Participatory development of mobile agricultural advisory driven by behavioural determinants of adoption

Adla, Soham; Aravindakshan, Aiswarya; Tyagi, Ashray; Guntha, Ramesh; Ponce-Pacheco, Mario Alberto; Nagi, Anukool; Pastore, Prashant; Pande, Saket

DOI
10.1016/j.jenvman.2025.124140

Publication date
2025

Document Version
Final published version

Published in
Journal of Environmental Management

Journal of Environmental Management 374 (2025) 124140

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Participatory development of mobile agricultural advisory driven by behavioural determinants of adoption

Soham Adla [a], Aiswarya Aravindakshan [b,*], Ashray Tyagi [c], Ramesh Guntha [b], Mario Alberto Ponce-Pacheco [a], Anukool Nagi [c], Prashant Pastore [c], Saket Pande [a]

[a] Department of Water Management, Delft University of Technology, Gebouw 23, Stevinweg 1, 2628 CN, Delft, the Netherlands
[b] Center for Wireless Networks & Applications (WNA), Amrita Vishwa Vidyapeetham, Amritapuri Campus, Amritapuri, Clappana P. O, Kollam, 690525, Kerala, India
[c] Solidaridad Network Asia Limited, A-5, Shankar Garden, Main Najafgarh Road, Vikaspuri, New Delhi, India

ARTICLE INFO

Keywords:
Agricultural advisory
Co-creation
Participatory
Behaviour
Adoption
Risk communication
Mobile application

ABSTRACT

Mobile applications have the potential to revolutionise agricultural advisories, providing farmers with real-time information and insights for improved decision-making. However, the adoption of such apps is influenced by various behavioural factors, necessitating a participatory approach of development with the stakeholders. This study proposes a framework that begins with a prototype app informed by a literature review and the identification of behavioral determinants of app adoption. Iterative participatory feedback, grounded in these determinants, is employed to refine the app. The framework is demonstrated through the case study of *Makara*, an app providing risk advisories for farm yield, income, and risk mitigating practices in Maharashtra, India.

A user-focused Theory of Change (ToC) was used to design a survey to identify socio-economic and behavioral drivers of agricultural app adoption. Data collected from 1354 farmers across four districts of Maharashtra during April–May 2023 informed a linear regression model that identified significant explanatory factors. Building on these findings, multiple feedback sessions with farmers were conducted over a year to iteratively co-develop the app's features.

Key behavioral determinants, including norms, trust, abilities, and attitudes towards adopting mobile-based agricultural advisories, significantly influenced adoption. The participatory design process addressed these factors, incorporating features such as multi-lingual support, intercropping and multi-cropping options, and multi-component budgeting to enhance trust and perceived ease in using the app. User-friendliness was further improved through redundant communication of risks, combining textual and audio-visual formats.

This paper presents a mixed-methods approach to integrating behavioral drivers of agricultural (advisory app) technology adoption into a participatory co-design framework (of such an app), enabling considerations for inclusivity and scaling in the design process of the app itself.

1. Introduction

The use of agricultural science and technology services has potential to improve the efficiency of modern agricultural production management (Saiz-Rubio and Rovira-Más, 2020). Such technology can support farmers via new crop varieties, intercultural operations (e.g., pest and nutrient management), input management, innovative technology use and IT services (Corbari et al., 2019; Gallardo et al., 2020; Li et al., 2023; Rupnik et al., 2019). In particular, Information and Communication Technology (ICT) can play a significant role in addressing agricultural challenges and eventually enhancing agricultural livelihoods (Mittal, 2012; Stienen et al., 2007). ICT, which include telecentres, the internet, geographic information systems, computers, mobile phones (via voice and text messages, videos and mobile applications) and traditional media such as TV and radio facilitate information availability for farmers (Sharma et al., 2021; Stienen et al., 2007). ICTs are also increasingly becoming popular as means to disseminate agricultural advisories (Steinke et al., 2021). Within ICTs, mobile phones have the potential to catalyse improvements in farm productivity and rural incomes, as well as the capacity to enhance the delivery of agricultural advisories (Fu and Akter, 2016; Mittal and Tripathi, 2009).

In lower and middle income countries such as India, the high

* Corresponding author.
E-mail address: aiswaryaa@am.amrita.edu (A. Aravindakshan).

https://doi.org/10.1016/j.jenvman.2025.124140
Received 30 September 2024; Received in revised form 5 January 2025; Accepted 11 January 2025
Available online 17 January 2025

penetration of mobile phones is a potential opportunity for mobile phone technology to facilitate this process (Sharma et al., 2021). These impacts can be further augmented by a massive and rapid uptake in popular trends via positive network effects (Cornell, 2020). The landscape for mobile applications (apps) for agriculture in India is diverse, reflecting the country's vast agricultural sector and the varied needs of farmers. These apps generally aim to enhance farm productivity, profitability, and sustainability through timely and site-specific advisories. Broadly, the primary functions of such apps span agricultural information and advisory, market linkage platforms, precision agriculture, financial services for agriculture and community engagement and peer learning.

Agricultural technologies, in particular digital, have generally seen a relatively lower adoption (Aker, 2011; George, 2014). While there is significant uptake of digital technologies amongst the general population, the challenge remains in reaching smallholder farmers, especially in countries such as India, who may have limited access to smartphones and the internet, limited digital exposure and digital literacy, and challenges in adopting a user-fee model due to financial constraints (Steinke et al., 2024). Factors that have influenced agricultural technology adoption have included sociodemographic factors, such as education or literacy, age of household head, gender, and socioeconomic characteristics, such as land size, assets, access to electricity, household labour availability, off-farm income and credit (Gido et al., 2015; Katengeza et al., 2011; Li et al., 2023). In some studies, factors such as farmer satisfaction with the advisory service were found to be significant (with other socioeconomic and farm factors) in explaining adoption (Li et al., 2023). Vroman et al. (2015) found that digital usage among older people was associated with education, age, attitudes towards digital technology adoption and socio-personal characteristics including being "satisfied with activities", "persevering" and having a "positive outlook." However, such cognitive understanding of farmers' behaviours seems to be limited to few studies that are based on behavioural science approaches in explaining adoption. Examples include Hatch et al. (2022) who found an ensemble of factors such as norms, risk perceptions of water scarcity, and attitude to be significant in demonstrating the adoption of irrigation technology.

Participatory approaches to app design is a prevalent approach to ensure user inputs are considered in the design with the expectation that this leads to better adoption (Steinke et al., 2022). However such approaches are often not dovetailed to the needs of users and as a result may be less efficient in achieving its objective of high adoption. The evaluation and selection of ideas may be overwhelmed by designer's enthusiasm rather than that of end-users, which may also ignore local realities for example of low literacy and confidence to use mobile phone-based applications (Steinke et al., 2022), referred to as mobile apps subsequently. Another challenge has been not to consider scalability of the product as part of the design process (Steinke et al., 2022), where changing individual behaviour in order to adopt new technology is one aspect of designing for scaling (Moore et al., 2015). Given the role that behaviour plays in adoption of irrigation technologies such as agricultural advisory apps and that there are few studies that provide conceptual framework on how to (Steinke et al., 2024), this study presents a novel mixed methods approach to co-designing a mobile agricultural advisory app, called Makara. The novelty is that first behavioural factors that influence adoption of mobile advisories are identified via a farmer survey representative of the target farmer population, and then used as the basis for iteratively developing the app.

