphasizes that adopting digital agricultural tools relies not just on technological access but also on harmony with local infrastructure, dependable institutional intermediaries (like NGOs and private advisors), alongside sociocultural elements such as literacy, networks of trust, and perceived urgency regarding climate issues. The research presents a scalable model for creating inclusive digital public goods across various regions and sectors within other states of India and in similar contexts globally.

From the research, the results identified regarding adaptability factors for better adoption are:

Advisory apps typically do not rely on expensive equipment or large-scale operations, so they are indeed more accessible and suitable for small-scale farms. These apps usually provide localized weather updates, crop advisories, pest alerts, and best practices, which can benefit individual farmers regardless of farm size. On the other hand, precision farming technologies (like drones, sensors, and automated machinery) often require significant upfront investment and infrastructure, making them more cost-effective at larger scales, where economies of scale can be realized. Therefore advisory app are most relevant to small-scale farms due to their low cost and implementation over shortened time period. (Jarial, 2022; Dibbern et al., 2024)

Multi-pronged communication strategy:

To tackle the digital divide issue, and make farmers use advisory services more effectively, considering the limited use of smartphones in rural areas, it is important to design targeted training programs. These program should focus on building skills and confidence of farmers in utilizing digital tools in general and specifically the simple advisory services. It is efficient to have one stop solution i.e. a single integrated platform for farmers to access various agricultural information. But on the other hand considering various levels of literacy and digital literacy it is goof to have a multi-pronged communication strategy approach, by using a combination of one or more basic devices such as mobile phones, audio-based tools, audio-video conferencing, multimedia learning resources, and in-person support like plant clinics. This will ensure advisory services reach a wider audience regardless of varying digital literacy levels. (Anabel et al., 2018; Kumar & Karthikeyan, 2020; Krishna & Naik, 2020)

Unified agricultural repository:

The possibility to transfer digital technology across regions and farming systems requires advisory apps and farm management software to capture farm-specific and local conditions. It cannot be applied universally to different farming systems. Localization of content will be key, not only in the context of microclimate but also considering the increasingly evident impacts of climate change. This will necessitate a unified agricultural data repository where farmers are registered along with references to geo-tagged land systems. Through multiple sources of validated data on farming practices, market information, and more, various services by different players could be built. This lowers development costs associated with these services while improving their efficiency. (Krishna & Naik, 2020; Abraham, 2022)

Community based local change agent approach:

A community-based local change agent approach can play a crucial role in bridging the gap between digital agricultural solutions and their effective adoption at the grassroots level. This involves building institutional capacity at the village level, focusing on empowering individuals and groups who can act as local facilitators of change. Designing interventions with a community-centric lens—through active consultation with villagers—ensures that the solutions are grounded in local realities and better aligned with the needs and preferences of the people they are meant to serve. Establishing community-based organizations as part of this process fosters ownership and long-term sustainability. Furthermore, forming partnerships with local stakeholders, such as panchayats, agricultural extension bodies, and academic institutions, can strengthen the initiative by providing technical support, credibility, and wider outreach.(Boateng et al., 2024; Abraham, 2022; Palanisamy & Bharadwaj, 2018)