The paper is organised as follows. The methodology includes the generic two-stage framework of participatory approach towards agricultural app development followed by implementation of the approach to the specific case of the Makara app in the study region, Maharashtra (India). Results are then presented specifically for the case study, about how the outcomes of the participatory approaches were used to enhance the features of the app. The paper then concludes with the scaling strategy and limitations.

2. Generic framework of participatory development

In developing the Makara app, we drew on the "Farmer First" approach (Chambers, 1993; Chambers et al., 1989), emphasising farmers' active participation in generating, testing, and evaluating digital advisory tools. This approach prioritises the role of farmers—especially smallholders with limited resources—in co-creating technologies that address their specific constraints and enhance productivity and income. This approach assumes that farmers possess a valuable, systematised body of local knowledge that can be integrated into new technologies to address their specific needs. Researchers work not only as information gatherers and planners but also as facilitators, encouraging farmers to voice their priorities and contribute actively to developing solutions. This participatory model aims to expand options for resource-poor farmers, particularly in complex farming environments, by enabling them to select from a "menu" of adaptable solutions rather than rigid interventions.

To achieve this, Farmer First combines formal research with participatory methods such as Farming Systems Research (FSR), Rapid and Participatory Rural Appraisals (RRA/PRA), and Participatory Technology Development (PTD). By involving farmers directly in these processes, researchers aim to create more relevant, scalable innovations that reflect farmers' realities and foster sustained adoption. This consultative-to-collaborative spectrum of participation allows for flexible involvement, making farmers not just respondents but co-creators in the development process (Probst et al., 2000).

Building upon this groundwork, one can use a systematic and iterative redevelopment process to refine and transform the app participatorily. This iterative, participatory approach can enable us to progressively align the app's design and functionality with the behavioural and practical needs identified within the target community.

This involves a two-stage process, visualised in Fig. 1.

- Stage 1: Identifying determinants for generic agricultural advisory adoption and initial prototype development

The conceptual design begins with the identification of key determinants influencing the adoption of agricultural advisory apps, indicated as (process) Box 1 in Fig. 1. This initial stage involves conducting a large-scale survey to capture and analyse the contextual, socioeconomic, and behavioural factors affecting app adoption among farmers. The significant determinants identified, and insights gathered through this survey provide a foundation to guide the collection of app-specific feedback in subsequent development phases. This approach ensures a user-centred focus that is grounded in the actual needs and preferences of the farming community.

Additionally, a prototype version of the app - either a wireframe or a paper prototype - can be developed as an independent process. This step may involve reviewing existing literature (Process Box 2) to identify effective communication strategies in agricultural advisories. Such a review helps determine the most appropriate content and formats for delivering advisory information, ensuring that the prototype effectively supports informed decision-making by farmers.

While the survey and prototype development are complementary processes, they do not necessarily need to be interdependent. This flexibility ensures that both processes adapt to emerging insights while remaining aligned with the overall objective of the participatorily developed app.

- Stage 2: Iterative feedback collection and participatory app development

The outcomes of the survey define the scope within which the prototype is refined during a participatory design phase that gathers iterative feedback on the mobile app from users. A diverse sampling strategy may allow for the capture of a range of perspectives from different user

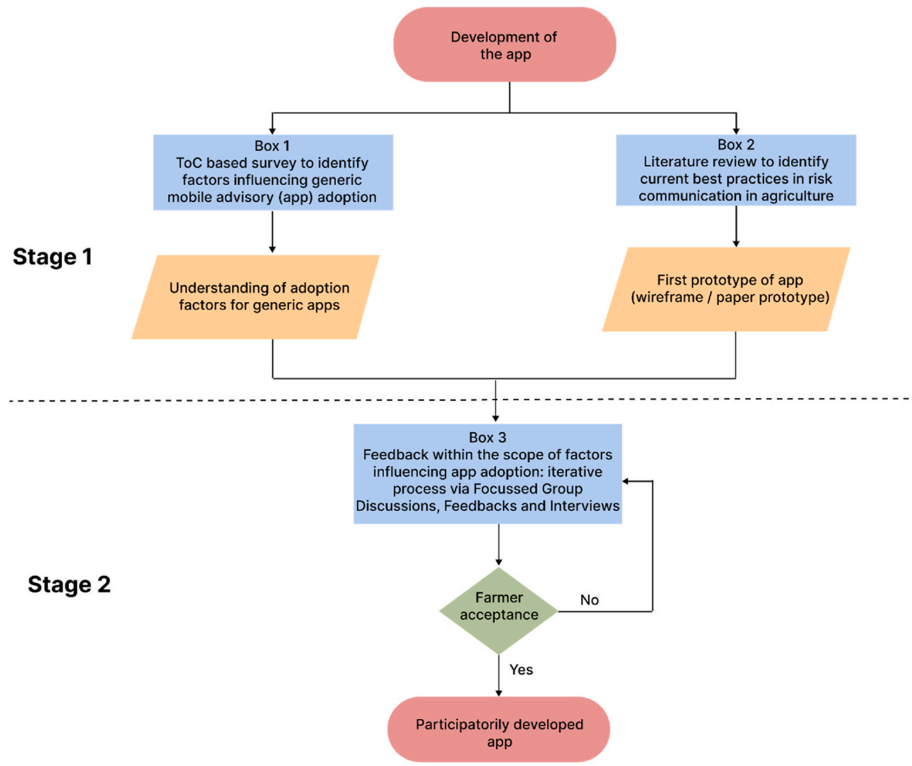

Fig. 1. Flowchart illustrating the conceptual framework for the participatory design process of the Makara app. Numbered process boxes facilitate cross-referencing with the methodological components described in the text.

segments, including (technologically) progressive farmers - those who are more experienced with digital tools - and others. Feedback can be collected through multiple rounds of feedback sessions leading to iterative refinement driven by user input.

This approach can incorporate both in-person and remote interactions, facilitating a wide range of insights through group discussions and individual walkthroughs and feedback collection. This mix may ensure a comprehensive understanding of usability and relevance across different user demographics. To enhance the validity of the feedback, additional input can be sought from users outside the initial sample.

3. Case study implementation of the generic framework: Makara app participatorily developed with farmers in Maharashtra (India)

3.1. Stage 1: Identification of determinants of generic mobile advisory adoption, and development of a prototype app

The first stage of designing Makara focused on understanding the factors influencing the adoption of mobile-based agricultural advisory systems and developing an initial app prototype. The stage comprised two key components: conducting a survey to identify determinants of advisory adoption (Box 1 in Fig. 1, detailed in sections 3.1.1. and 3.1.2.), and developing an initial prototype informed by best practices in communication and design (Box 2 in Fig. 1, presented in 3.1.3.).

3.1.1. The user-focused Theory of Change (ToC)

The Theory of Change (ToC) served as the preferred framework for explaining technology adoption due to its comprehensive, user-centred approach, accounting for the determinants of acceptance, support, and behavioural change (Contzen et al., 2023). It highlights the significance of understanding contextual and psychological factors, as well as change techniques, to facilitate adoption. It has integrated the Risk-Attitude-Norms-Abilities-Self-Regulation (RANAS) model, which encompasses five psychological components: risk, attitude, norms, abilities, and self-regulation (Mosler, 2012). Risk factors reflect an individual's perception of the dangers associated with the absence of agricultural advisory information. Attitude factors pertain to the individual's beliefs about the costs and benefits linked to the specific behaviour under consideration, mobile agricultural advisory adoption. Norm factors relate to perceived social norms, whether these are social expectations around the behaviour, social approval by others, or personal obligations. Ability factors capture the individual's self-assessed capability to execute the behaviour, while self-regulation factors refer to the individual's perceived capacity to maintain and sustain the behaviour over time. Further details on this model can be found in the existing literature (Mosler, 2012; Mosler and Contzen, 2016).

In addition to the RANAS framework, the determinants of technology adoption also encompass perceived fairness, trust in water authorities, and psychological ownership, all of which are considered within the ToC framework (Contzen and Marks, 2018). Perceived fairness, which refers to the perception of an equitable distribution of costs, risks, and benefits among different societal groups, as well as fairness in the decision-making process, has been linked to higher levels of user acceptance (Huijts et al., 2022; Siegrist et al., 2012). Trust in operators, operation and maintenance management (OMM), and the technology itself are also potentially significant factors in the adoption of decentralised treatment technologies (Huijts et al., 2022). Additionally, collective psychological ownership has been identified as a factor influencing technology use, with research indicating that the more individuals perceive the technology as "their own," the more likely they are to utilise it (Marks et al., 2013). These influencing factors are considered in the survey design described below.

3.1.2. ToC based survey design to identify factors influencing the adoption of generic mobile-based agricultural advisories

A quasi-experimental study (Abrahamse et al., 2016) was conducted to evaluate the impact of in-person training and the experience with mobile phone-based agricultural advisories on the adoption of good agricultural practices. This study (Box 1 in Fig. 1), informed by the Theory of Change (ToC, Contzen et al., 2023), was carried out between April and July 2023, involving a survey of 2442 respondents across four districts in Maharashtra: Amravati, Nagpur, Wardha, and Yavatmal. Two treatment groups were identified within the broader study, specifically focusing on the determinants influencing the adoption of mobile phone-based agricultural advisories. This analysis was based on data from 1354 respondents from these treatment groups.

The data preparation process was partly inspired by the protocol to conduct RANAS based socio-hydrological (SH) surveys (Adla et al., 2023). The initial dataset comprised 2442 respondents, which underwent Winsorization to reduce the impact of extreme outliers and ensure the robustness of the statistical analysis. A total of 273 outliers were removed from key variables, including annual total income, annual off-farm income, annual expenditure, agricultural debt amount, agricultural debt duration, area under cotton cultivation, and self-reported cotton yield. Among these, 199 outliers were identified within the two groups of mobile advisory app users (n = 1354). This process resulted in a refined dataset of 2169 respondents across all four groups and 1199 respondents specifically within the mobile app advisory user groups.

Furthermore, within the two groups of mobile advisory users, an additional 54 respondents were excluded due to being outliers concerning the length of time they had used mobile phone-based agricultural advisories; they reported internet usage exceeding the typical availability of mobile internet in rural India. Following these adjustments, a final sample of 1145 respondents was retained for the development of the regression model used in this study.

The independent variables were categorised into several distinct groups to comprehensively assess factors influencing mobile advisory adoption. These categories included (i) mobile phone properties: characteristics such as the type of phone (feature phone or smartphone) and the availability of internet access; (ii) socio-economic and demographic factors: variables like income, education level, age, and agricultural experience; and (iii) socio psychological perceptions: towards technology adoption, which included ToC related variables measured on the Likert scale, listed in Table 1. The primary dependent variable in this study was the number of years respondents had used mobile phone-based agricultural advisories. This variable served as a key indicator of the extent to which mobile advisories have been adopted by the respondents and was used to assess the influence of the independent variables on the adoption process.

3.1.3. *Literature review for first prototype version of the app*

The prototype version of the app was designed through a comprehensive review of existing literature on effective risk communication methods in agriculture (Box 2 in Fig. 1), with particular attention to the optimal content and format for conveying agricultural risks to end users (Ekström and Halonen, 2021). The reviewed literature elaborated on how agricultural risks could be framed, presented, and communicated to resonate with farmers and support informed decision-making (Medhi et al., 2006; Senapati, 2020; Spiegelhalter et al., 2011).

The detailed technical development of the prototype, including coding, user interface (UI) design, and backend integration, is beyond the scope of this publication. Instead, this paper focuses on the participatory design process and iterative improvements in subsequent phases, rather than the specifics of the app's initial technical implementation. More details about the model behind the initial app are presented in Pande and Savenije (2016) and Pacheco et al. (2024), and the initial UI design is presented in Ekström and Halonen (2021).

3.2. *Stage 2: Iterative feedback collection and participatory app development*

Participatory approaches emphasise active engagement of the

Table 1
Overview of the independent and dependent variables used in the survey.

Independent variable category	Independent variable sub-category	Independent variable	Dependent variable
Socio-economic variables		● Annual household income (INR/year) ● Annual household expenditure (INR/year) ● Debt to income ratio = (agricultural debt/total income) (−) ● Perception of how household savings are changing (Likert scale) ● Assets: house ownership, house material, toilet type, household fuel, water source ● Educational level	Number of years of having used mobile agricultural advisories (−)
Mobile phone related variables		● Mobile phone type (feature or smartphone) (−) ● Internet availability on mobile phones (yes/no) (−)	
ToC questions: Risk	● Risk (factual knowledge, R1) ● Risk (perceived severity, R2)	● R1: Are your crops affected if you don't get useful information from mobile apps? ● R2: How severe is the impact on you when you do not have any useful information from mobile apps?	
ToC questions: Attitude	● Attitude (instrumental beliefs, At1) ● Attitude (affective beliefs, At2) ● Attitude (instrumental beliefs, At3) ● Attitude (affective beliefs, At4) ● Attitude (affective beliefs, At5)	● At1: Are there any financial costs related to your farming that are saved if you would use mobile apps? ● At2: Are there any financial benefits related to your farming if you use mobile apps? ● At3: How much are you willing to pay a monthly payment for a mobile app (Rs/month)? ● At4: How do you feel about using only your own knowledge to make decisions on your farm? ● At5: How do you feel about the (potential) use of mobile apps for making farming related decisions?	
ToC questions: Norms	● Norms (descriptive, N1) ● Norms (injunctive, N2)	● N1: What percentage of your village uses mobile phone apps to make farming related decisions?	

(*continued on next page*)

Table 1 (*continued*)

Independent variable category	Independent variable sub-category	Independent variable	Dependent variable
		● N2: Do people close to you approve of using mobile apps for farming related decisions?	
ToC questions: Abilities	● Ability (self-efficacy, Ab1) ● Ability (action knowledge, Ab2) ● Ability (maintenance self-efficacy, Ab3)	● Ab1: How easy or difficult would it be for you to generally use mobile apps usefully? ● Ab2: How self-confident are you about installing a mobile app? ● Ab3: How many obstacles would it take to keep you from using mobile phone apps within the next 5 years?	
ToC questions: Self-regulation	● Self-regulation (action control, S1) ● Self-regulation (coping planning, S2) ● Self-regulation (recovery self-efficacy, S3) ● Self-regulation (habit, S4)	● S1: Do you have a daily schedule for when you use the mobile app? ● S2: Do you have a detailed plan if you are unable to use mobile apps on your phone? ● S3: How many times should your app not work (due to damaged phone or other problems), to stop you from using it? ● S4: Do you automatically use the agricultural advisory mobile phone app everyday?	
ToC questions: Trust	● Trust (in technology, T1) ● Trust (in technology provider, T2)	● T1: Is a mobile app effective in providing useful advice for farms? ● T2: Do you trust in your local mobile repair centre to fix your phone quickly, effectively, and inexpensively?	

stakeholders involved in the research process. The methods in this approach provide in-depth insights through a variety of data collection tools such as focus group discussions (FGDs), one to one interview, walk-throughs, question-and-answer sessions (Q&A), and individual feedback mechanisms. These tools form the foundation of a participatory research framework, a mix of which are implemented in the current study and explained below (Box 3 in Fig. 1).