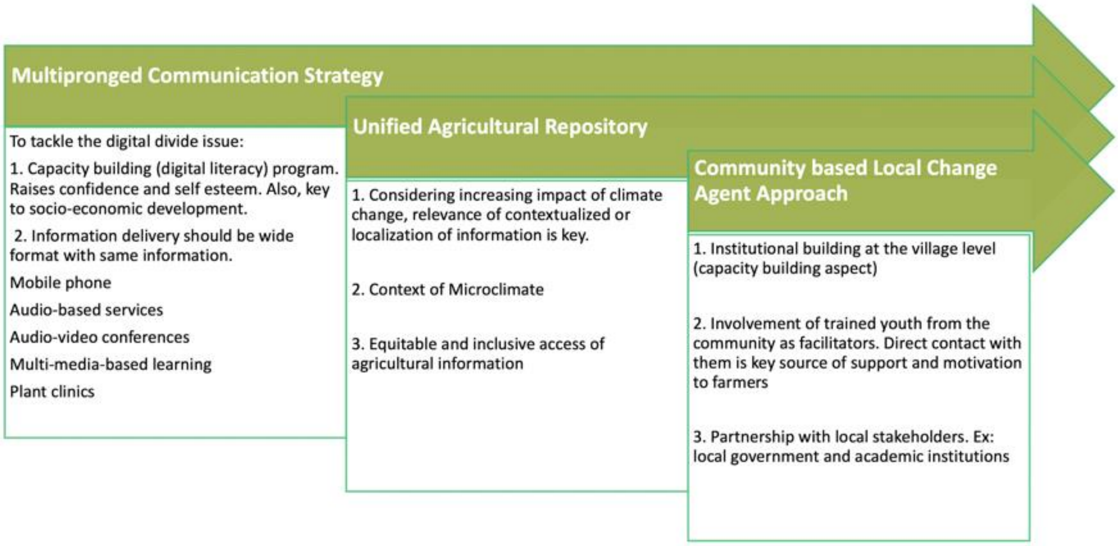


Figure 76: Global implications

8.3 Limitations of the research

A significant limitation of this research is its sample size and scope. The reconnaissance stage included an initial survey of 50 farmers, followed by a more comprehensive survey with slightly over 200 participants. Although this yielded valuable insights, the relatively small and localized sample narrows the findings' broader relevance. Considering Tamil Nadu’s extensive and diverse agricultural landscape, which encompasses various agro-climatic zones, crops, and socio-economic conditions whose results might not fully represent the complexities and differences within the entire farming community.

Additionally, a majority of the participants were primarily rice farmers. This crop-centric focus constrains the applicability of the findings to other agricultural systems like horticulture, millets, pulses, or cash crops. Farmers involved in different cultivation types may encounter unique challenges and exhibit distinct digital needs or adoption behaviors. Consequently, the insights from this study may not completely reflect the experiences or views of those engaged in farming practices that do not center on rice. Future research with a larger, more diverse sample that includes various cropping patterns and regional contexts would enhance the robustness and generalizability of the conclusions.

8.4 Conclusion

This research highlights the need to strengthen the design, accessibility, and effectiveness of digital agricultural advisory services in Tamil Nadu. Findings from farmer interviews and institutional assessments indicate that while digital tools have potential, their full impact remains constrained by infrastructural gaps, uneven digital literacy, and a lack of localization in content and outreach methods.

Policy Changes :

- Enable NGOS to act as first responders so as to improve digital literacy, climate risk awareness, and participatory planning.
- Re-integrate Public extension through Multi pronged communication strategy by making policy updates as part of weekly WhatsApp videos and IVR calls by extension agents
- Institutional building and ICT infrastructure should be made mandatory at village level by implementation in collaboration with the panchayat level government.
- Promote krishi vigyan kendras for Farm trials, front line demos and training.
- Improve Extension quality over quantity by shifting extension KPIs from "number of contacts" to problem-solving success rate.

Technology Changes:

- Develop integrated, moderated platforms (mobile + physical) that curate relevant, localized, and season-specific advisory content.
- Tools that require less mobile data, useful to both men and women farmers have to be selected properly.
- Voice SMS should be inbuilt in monitoring system for collection of feedback and periodical evaluation

Educational Awareness:

- Launch community demonstrations at three levels(institutional, community, individual).
- Adopt diversified approach based on the user, with special effort to reach women farmers.
- Promote awareness and farmer registration.
- Conduct trainings for public agents to promote solution-oriented, two-way engagement

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APPENDIX

Appendix A

The questionnaire below focuses on assessing farmers' perceptions of using the *Uzhavan app based on five key factors: Relative advantage, compatibility, complexity, trialability, and observability.

Demographic Information:

Age:

1. Less than 18. 2.18-28 3. 29-38 4. Above 38

Gender:

1. Male. 2. Female

Education:

1. Illiterate 2. School level 3. UG 4. PG. 5. Agricultural Education 6. Others

Farm size:

1. Small (< 1 acre) 2.Medium (1-5 acres) 3. Large (> 5 acres)

Income:

1. Less than 15000. 2. 15001 to 25000. 3. 25001 to 30000. 4. More than 30000

Years of farming experience: ________

Location: ________

1. Do you use the Uzhavan app? When did you start using it?
2. How much do you feel using the Uzhavan app improves the reception of digital agricultural information?
3. Does the Uzhavan app help you stay prepared for weather changes and market price updates?
4. How helpful is the Uzhavan app in providing updated information on subsidies and government schemes?
5. How easy is it to identify the availability of seeds, fertilizers, and stock levels using the Uzhavan app?
6. How effective is the reception of digital agricultural information through the Uzhavan app?
7. How compatible is the Uzhavan app with your mobile phone configuration?
8. Does the Uzhavan app provide all necessary access to Tamil language information and make it easy to use?
9. Does using the Uzhavan app require less mental effort than other tools or apps you've used?
10. Is it difficult to use the Uzhavan app?
11. How easy is it to learn to use the Uzhavan app?
12. Would you continue using the Uzhavan app if you did not like it much?
13. Are you able to use the Uzhavan app on a trial basis to see how it helps you in farming?
14. Do you have opportunities to explore the Uzhavan app to understand what it can do?