- *Focus Group Discussions (FGDs):* FGDs were organised to explore a specific set of issues such as people's views and experiences. Such discussions support examination of how knowledge and ideas both develop together and operate within a given cultural context. They were ideal for inductive approaches aimed at generating concepts and hypotheses.
- *In-Depth Interviews:* This method allowed researchers and developers to capture personal experiences of individuals and to gather suggestions for improving the app. The interviews were particularly useful for gathering detailed insights from farmers and also included household surveys to understand behavioural drivers of app adoption by the farmers that are part of stage 1.
- *Walkthroughs:* Farmers were guided through the Makara app for them to understand its functionality, identity issues, and suggest improvements. This method was crucial for ensuring that all participants had a clear understanding of the app and contribute meaningfully to the development process.
- *Question and answer sessions:* This method involved structured question-and-answer sessions that allowed farmers to share their knowledge, experiences, and perspectives. The method encouraged active participation, facilitating exchange of information between researchers and farmers, and promoted mutual understanding of the issues and opportunities.
- *Individual Feedback:* Individual feedback allowed farmers, researchers and developers to reflect on the actions, provide inputs, and adjust strategies. The feedback sessions and channels promoted collective learning.

The overall feedback strategy implemented with the farmers that was a mixture of FGDs both in person and virtual, individual feedback and discussion sessions as well as household surveys is as follows. Two FDGs were conducted in March and Sep–Nov 2023 and individual feedback were conducted in Jan and Aug 2023. The household survey based on ToC was conducted in April–May 2023, which is discussed in section 3.1.2, after which FDGs and individual feedback were conducted.

Out of the total sample size of 2242 farmers across the four districts in Maharashtra, the survey included 1345 participants who had used mobile phone based agricultural advisories earlier. To ensure consistency in the feedback and ease the tracking of improvements in the app over time, some farmers were included in multiple feedback sessions. Sixteen of these farmers participated in Feedback 1, and 53 farmers participated in Feedback 2, which included all the 16 farmers from Feedback 1. FGD 1 and FGD 2 were held with 43 and 15 participants respectively, who had not been involved in either the survey or the Feedback sessions.

3.2.1. Focused group discussion 1 (Mar 2023)

In March 2023, our initial engagement with farmers took place in Maharashtra, involving a team of developers visiting a cluster of 43 farmers across four villages in Wardha districts namely Saigavhan, Faridpur, Wagheda and Waigaon (see Fig. 2).

During this interaction, we introduced various features of the app (walkthrough) and actively sought feedback. To facilitate understanding, we walked the farmers through a comprehensive process flow, starting with account creation, followed by land details input, and culminating in crop selection from predictive suggestions. The functionalities of each screen were elaborated upon using interface screenshots presented in both English and Marathi.

Following the presentation, farmers were encouraged to install the app on their mobile devices and independently create their land profiles and crop entries. The group of farmers encompassed individuals from different age groups, with the younger generation serving as influencers within the community. Typically, these younger farmers played a vital role in educating their older counterparts about the usage of mobile apps. Consequently, in our case, one such young farmer took the initiative to install the app initially, showcasing its workflow to fellow farmers. Developers provided assistance in this process to ensure a smooth transition to using the app. We additionally requested farmers to provide us with an explanation of the risk prediction graph to confirm their comprehension of its interpretation.

3.2.2. Individual feedback sessions (Aug 2023, Jan 2024)

Two comprehensive feedback sessions were conducted in August 2023 (Feedback1) and January 2024 (Feedback 2) to assess the usability and impact of the app among farmers. These sessions aimed to gather

Fig. 2. Photographs of the stakeholder engagement during Focussed group discussion (FGD) 1 and Feedback 1, in March and August 2023, respectively.

detailed insights into the farmers' experiences, attitudes, and the effectiveness of the app's features. Both were designed in terms of questions based on the findings of the survey.

The sampling strategy employed was random sampling from the pool of farmers who had received training and were already using digital advisory based services from the ongoing RVO supported Sustainable Water Fund programme. The Sustainable Water Fund programme (FDW) is a public-private partnership (PPP) facility that aims to contribute to developing countries' water safety and water security. This approach ensured that the sample represented a diverse group of farmers who were already familiar with some level of agricultural training and digital tools, providing relevant context for evaluating the app.

In August 2023, the first feedback session was conducted with farmers from selected villages in Yavatmal and Amravati districts. The feedback on the app was gathered from 16 farmers individually. Data collection involved both qualitative and quantitative questions, focusing on attitudes towards the app, perceived norms regarding mobile phone usage for agriculture, ease of use, and trust in agricultural apps. Key metrics assessed included farmers' feelings about the potential use of the app, the extent of mobile phone usage for agricultural purposes, the ease or difficulty of using the app, and the level of trust in agricultural-related mobile apps.

The second feedback session, conducted in January 2024, involved a wider range of farmers, including those from initial villages and additional villages in Nagpur and Wardha districts to get a more comprehensive understanding. This session included feedback from 53 farmers representing 30 villages from Yavatamal, Nagpur, Wardha, and Amravati. Similar to the first session, this feedback round included both qualitative and quantitative questions but also focussed on specific features of the second iteration of the app. Data collection methods included structured questionnaires, interviews, and observational walkthroughs to gather contextual insights. The key metrics assessed were the acceptance and effectiveness of the app's audio-visual communication, user experience with the app's navigation, the importance and impact of mobile app and advisory services on agricultural practices, and overall feelings and acceptance towards using the app.

3.2.3. Focused group discussion 2 (online/virtual feedback)

Additionally, two virtual sessions were conducted in September and October 2023 with 15 farmers who were not from the project to gather independent feedback on the respectively prevailing versions of the app. Generic feedback on the overall outlook of the app were collected along with specific feedback on the risk communication visualisations. The development of the app between the two sessions was inspired by the principles of agile software development (Shore and Warden, 2021). Hence, a video simulating the features suggested by the farmers during the first session was generated for the second session, instead of fully developing app functionality which may have taken significantly more time. The meetings were held over WhatsApp video to ensure maximum access to most users. Both the sessions started with the simulation video being shown to each farmer one by one, and then focused group discussions aimed towards understanding their perspectives and suggestions for improving the app's usability.

4. Results and discussion

4.1. Stage 1: Determinants for generic agricultural advisory adoption

4.1.1. Description of mobile advisories in the region

Out of the 1145 respondents (after removing outliers) who had used mobile agricultural advisories, the number of agricultural apps used was between 0 and 10, with a mean value of 3 ± 1.5. The advisories could be classified into agro-meteorological apps, agronomic advisories, agricultural Price Aggregation Services, carbon credit (regenerative agriculture) Apps, insurance Claim Verification Apps and social media apps. The users' engagement with these tools varied. The number of different agricultural apps utilised by respondents ranged from none to a maximum of ten, with an average of approximately 3 apps per user (mean value of 3 ± 1.5).

The analysis of app category mentions revealed a clear hierarchy in their prevalence. Out of a total of 3812 instances, social media apps were reported in 45% of the mentions by the respondents, underlining their dominant role for widespread community engagement and collaboration leveraging mobile and internet technologies. Following this, farm management apps were reported in 20% of the cases, reflecting a substantial interest in agricultural technology. Insurance apps accounted for 15% of the mentions, highlighting their essential role in financial planning and risk management. Weather apps were mentioned 10% of the time, indicating some interest in weather-related information for farm (or other) decision-making. Carbon credit apps made up 8% of the mentions, pointing to some limited focus on environmental sustainability. Finally, price-aggregator apps were the least mentioned at 2%, suggesting a more niche interest compared to other categories. These findings illustrated varying levels of engagement and emphasised the prominence of social media alongside the specialised focus on farm management and insurance.

4.1.2. Factors driving and hindering generic mobile advisory adoption

Table 2 lists the significant explanatory factors in the linear regression analysis ($R^2 = 0.31$) explaining the adoption of generic mobile agricultural advisories, grounded in the ToC. The regression model used beta coefficients (β) and standard errors (SE(β)) to quantify the impact of these variables, with statistical significance determined at the $\alpha = 0.05$ level.\

One of the most significant barriers to the adoption of mobile advisory services identified in the study was the lack of reliable mobile phone internet access. This factor emerged as a critical obstacle, as it directly limits the ability of farmers to access real-time information and updates through mobile apps or advisory services. This is confirmed by other studies which highlight the need for an enabling environment and infrastructures for emerging Information and Communication Technologies (ICTs) (Wawire et al., 2017).

Contextual factors, particularly access to water resources, played a

Table 2
Significant socio-economic (SEC) and psychological (RANAS) factors in the linear regression ($R^2 = 0.31$) for the 2023 survey data. β: coefficient, SE(β): standard error in β, $\alpha = 0.05$, and ToC stands for Theory of Change (Contzen et al., 2023). Potential responses to Likert scale questions are provided in square parentheses, e.g., the responses for the Mobile phone related question increase from "no" to "yes"; the ToC: Abilities question has 5 Likert Scale responses, increase from "very difficult" until "very easy".

Variable category	Variable description	β	SE(β)
Socio-economic	Total annual income (agricultural, off-farm, family)	0.14	0.036
	Change in household savings [decrease, stable, increase]	−0.24	0.059
	Tractor [no/yes]	−0.28	0.14
	(Irrigation) water source: open well [no/yes]	0.32	0.15
	Community (irrigation) water source: River [no/yes]	0.56	0.211
	Irrigation technology [rainfed < flood < furrow < micro]	−0.26	0.044
Mobile phone related	Mobile phone without internet [no/yes]	−0.45	0.077
ToC: Attitude	How much are you willing to pay a monthly payment for an agricultural mobile app (Rs/month)? [not willing … willing to pay regularly]	0.17	0.039
ToC: Attitude	How do you feel about using only your own knowledge to make decisions on your farm? [very pleasant … very unpleasant]	−0.29	0.043
ToC: Norms	Injunctive norms: If you use agriculture related apps/advisories to make farming related decisions, how do the people important to you approve? [strongly disapprove … strongly approve]	0.17	0.045
ToC: Abilities	How easy or difficult would it be for you to generally use agriculture related mobile apps or advisory messages/phone calls usefully? [very difficult … very easy]	0.20	0.042
ToC: Trust	Are agriculture related apps or advisories on mobile phones useful for decision making in farms? [not at all … extremely useful]	0.13	0.047

crucial role in determining the adoption of mobile advisories. The study found that both individual and community access to water sources had a positive effect on adoption rates. The access to water may be interpreted as a proxy for some aspects of economic well-being (Young, 2021), and hence a certain level of economic well-being could be associated with longer durations of adoption. However, more efficient irrigation technologies were negatively associated with adoption, which perhaps is an indicator towards their being a limit to which economic-well being influences adoption.

An analysis of the socio psychological factors revealed the following. Attitudinal factors were significant: instrumental beliefs (an assessment of pros and cons operationalized as a willingness to pay) were directly associated with the duration of advisory adoption. Similarly, affective beliefs (i.e., a negative feeling of using their own knowledge for agricultural decision making) were negatively associated with advisory duration, which implies that farmers who were more confident of their own abilities were also more likely to adopt advisories.

Factors such as more favourable injunctive norms, perceived ease of use, and increased trust in advisory services were significant predictors of sustained use of mobile advisories. Norms have been highlighted as a key factor in the adoption of digital farm advisories (Hüttel et al., 2022). Conversely, low user skills, which contrast with the perceived ease of use, have been identified as barriers to the adoption of ICT in agriculture (Ayim et al., 2022). Previous research has shown that many farmers may be distrustful of traditional agricultural extension services (Cole and Sharma, 2018). Additionally, farmers may be sceptical of digital agricultural advisories, particularly when the information provided does not align with their objectives, is presented in a complex manner, or includes overly frequent reminders that may be perceived as patronising (Fabregas et al., 2019). These findings suggest that advisory services that are perceived as accessible, easy to use, and trustworthy are more likely to be adopted and used by farmers over extended periods.

Out of the above factors, the further development of the Makara app was inspired by two socio psychological factors - abilities (self-efficacy or perceived ease of use) and trust in the app. This implies that further development of the app was based on making the app's interface more user-friendly, and increasing trust in the risk communication by improving the yield forecasts by calibrating the prediction model using field data. Injunctive norms (i.e., approval of people one considers important) were also identified as a significant explanatory factor. This was used as a basis for engaging technologically progressive farmers for the focused group discussions sessions described in Section 3.2. This would imply that the feedback from these farmers would help in developing the app in a way that they would approve of the app, and consequently increase their approval of other farmers who may use the app as well. This potential increase in approval from technologically progressive farmers could then lead to more sustained adoption. These bring in considerations of scaling in the design of the app.

4.2. Stage 2: Iterative feedback sessions and participatory app development

4.2.1. Results of focussed group discussion (FGD) 1 (March 2023)

This section lists the feedback we received from the farmers from the face-to-face focussed group discussion conducted in March 2023 with 43 farmers.

- *Cropping methods - inter and multi cropping:* Through interactions with farmers, we learned they often grow multiple crops on the same land each season using two methods: intercropping (planting crops in adjacent or alternate rows) and mixed cropping (growing crops in separate designated areas). While our app already includes an intercropping feature, farmers suggested adding a multi-cropping feature as well.
- *Labour expenditure table:* In addition to the income and yield forecast, the farmers expressed the desire for the inclusion of a profit forecast and a dedicated budget section within the app. They highlighted the importance of having this profit forecast visualization that incorporates expenditure data to better understand overall profits.
- *Mobile number based registration:* The app's login process initially included both email and mobile registration, with OTP (One Time Password) authentication for mobile verification. However, interactions with farmers revealed they frequently change mobile numbers, which could lead to authentication failures due to altered numbers.
- *Distinct colors for yield forecast:* Initially, the forecast graph illustrating yield, income, and profit risk was presented as a stacked bar graph, with five levels of forecast (Very Likely - 90%, Likely - 75%, Possible - 50%, Unlikely - 25%, and Very Unlikely - 10%) with different colors representing yield ranges within each level. However, farmers found it confusing to interpret the upper and lower yield limits and requested a simpler visualization with clearer, contrasting colors.
- *Land section area slider:* We introduced a slider design to help farmers interactively allocate land areas for intercropping. The slider represents 100% of the land, with each side denoting the area for each crop. By dragging the slider, farmers can adjust the percentage allocated to each crop before finalising. However, farmers found this design confusing.