15. Can people around you clearly notice the positive changes brought by Uzhavan app usage?
16. Are the effects of using the Uzhavan app easy to demonstrate to others?

* The *Uzhavan app is used by Type A farmers in Chengalpattu. The Uzhavan app is substituted for the type B farmers with digital agricultural services provided by MSSRF at the VKC.*

Tamil Version:

கேள்வித்தாள்

கீழே உள்ள கேள்விகள், *உழவன் செயலியைப்* பயன்படுத்துவதற்கான விவசாயிகளின் பார்வைகளை ஐந்து முக்கியக் காரணிகளின் அடிப்படையில் மதிப்பீடு செய்வதற்காகத் தயாரிக்கப்பட்டுள்ளன:

சார்ந்த நன்மை, பொருந்தக்கூடிய தன்மை, சிக்கலான தன்மை, முயற்சி செய்யக்கூடிய தன்மை மற்றும் கவனிக்கத்தக்க தன்மை.

புள்ளிவிவரத் தகவல்கள்:

வயது:

1. 18க்கு குறைவாக
2. 18–28
3. 29–38
4. 38க்கு மேல்

பாலினம்:

1. ஆண்
2. பெண்

கல்வி:

1. கல்வியறிவில்லை
2. பள்ளிப் படிப்பு
3. இளங்கலை
4. மேற்படிப்பு
5. விவசாயக் கல்வி
6. மற்றவை

விவசாய நில அளவு:

1. சிறிய நிலம் (<1 ஏக்கர்)
2. நடுத்தர நிலம் (1–5 ஏக்கர்)
3. பெரிய நிலம் (>5 ஏக்கர்)

வருமானம்:

1. ₹15,000க்கு குறைவாக
2. ₹15,001 – ₹25,000
3. ₹25,001 – ₹30,000
4. ₹30,000க்கு மேல்

விவசாய அனுபவம் (ஆண்டுகளில்): _______
இடம்: _______

கேள்விகள்:

1. நீங்கள் உழவன் செயலியை பயன்படுத்துகிறீர்களா? எப்போது பயன்படுத்த தொடங்கினீர்கள்?
2. உழவன் செயலி மூலம் நீங்கள் பெறும் வேளாண்மை தகவல்கள் மேம்பட்டுள்ளதா?
3. காலநிலை மாற்றங்கள் மற்றும் சந்தை விலை மேம்பாடுகளுக்குத் தயார் இருக்க உதவுகிறதா?
4. உழவன் செயலி மூலம் அரசுத் திட்டங்கள் மற்றும் ஊக்கத்தொகைகள் குறித்து புதுப்பிக்கப்பட்ட தகவல்களை பெறுவது எவ்வளவு பயனுள்ளதாக இருக்கிறது?
5. விதைகள், உரங்கள் மற்றும் கையிருப்பு நிலைகள் பற்றிய தகவலை கண்டறிதல் எளிதா?
6. உழவன் செயலியின் மூலம் வேளாண்மை தகவல்கள் பெறுதல் எவ்வளவு பயனுள்ளது?
7. உழவன் செயலி உங்கள் மொபைல் கட்டமைப்புடன் பொருந்துகிறதா?
8. உழவன் செயலி தமிழில் அனைத்து தகவல்களையும் வழங்குகிறதா மற்றும் பயன்படுத்த எளிதா?
9. உழவன் செயலியை பயன்படுத்துவதற்கு நீங்கள் குறைவான மனச்சுமையுடன் செயல்படுகிறீர்களா?
10. உழவன் செயலியைப் பயன்படுத்துவது கடினமாக இருக்கிறதா?
11. உழவன் செயலியைப் பயன்படுத்தக் கற்றுக்கொள்வது எளிதா?
12. உழவன் செயலி மிகவும் விருப்பமில்லாததாக இருந்தாலும் தொடர்ந்து பயன்படுத்துவீர்களா?
13. உழவன் செயலியை சோதனையாகப் பயன்படுத்தி அதன் பயனை தெரிந்து கொள்ள வாய்ப்பு உங்களிடம் இருக்கிறதா?
14. உழவன் செயலியின் செயல்பாடுகளை ஆராய்ந்து புரிந்து கொள்ள வாய்ப்பு உங்களிடம் உள்ளதா?
15. உழவன் செயலி பயன்படுத்துவதால் ஏற்பட்ட நல்ல மாற்றங்களை உங்களைச் சுற்றியுள்ளவர்கள் தெளிவாகக் கவனிக்கிறார்களா?
16. உழவன் செயலியைப் பயன்படுத்துவதால் ஏற்பட்ட விளைவுகளை மற்றவர்களுக்கு எளிதாக விளக்க முடியுமா?