4.2.2. Results of individual feedback (Aug 2023, Jan 2024)

In this section, findings from two farmer feedback sessions conducted in August 2023 and January 2024 are presented. These sessions aimed to evaluate the farmers' attitudes, norms, abilities, and trust concerning the use of the app, based on the outcomes of the household survey and the identified behavioural drivers.

4.2.2.1. Feedback 1 (August 2023). The first farmers' feedback, conducted in August 2023, gathered feedback from farmers in Yavatmal district of Maharashtra, India. The results indicated a generally positive attitude towards the app. Farmers described their feelings about the app as "pleasant", demonstrating a favourable reception. Initially, the majority of the respondents felt positively about the potential use of the app, and this sentiment remained neutral after its introduction, indicating consistent acceptance.

- *Mobile Phone Usage for Agriculture:* Pre-app introduction: 20–40% of the village population used mobile phones for agriculture. Post-app introduction: Usage increased to 40–80%, indicating a positive shift in communal norms towards digital tools.
- *Ease of Use:* Mixed feedback received on usability. Some farmers found it moderately easy to use, while others experienced challenges. They highlighted the need for additional user training, support, and UI improvements. Overall usability rated as moderately easy, suggesting potential for further enhancement.
- *Trust in Agricultural Apps:* Trust levels among farmers were initially moderate and remained stable post-app introduction. Indicated moderate to high trust in the app's credibility and a willingness to rely on it for agricultural support.

4.2.2.2. Feedback 2 (January 2024). The second feedback session, conducted in January 2024, provided further insights into the app's usability and general acceptance among the farmers.

- *Audio-Visual Communication Features:* Farmers positively received the app's audio-visual features, finding them beneficial for understanding and engaging with the app.
- *Sequence and Navigation Flow:* Farmers appreciated the app's logical navigation flow, especially the sequence starting from the farm setup screen, which facilitated intuitive use.
- *Significance of Mobile Apps and Advisory Services:* Farmers acknowledged the role of mobile apps in enhancing agricultural practices and expressed a readiness to incorporate the app into their daily activities.
- *Overall Sentiment and Adoption Potential:* Positive feedback on the app's usability, norms, ability, and trust suggests strong potential for adoption.

The combined insights from August 2023 and January 2024 highlight the value of iterative feedback in improving the app's design for broader scaling and adoption.

4.2.3. *Results of focussed group discussion (FGD) 2 (virtual/online feedback - September, November 2023)*

The prevailing version of the app before the first virtual feedback session communicated risk via icon arrays, which have been shown as an evidence based risk communication technique to improve users' understanding and satisfaction in other fields (Zipkin et al., 2014). The icon arrays designed to convey yield forecasts, with each farmer-icon representing 20% probability and color-coded "bags of produce" indicating yield levels, faced several challenges. Farmers struggled to identify their personal position within the icons, found the reading direction unclear, and expressed a preference for audio outputs. They felt audio would reduce the potential for misinterpretation, particularly for those with limited reading skills, thereby making the information more accessible and clear.

In the second session, a revised risk communication strategy was employed to convey the yield forecast information. This new approach integrated text, a simplified infographic, and an audio explanation to enhance clarity and accessibility. The infographic, given in Fig. 3, displayed yield predictions across a range of potential outcomes, anchored by both the highest and lowest possible yields. The infographic prominently featured a double-sided vertical arrow on the right side, colour-coded from green (highest yield) at the top to red (lowest yield) at the bottom. This visual cue was designed to help farmers intuitively grasp the spectrum of possible outcomes. To the left of the arrow, specific yield values (in kg/area unit provided, e.g., kg/acre) were listed in descending order, representing different levels of yield associated with various cumulative probabilities of occurrence. A key feature of the infographic was the inclusion of a "70%" probability bracket, positioned between the listed yield values. This percentage indicated the likelihood of achieving a yield within the specified range, helping farmers understand the risk associated with their agricultural decisions. To address potential literacy challenges and ensure that the information was accessible to all users, an audio explanation accompanied the visual elements. The audio provided a verbal description of the yield forecast, reinforcing the key points and aiding those who might struggle with interpreting the text or infographic alone.

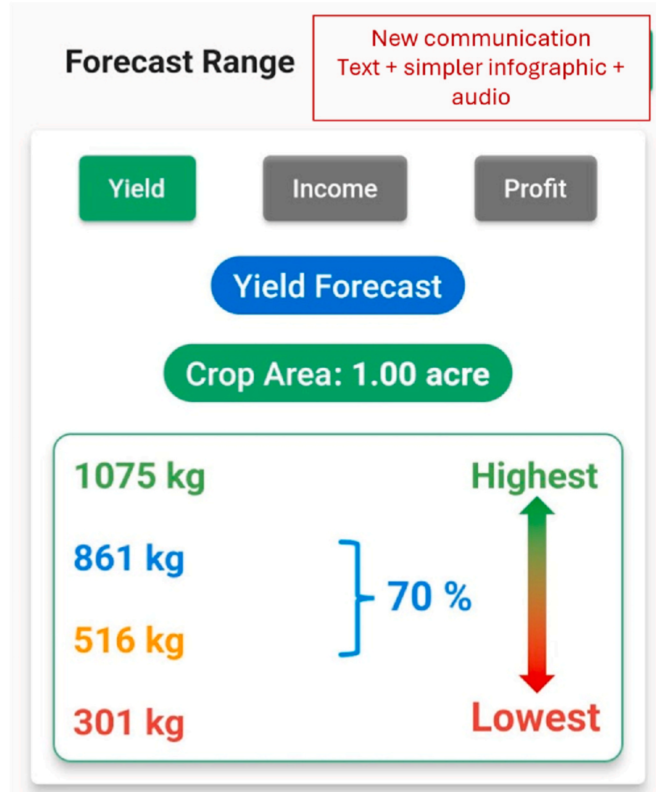

Fig. 3. Updated risk communication through audio-visual infographic combining text, an infographic, and audio to convey yield predictions during virtual feedback session 2. The yield outcomes are shown as colour-coded values ranging from the highest (green) to the lowest (red), with a "70%" probability bracket indicating the most likely range of yields.

The following feedback were collected from the farmers who participated in this session.

- *Interpretation of Audio-Visual Infographic:* Farmers found the app's yield prediction feature understandable but initially misinterpreted the "70% chance" as 70% of maximum yield rather than a probability. They suggested adding clearer explanations of the uncertainties affecting yield probability.
- *Yield Prediction and Weather Dependence:* Farmers highlighted the impact of rainfall on yields, as seen with crops like soybean and cotton, and suggested incorporating this dependency into the app.

- *Technological Literacy:* Some farmers, especially older ones, had difficulty understanding the app without clarification, suggesting that younger family members might assist in explaining features.
- *Precision Farming Suggestions:* Farmers expressed interest in precision farming advice for disease management, input availability, and improving yield reliability, although this was outside the study's scope.
- *Intercropping and Mixed Farming:* Farmers requested expanded support for intercropping and mixed farming strategies, relevant to their existing practices.

The feedback from the farmers in this session indicated that while the new format was generally effective, there were still challenges in ensuring that all users fully understood the probabilistic nature of the information presented. A page which provided an explanation of the context of predictions was included as a feature in the next version of the app. The dependence of the predictions on weather was a limitation of the input weather data that were used for the backend modelling. Intercropping was already a feature in the app, though it was not used for this particular audio-visual demonstration. The suggestion to provide precision farming recommendations was beyond the scope of the study, and this was communicated to the farmers.

The synthesis of App development based on the survey and feedback results, along with the core features of the Makara App is mentioned in the supplementary material (Section S1). Samples of participant responses (translated into English) have also been included in the supplementary material (Section S2).

4.3. Strategy for scaling as per app design

Injunctive norms (i.e., approval of people one considers important) was identified as another behaviour driver of adoption of mobile advisories (Section 3.1.2). Hence, the insights and feedback of technologically progressive farmers were incorporated in the app (Section 3.2). The expectation is that the endorsement of such progressive farmers who are considered important is crucial for a broader acceptance by their peers, potentially enhancing scalability. By leveraging peer influence, these farmers were well-positioned to influence their networks, providing a trusted source of information and encouraging their peers to adopt the app.

The current scaling strategy continues to leverage on the feedback and engagement of the technologically progressive farmers going forward with deployment of the app in an operational environment. This has been done in two steps. First, progressive farmers were contacted individually via the previously described feedback campaigns to establish a strong foundation of support. Next, these farmers were appointed as WhatsApp group administrators, empowering them to lead discussions and share information about the app within their communities. These groups are initially necessary to create local technology clusters, which could potentially become a platform for further upscaling (Hüttel et al., 2022) and has led to the adoption of Makara by 657 unique users in the study region. The next stage entails generating comprehensive usage statistics after the 2024 cotton cultivation season, update the app based on feedback generated thereafter and scale it up further to a wider set of farmers in upcoming growing seasons.

4.4. Limitations of the study

The Theory of Change (ToC) framework used in this study has primarily been developed in the context of decentralised water technologies (Contzen et al., 2023). While ToC and its precursor, the RANAS model (Mosler, 2012), have been used for technology adoption in agriculture (Adla, S. et al., 2024; Hatch et al., 2022), its applicability in agriculture may overlook specific complexities such as stage specific barriers to adoption, leading to gaps in understanding the dynamics between interventions and outcomes.

Our belief that the risk advisory and best management practices chosen were the most effective solutions may be a limitation as agricultural decision making may not explicitly account for risks. However, experts and farmers often perceive climate-related and other livelihood risks differently (Eitzinger et al., 2018). For instance, while experts could view unreliable weather contributing to the highest risks for farmers, farmers themselves may identify crop production failures as their primary concerns. Thus, the provision of outputs related to the risk translating into their crop production may still be vital for farmers.

The process of collecting feedback was also hindered by language barriers and challenges in translation, as the surveys were initially developed in English, translated to Hindi by the first author and Marathi by a native speaker. While the residents of Vidarbha (wherein the study region lies) speak Varhadi Marathi and tend to have Hindi-Marathi bilingual abilities (Tarfe and Bagul, 2024), farmers may have still struggled to fully understand the questions posed to them, which could affect the accuracy and depth of their responses. Additionally, the nuances of farmers' feedback might have been lost or misinterpreted during translation, leading to a lack of clarity in their concerns and suggestions.

Finally, we operated under the assumption that the farmers participating in our study were representative of the broader agricultural community. However, this assumption may not hold true, as geographic location, socioeconomic status, and farming practices can vary widely within and across regions. Consequently, the insights gained from our sample may not accurately reflect the experiences and needs of all farmers, limiting the generalizability of our findings. Acknowledging these limitations helps provide a more nuanced understanding of our study's results and informs future research directions.

5. Conclusions

A novel mixed method approach to a participatory design of an agricultural advisory app called Makara was presented. The novelty was the consideration of behavioural drivers of mobile advisories adoption in the participatory design process itself. For this a farmer survey, grounded in Theory of Change (ToC) and representative of the population of the farmers in the study area, was first conducted to assess the behavioural drivers of mobile advisories. The key drivers identified were trust, ease of use and norms of app usage and attitude towards the use of digital technologies such as the app.

The iterative feedback, from focus group discussion or individual feedback, on app enhancements were then assessed and found to be sustaining trust in and improving the ease of use of the app. The feedback sessions were facilitated by progressive farmers to influence other farmers, who look up to these progressive farmers, to actively provide feedback with the intention to change their attitude towards the app and the prevailing norms surrounding digital technologies. By considering behavioural drivers as part of the co-design process itself, inclusivity and scaling were thus integral part of the participatory process.

As a result, features of the app such as multi-lingual support, intercropping and multi-cropping options, and multi-component budgeting were incorporated and frontend features were transformed to enhance user interface friendliness and incorporate redundancy (e.g., text and audio-visual communication) in communicating risk. The app was deployed, in groups led by progressive farmers, in their operational environment with >600 farmers adopting in the very first season. Following up on the strategy grounded in behavioural theory, the future steps are to continue to scale the app based on feedback in upcoming growing seasons and assess the app versions with respect to the key behavioural drivers to ensure long run sustained and widespread adoption.

CRediT authorship contribution statement

Soham Adla: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Aiswarya Aravindakshan:** Writing – review & editing, Writing – original draft, Software. **Ashray Tyagi:** Writing – review & editing, Writing – original draft, Methodology. **Ramesh Guntha:** Writing – original draft, Software, Methodology. **Mario Alberto Ponce-Pacheco:** Software, Resources, Methodology, Data curation. **Anukool Nagi:** Resources, Project administration. **Prashant Pastore:** Resources, Project administration. **Saket Pande:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors sincerely thank Anand Tiwari and Mangesh Deulkar from Solidaridad Regional Expertise Centre (SREC) India, and Santosh Deshmukh from the Welspun Foundation, for their crucial role in engaging with and facilitating stakeholder participation. They also appreciate the support of Sumit Meshram and Shilpa Ganvir, who connected them with independent farmers from their respective networks, helping broaden the project's reach. The authors extend their gratitude to all the farmers whose insights and feedback were invaluable in developing Makara. This work was supported by the Rijksdienst voor Ondernemend Nederland [NL-KVK-27378529-FDW17109IN].

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.124140.

Data availability

Data will be made available on request.

References

Abrahamse, W., Schultz, P.W., Steg, L., 2016. Research designs for environmental issues. In: Research Methods for Environmental Psychology. John Wiley & Sons, Ltd, pp. 53–70.

Adla, S., Callejas Moncaleano, D.C., Alam, M.F., Daniel, D., Pande, S., 2023. Guidelines to conduct RANAS based socio-hydrological (SH) surveys to understand behaviour (Protocol). Protocols.io. https://doi.org/10.17504/protocols.io.rm7vzb725vx1/v1.