குறிப்பு: *செங்கல்பட்டு மாவட்டத்தில் வகை A விவசாயிகள் உழவன் செயலியைப் பயன்படுத்துகிறார்கள். வகை B விவசாயிகளுக்கு MSSRF அமைப்பின் VKC மையத்தில் வழங்கப்படும் டிஜிட்டல் வேளாண்மை சேவைகள் மாற்றாக உள்ளன.*

Appendix B

This questionnaire aims to understand farmers' demographics, farming practices, and their use of digital tools and extension services for climate-smart agriculture (CSA). It explores challenges in adopting CSA, assesses awareness of government schemes, and gathers perceptions on how digital platforms impact efficiency, crop management, and access to information. Additionally, it looks into the costs and accessibility of these technologies.

1. Gender : 1. Male 2. Female

2. Age : 1. Less than 18 2.18-28 3. 29-38 4. Above 38 Above

3. Marital status : 1. Married 2. Unmarried

4. Education School Level: 1. Illiterate 2. School level 3. UG 2.PG 3. Agricultural Education 4. Others

5. Occupation : 1. Farming only 2. Farming Business 3.Farming Education 4. Farming Service 5.Farming Teaching 6.Farming Entrepreneur 6.Farming House Keeping 7.Farming NGO 8.Other (specify)

6. Farming Monthly Income: 1. Less than 15000 2. 15001 to 25000 3. 25001 to 30000 4. More than 30000

7. How many members are in a family? 1. Less than 3 2. 4 to 6 3. Above 6

8. Location: 1. Rural 2. Urban 3. Semi-Urban 4. Migrant

9. Types of Landholding: 1. Own 2. Rented 3. Leased 4. Others

10. In total how many hectares of land do you own? (In Hectare): 1. Marginal (Below 1 Hectare) 2. Small (1- 2 Hectare) 3. Semi –Medium (2-4 hectare) 4. Medium (4-10 hectare) 5. Large (above 10 hectare)

11. Amount of land used for agriculture: 1. Less than 1 hectare 2. 1-2 Hectare 3. 2-5 Hectare 4. More than 5 Hectares

12. How many years do you have experience in farming? 1. Less than 1 yr 2. 1 to 5 years 3. 5 to 10 years 4. Above 10 years

13. What measures have you taken to adapt to changes in weather patterns?

1. Changed planting dates 2. Using drought-resistant varieties 3. Implemented water-saving techniques 4. Others (specify)

14. How do you manage water supply for rice cultivation during the dry season?

1. Irrigation system 2. Rainwater harvesting 3. using drought-resistant rice varieties 4. implementing soil moisture conservation techniques such as mulching 5. Others (specify)

15. Give your basic information using ICT products and their knowledge.

S.No	ICT products	Yes	No
1	Do you have a smartphone?		
2	Do you have computer knowledge?		
3	Do you use the Internet?		
4	Do you use a Laptop/Tab/ Desktop?		

16. Can you access any extension services: 1. Yes 2. No

17. If yes means who provides the extension service: 1. Government 2. Private 3. NGO 4. Others (specify)

18. Do you receive information about the forecasted data onset of the rainy season? 1. Yes 2. No

19. If yes from which source you received the information? 1. Government agricultural extension service 2. Private agricultural extension service 3. Government crop insurance service 4. NGO farmers' association 5. Electronic media (TV, Radio, etc) 06=Lead farmer 7. Peer farmer (Neighbor/Relative) 8. Paper media (Newspaper) 9. Other (Specify)

20. How often do you interact with the extension agency? 1. Frequently 2. Occasionally 3. Rarely 4. Never

21. Challenges faced in adopting DCSA:

S.No	challenges	Yes	No
1	Poor public relations of agricultural extension works		
2	Information aired through sources in odd hours		
3	Too much distance to access information		
4	Illiteracy		
5	Network problem		
6	Lack of technical knowledge		
7	Poor administration		

8	Lack of awareness of government policies		
9	Language barrier		
10	Lack of proper training and program		
11	Lack of time-bound information		
12	Others		

22. The following statement for the adoption of digitalization of climate-smart agricultural(DCSA) practices and farmers' perception
(SA= Strongly Agree, A=agree, DA=disagree and SDA=strongly disagree)

S.No	Statements	SA	A	D	SD
	Awareness and DCSA adoption				
1	Conduct workshops and field demonstrations to educate farmers				
2	Promote awareness among farmers through extension channels.				
3	Limited access to internet services in rural areas.				
4	Credible information enhances farmers' trust				
5	Farmers struggle to use smartphones due to low levels of literacy				
	Accessibility & availability of DCSA information				
1	The interface is user-friendly and allows access to information with a single click.				
2	Farming activities are clearly mentioned				
3	The provided information is trustworthy.				
4	The delivery of the information is clear and straightforward				
5	The information was given in easy to read format				
6	Reliable and precise information is provided				
	Reception of climate/weather information				
1	Farmers receive region-specific data based on seven agro-climatic zones.				
2	Reservoir levels are provided for irrigation planning.				
3	It offers alerts and advice for safeguarding crops.				
4	Remember to maintain soil health through crop rotation and cover cropping to enhance soil fertility.				
5	Manage pests in an environmentally friendly way.				

	Reception of other agricultural inputs information				
1	Farmers know the facilities of hiring centres at economical rates				
2	It provides the availability of seeds and fertilizers near location				
3	It helps farmers access the crops' daily market prices to facilitate product sales				
4	Farmers check the crop insurance and updates for receiving compensation				
5	It ensures and tracks the extension officers visit farmers to plan and prepare for interaction				
	Awareness of Government policies				
1	The various subsidy schemes are available for farmers to help them avoid unavoidable financial burdens.				
2	It provides a crop calendar and farmer tips based on soil and climate conditions				
3	Daily weather forecast and advice given to the farmers to plan for cultivation				
4	The farmers receive the solution for pest infection and manage all farmers' challenges.				
5	The information for the availability of seeds and fertilizer near government and private outlets				
	Extension agency contact				
1	The extension agency interacts with the farmers regularly				
2	The quality of the interaction with the extension officers				
3	The officers are available to assist with addressing any queries.				
4	The agency provides timely information to the farmers				
5	It provides invaluable advice and unwavering support to farmers for their agricultural endeavours.				
	Farmers perceptions				
1	The registration process is very simple				
2	It gives updates on the Market price				
3	It helps me to be prepared for weather changes.				
4	It helps me to get updated information on Subsidies and government schemes				

5	The app provides all access in the Tamil language making it easy to use				
6	It enables access to the contact information of registered farm practitioners				
7	The data provided are Up-to-date				
8	It is compatible with configuration mobile phones and also				
9	It helps me to identify the location of the Seeds' availability, fertilizer shops, and stock level.				

23. How have these apps impacted your farming operations?
a. Increased efficiency
b. Reduced losses
c. Improved crop management
d. Other (please specify)
24. Do you pay for any of the apps you use? 1. Yes 2. No

25. If yes, how much do you spend? 1. monthly 2. annually on app subscriptions

26. What are the additional costs of using these apps? 1. internet charges 2. device costs, 3. Training

Tamil Version:

கேள்வித்தாள்
பெயர்

1. பாலினம் : 1. ஆண் 2. பெண்
2. வயது : 1. 18 க்கும் குறைவானது 2.18-28 3. 29-38 4. 38க்கு மேல்
3. திருமண நிலை : 1. திருமணமானவர் 2. திருமணமாகாதவர்
4. கல்வி பள்ளி நிலை: 1. கல்வியறிவு இல்லாதவர் 2. பள்ளி நிலை 3. யுஜி 4.பி.ஜி. 5. விவசாயக் கல்வி 6. மற்றவர்கள்
5. தொழில் : 1. விவசாயம் மட்டும் 2. விவசாயத் தொழில் 3.விவசாயக் கல்வி 4. விவசாய சேவை 5.விவசாய கற்பித்தல் 6.விவசாய தொழில்முனைவோர் 6.விவசாய வீடு பராமரிப்பு 7.விவசாய தன்னார்வ தொண்டு நிறுவனம் 8.மற்றவை (குறிப்பிடுக)
6. விவசாயம் மாத வருமானம்: 1. 15000 க்கும் குறைவாக 2. 15001 முதல் 25000 வரை 3. 25001 முதல் 30000 வரை 4. 30000 க்கும் மேற்பட்டவை
7. ஒரு குடும்பத்தில் எத்தனை உறுப்பினர்கள் உள்ளனர்? 1. 3 ஐ விட குறைவாக 2. 4 முதல் 6 வரை 3. 6 க்கு மேல்
8. இடம்: 1. கிராமப்புறம் 2. நகர்ப்புறம் 3. அரை நகர்ப்புறம் 4. குடியேறுபவர்
9. நில உடைமையின் வகைகள்: 1. சொந்தம் 2. வாடகைக்கு 3. குத்தகைக்கு விடப்பட்டது 4. மற்றவர்கள்
10. மொத்தம் எத்தனை ஹெக்டேர் நிலம் உங்களுக்கு சொந்தமானது? (ஹெக்டேரில்): 1. விளிம்பு (1 ஹெக்டேருக்கு கீழே) 2. சிறிய (1- 2 ஹெக்டேர்) 3. அரை நடுத்தர (2-4 ஹெக்டேர்) 4. நடுத்தர (4-10 ஹெக்டேர்) 5. பெரியது (10 ஹெக்டேருக்கு மேல்)
11. விவசாயத்திற்கு பயன்படுத்தப்படும் நிலத்தின் அளவு: 1. 1 ஹெக்டேருக்கும் குறைவாக 2. 1-2 ஹெக்டேர் 3. 2-5 ஹெக்டேர் 4. 5 ஹெக்டேருக்கு மேல்

12. விவசாயத்தில் உங்களுக்கு எத்தனை வருட அனுபவம் உள்ளது? 1. 1 வருடத்திற்கும் குறைவாக 2. 1 முதல் 5 ஆண்டுகள் 3. 5 முதல் 10 ஆண்டுகள் 4. 10 ஆண்டுகளுக்கு மேல்

13. மழைப்பொழிவு முறைகளில் ஏற்படும் மாற்றங்களுக்கு ஏற்ப தகவலமைத்துக் கொள்ள நீங்கள் மேற்கொண்ட நடவடிக்கைகள் யாவை?

1. மாற்றப்பட்ட நடவு தேதிகள் 2. வறட்சியைத் தாங்கி வளரும் இரகங்களைப் பயன்படுத்துதல் 3. நீர் சேமிப்பு உத்திகளை அமல்படுத்தியது 4. மற்றவை (குறிப்பிடுக)

14. வரட்சியான காலங்களில் நெற்பயிர்ச் செய்கைக்கான நீர் விநியோகத்தை எவ்வாறு முகாமைத்துவம் செய்வாய்?

1. பாசன அமைப்பு 2. மழைநீர் சேகரிப்பு 3. வறட்சியைத் தாங்கும் நெல் இரகங்களைப் பயன்படுத்துதல் 4. தழைக்கூளம் போன்ற மண்ணின் ஈரப்பத பாதுகாப்பு நுட்பங்களை செயல்படுத்துதல் 5. மற்றவை (குறிப்பிடுக)

15. தகவல் தொடர்பாடல் தொழில்நுட்ப உற்பத்திகளைப் பயன்படுத்தி உங்கள் அடிப்படைத் தகவல்களையும் அவற்றின் அறிவையும் கொடுங்கள்.

S.No	ICT தயாரிப்புகள்	ஆம்	இல்லை
1	உங்களிடம் ஸ்மார்ட்போன் உள்ளதா?		
2	உங்களுக்கு கம்ப்யூட்டர் அறிவு இருக்கா?		
3	நீங்கள் இணையத்தைப் பயன்படுத்துகிறீர்களா?		
4	நீங்கள் லேப்டாப் / டேப் / டெஸ்க்டாப் பயன்படுத்துகிறீர்களா?		

16. நீங்கள் எந்த நீட்டிப்பு சேவைகளையும் அணுக முடியுமா: 1. ஆம் 2. இல்லை

17. ஆம் என்றால் விரிவாக்க சேவையை யார் வழங்குகிறார்கள்: 1. அரசு 2. தனியார் 3. என்.ஜி.ஓ 4. மற்றவை (குறிப்பிடுக)

18. மழைக்காலத்தின் முன்னறிவிக்கப்பட்ட தரவு பற்றிய தகவல் உங்களுக்கு கிடைக்கிறதா? 1. ஆம் 2. இல்லை

19. ஆம் எனில், எந்த ஆதாரத்திலிருந்து நீங்கள் தகவலைப் பெற்றீர்கள்? 1. அரசு வேளாண்மை விரிவாக்கப் பணி 2. தனியார் வேளாண் விரிவாக்கப் பணி 3. அரசு பயிர் காப்பீடு சேவை 4. என்.ஜி.ஓ விவசாயிகள் சங்கம் 5. மின்னணு ஊடகங்கள் (தொலைக்காட்சி, வானொலி போன்றவை) 6. முன்னணி விவசாயி 7. சக விவசாயி (அண்டை வீட்டுக்காரர் / உறவினர்) 8. காகித ஊடகம் (செய்தித்தாள்) 9. மற்றவை (குறிப்பிடுக)

20. விரிவாக்க நிறுவனத்துடன் நீங்கள் எவ்வளவு அடிக்கடி தொடர்பு கொள்கிறீர்கள்? 1. அடிக்கடி 2. எப்போதாவது 3. அரிதாக 4. ஒருபோதும் இல்லை

21. DCSA ஐ ஏற்றுக்கொள்வதில் எதிர்கொள்ளும் சவால்கள்:

S.No	சவால்கள்	ஆம்	இல்லை
1	வேளாண் விரிவாக்கப் பணிகளில் மக்கள் தொடர்பு மோசமாக இருத்தல்		
2	மூலங்கள் மூலம் தேவையற்ற நேரங்களில் ஒளிபரப்பப்படும் தகவல்கள்		
3	தகவலை அணுக அதிக தூரம்		
4	கல்வியறிவின்மை		

5	நெட்வொர்க் சிக்கல்		
6	தொழில்நுட்ப அறிவு இல்லாமை		
7	மோசமான நிர்வாகம்		
8	அரசாங்க கொள்கைகள் குறித்த விழிப்புணர்வு இல்லாமை		
9	மொழி தடை		
10	சரியான பயிற்சி மற்றும் திட்டம் இல்லாமை		
11	நேரத்திற்குட்பட்ட தகவல் இல்லாமை		
12	மற்றவை		

22.விவசாயிகளின் பார்வையில் டிஜிட்டல் தொழில்நுட்பத்தை ஏற்றுக்கொள்வதற்கான பின்வரும் அறிக்கை

(SA= உறுதியாக ஒப்புக்கொள்கிறேன், A = ஒப்புக்கொள்கிறேன், DA = உடன்படவில்லை மற்றும் SDA = கடுமையாக உடன்படவில்லை)

S.No	கூற்றுகள்	SA	A	D	SD
	விழிப்புணர்வு மற்றும் DCSA தத்தெடுப்பு				
1	விவசாயிகளுக்கு விழிப்புணர்வு ஏற்படுத்த பயிலரங்குகள் மற்றும் செயல்முறை விளக்கங்கள் நடத்துதல்				
2	விரிவாக்க வழிகள் மூலம் விவசாயிகளிடையே விழிப்புணர்வை ஏற்படுத்துதல்.				
3	கிராமப்புறங்களில் இணைய சேவைகளுக்கான மட்டுப்படுத்தப்பட்ட அணுகல்.				
4	நம்பகமான தகவல்கள் விவசாயிகளின் நம்பிக்கையை மேம்படுத்துகின்றன				
5	கல்வியறிவு குறைவாக இருப்பதால் ஸ்மார்ட்போன் பயன்படுத்த முடியாமல் விவசாயிகள் திணறல்				
	DCSA தகவல்களின் அணுகுமுறை மற்றும் கிடைமுறை				
1	இடைமுகம் பயனர் நட்பு மற்றும் ஒரே கிளிக்கில் தகவல்களை அணுக அனுமதிக்கிறது				
2	விவசாய நடவடிக்கைகள் தெளிவாக குறிப்பிடப்பட்டுள்ளன				
3	வழங்கப்பட்ட தகவல் நம்பகமானது				
4	தகவலின் விநியோகம் தெளிவானது மற்றும் நேரடியானது				
5	தகவல்கள் எளிதாக படிக்கும் வடிவத்தில் வழங்கப்பட்டன				
6	நம்பகமான மற்றும் துல்லியமான தகவல்கள் வழங்கப்படுகின்றன				
	பருவநிலை/வானிலை தகவல்களின் பெறுதல்				
1	விவசாயிகள் ஏழு வேளாண்-காலநிலை மண்டலங்களின் அடிப்படையில் பிராந்திய வாரியான தரவைப் பெறுகிறார்கள்.				
2	நீர்த்தேக்க நீர்மட்டங்கள் பாசனத் திட்டத்திற்காக அமைக்கப்பட வேண்டும்.				
3	பயிர்களை பாதுகாப்பதற்கான எச்சரிக்கை மற்றும் ஆலோசனைகளை வழங்குகிறது				
4	பயிர் சுழற்சி மற்றும் மூடுபயிர் சாகுபடி மூலம் மண்ணின் வளத்தைப் பேண வேண்டும்.				
5	சுற்றுச்சூழலுக்கு உகந்த முறையில் பூச்சிகளை நிர்வகிக்கவும்				
	வேறு விவசாயத் தகவல்களின் பெறுதல்				
1	குறைந்த விலையில் வாடகை மையங்களின் வசதிகளை விவசாயிகள் அறிவார்கள்				
2	இது இருப்பிடத்திற்கு அருகிலுள்ள விதைகள் மற்றும் உரங்கள் கிடைப்பதை வழங்குகிறது				
3	இது விவசாயிகளுக்கு பயிர்களின் தினசரி சந்தை விலைகளை அணுக உதவுகிறது, மற்றும் தயாரிப்பு விற்பனையை எளிதாக்குகிறது.				
4	விவசாயிகள் பயிர் காப்பீடு மற்றும் இழப்பீடு பெறுவதற்கான புதுப்பிப்புகளை சரிபார்க்கலாம்				

5	விவசாயிகளை சந்தித்து கலந்துரையாடலுக்கு திட்டமிடவும் தயார் செய்யவும் இது உறுதி செய்கிறது மற்றும் கண்காணிக்கிறது				
	அரசாங்க கொள்கைகள் பற்றிய விழிப்புணர்வு				
1	தவிர்க்க முடியாத நிதிச் சுமைகளைத் தவிர்க்க விவசாயிகளுக்கு உதவும் வகையில் பல்வேறு மானியத் திட்டங்கள் கிடைக்கின்றன.				
2	இது மண் மற்றும் காலநிலை நிலைமைகளின் அடிப்படையில் பயிர் நாட்காட்டி மற்றும் உழவர் உதவிக்குறிப்புகளை வழங்குகிறது				
3	தினசரி வானிலை முன்னறிவிப்பு மற்றும் சாகுபடிக்கு திட்டமிட விவசாயிகளுக்கு வழங்கப்படும்				
4	விவசாயிகள் பூச்சி தொற்றுக்கான தீர்வைப் பெறுகிறார்கள் மற்றும் விவசாயிகளின் அனைத்து சவால்களையும் சமாளிக்கிறார்கள்.				
5	அரசு மற்றும் தனியார் விற்பனை நிலையங்களுக்கு அருகில் விதைகள் மற்றும் உரங்கள் இருப்பதற்கான தகவல்கள்				
	விரிவாக்க முகமை தொடர்பு				
1	விரிவாக்க நிறுவனம் விவசாயிகளுடன் தொடர்ந்து தொடர்பு கொள்கிறது				
2	விரிவாக்க அலுவலர்களுடனான உரையாடலின் தரம் நன்றாக இருந்தது				
3	எந்தவொரு சந்தேகத்தையும் நிவர்த்தி செய்ய உதவ அதிகாரிகள் உள்ளனர்.				
4	இந்த நிறுவனம் விவசாயிகளுக்கு சரியான நேரத்தில் தகவல்களை வழங்குகிறது				
5	இது விவசாயிகளின் வேளாண் முயற்சிகளுக்கு விலைமதிப்பற்ற ஆலோசனைகளையும், அசைக்க முடியாத ஆதரவையும் வழங்குகிறது.				
	விவசாயிகளின் உணர்வுகள்				
1	பதிவு செயல்முறை மிகவும் எளிது				
2	இது சந்தை விலை குறித்த புதுப்பிப்புகளை வழங்குகிறது				
3	வானிலை மாற்றங்களுக்கு தயாராக இருக்க இது எனக்கு உதவுகிறது				
4	மானியங்கள் மற்றும் அரசுத் திட்டங்கள் பற்றிய புதுப்பிக்கப்பட்ட தகவல்களைப் பெற இது எனக்கு உதவுகிறது				
5	இந்த செயலி தமிழ் மொழியில் அனைத்து அணுகலையும் வழங்குகிறது, இது பயன்படுத்த எளிதானது				
6	இது பதிவுசெய்யப்பட்ட பண்ணை பயிற்சியாளர்களின் தொடர்புத் தகவலை அணுக உதவுகிறது				
7	வழங்கப்பட்ட தரவு புதுப்பித்த நிலையில் உள்ளது				
8	பயன்பாடு கட்டமைப்பு மொபைல் போன்களுடன் இணக்கமானது				
9	விதைகளின் இருப்பிடம், உரக் கடைகள் மற்றும் இருப்பு நிலை ஆகியவற்றை அடையாளம் காண இது எனக்கு உதவுகிறது.				

23. இந்த பயன்பாடுகள் உங்கள் விவசாய நடவடிக்கைகளை எவ்வாறு பாதித்துள்ளன?

அ. அதிகரித்த செயல்திறன்

ஆ. குறைக்கப்பட்ட இழப்புகள்

இ. மேம்படுத்தப்பட்ட பயிர் மேலாண்மை

d. மற்றவை (தயவுசெய்து குறிப்பிடவும்)

24. நீங்கள் பயன்படுத்தும் எந்த பயன்பாடுகளுக்கும் பணம் செலுத்துகிறீர்களா? 1. ஆம் 2. இல்லை

25. ஆம் எனில், நீங்கள் எவ்வளவு செலவு செய்கிறீர்கள்? 1. மாதாந்திர 2. பயன்பாட்டு சந்தாக்களில் ஆண்டுதோறும்

26. இந்த பயன்பாடுகளைப் பயன்படுத்துவதற்கான கூடுதல் செலவுகள் என்ன? 1. இணைய கட்டணம் 2. சாதன செலவுகள், 3. பயிற்சி கட்டணம்