Adla, S., Šaponjić, A., Tyagi, A., Nagi, A., Pastore, P., Pande, S., 2024. Steering agricultural interventions towards sustained irrigation adoption by farmers: sociopsychological analysis of irrigation practices in Maharashtra, India. Hydrol. Sci. J. https://doi.org/10.1080/02626667.2024.2376709.

Aker, J.C., 2011. Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. Agric. Econ. 42, 631–647.

Ayim, C., Kassahun, A., Addison, C., Tekinerdogan, B., 2022. Adoption of ICT innovations in the agriculture sector in Africa: a review of the literature. Agric. Food Secur. 11, 22. https://doi.org/10.1186/s40066-022-00364-7.

Chambers, R., 1993. Challenging the Professions. Frontiers for Rural Development. PRACTICAL ACTION PUBLISHING. https://doi.org/10.3362/9781780441801.

Farmer first. In: Chambers, R., Pacey, A., Thrupp, L.A. (Eds.), 1989. Farmer Innovation and Agricultural Research. PRACTICAL ACTION PUBLISHING. https://doi.org/10.3362/9781780440149.

Cole, S., Sharma, G., 2018. The promise and challenges in implementing ICT for agriculture. India Policy Forum 14, 173–240.

Contzen, N., Kollmann, J., Mosler, H.-J., 2023. The importance of user acceptance, support, and behaviour change for the implementation of decentralised water technologies. Nature Water 1–13.

Contzen, N., Marks, S.J., 2018. Increasing the regular use of safe water kiosk through collective psychological ownership: a mediation analysis. J. Environ. Psychol. 57, 45–52. https://doi.org/10.1016/j.jenvp.2018.06.008.

Corbari, C., Salerno, R., Ceppi, A., Telesca, V., Mancini, M., 2019. Smart irrigation forecast using satellite LANDSAT data and meteo-hydrological modeling. Agric. Water Manag. 212, 283–294.

Cornell, 2020. India's internet explosion: a manifestation of network effects : networks course blog for INFO 2040/CS 2850/econ 2040/SOC 2090. URL. https://blogs.cornell.edu/info2040/2020/12/13/indias-internet-explosion-a-manifestation-of-network-effects/. (Accessed 20 June 2023).

Eitzinger, A., Binder, C.R., Meyer, M.A., 2018. Risk perception and decision-making: do farmers consider risks from climate change? Climatic Change 151, 507–524. https://doi.org/10.1007/s10584-018-2320-1.

Ekström, E., Halonen, J., 2021. Hydro-climatic Risk Assessment and Communication for Smallholder Farmers in Maharashtra (Bachelor Thesis). KTH School of Industrial Engineering and Management, Stockholm.

Fabregas, R., Kremer, M., Schilbach, F., 2019. Realizing the potential of digital development: the case of agricultural advice. Science 366, eaay3038. https://doi.org/10.1126/science.aay3038.

Fu, X., Akter, S., 2016. The impact of mobile phone technology on agricultural extension services delivery: evidence from India. J. Dev. Stud. 52, 1561–1576. https://doi.org/10.1080/00220388.2016.1146700.

Gallardo, M., Elia, A., Thompson, R.B., 2020. Decision support systems and models for aiding irrigation and nutrient management of vegetable crops. Agric. Water Manag. 240. https://doi.org/10.1016/j.agwat.2020.106209.

George, T., 2014. Why crop yields in developing countries have not kept pace with advances in agronomy. Global Food Secur. 10. https://doi.org/10.1016/j.gfs.2013.10.002.

Gido, E.O., Sibiko, K.W., Ayuya, O.I., Mwangi, J.K., 2015. Demand for agricultural extension services among small-scale maize farmers: micro-level evidence from Kenya. J. Agric. Educ. Ext. 21, 177–192. https://doi.org/10.1080/1389224X.2013.872045.

Hatch, N.R., Daniel, D., Pande, S., 2022. Behavioral and socio-economic factors controlling irrigation adoption in Maharashtra, India. Hydrol. Sci. J. 67, 847–857. https://doi.org/10.1080/02626667.2022.2058877.

Huijts, N.M.A., Contzen, N., Roeser, S., 2022. Unequal means more unfair means more negative emotions? Ethical concerns and emotions about an unequal distribution of negative outcomes of a local energy project. Energy Pol. 165, 112963. https://doi.org/10.1016/j.enpol.2022.112963.

Hüttel, S., Leuchten, M.-T., Leyer, M., 2022. The importance of social norm on adopting sustainable digital fertilisation methods. Organ. Environ. 35, 79–102. https://doi.org/10.1177/1086026620929074.

Katengeza, S.P., Okello, J.J., Jambo, N., 2011. Use of mobile phone technology in agricultural marketing: the case of smallholder farmers in Malawi. Int. J. ICT Res. Dev. Afr. (IJICTRDA) 2, 14–25. https://doi.org/10.4018/jictrda.2011070102.

Li, X., Yu, G., Wen, L., Liu, G., 2023. Research on the effect of agricultural science and technology service supply from the perspective of farmers' differentiation. Innovation and Green Development 2, 100055. https://doi.org/10.1016/j.igd.2023.100055.

Marks, S.J., Onda, K., Davis, J., 2013. Does sense of ownership matter for rural water system sustainability? Evidence from Kenya. J. Water, Sanit. Hyg. Dev. 3, 122–133. https://doi.org/10.2166/washdev.2013.098.

Medhi, I., Sagar, A., Toyama, K., 2006. Text-free user interfaces for illiterate and semi-literate users. In: 2006 International Conference on Information and Communication Technologies and Development. Presented at the 2006 International Conference on Information and Communication Technologies and Development, pp. 72–82. https://doi.org/10.1109/ICTD.2006.301841.

Mittal, S., 2012. Modern ICT for agricultural development and risk management in smallholder agriculture in India. DF. CIMMYT, Mexico. Working paper no. 3).

Mittal, S., Tripathi, G. (Eds.), 2009. Role of mobile phone technology in improving small farm productivity. Agricultural Economics Research Review Agricultural Economics Research Review. https://doi.org/10.22004/ag.econ.57502.

Moore, M.-L., Riddell, D., Vocisano, D., 2015. Scaling out, scaling up, scaling deep: strategies of non-profits in advancing systemic social innovation. J. Corp. Citizen. 67–84.

Mosler, H.-J., 2012. A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. Int. J. Environ. Health Res. 22, 431–449. https://doi.org/10.1080/09603123.2011.650156.

Mosler, H.-J., Contzen, N., 2016. Systematic Behavior Change in Water, Sanitation and Hygiene. A Practical Guide Using the RANAS Approach. Swiss Agency for Development and Cooperation SDC, Version 1.1.

Pande, S., Savenije, H.H., 2016. A sociohydrological model for smallholder farmers in Maharashtra, India. Water Resour. Res. 52 (3), 1923–1947.

Pacheco, M.A.P., Adla, S., Guntha, R., Aravindakshan, A., Presannakumar, M., Tyagi, A., Nagi, A., Pastore, P., Pande, S., 2024. Makara: A tool for cotton farmers to evaluate risk to income. Smart Agricultural Technology, 100759. https://doi.org/10.1016/j.atech.2024.100759.

Probst, K., Hagmann, J., Becker, T., Fernandez, M., 2000. Developing a framework for participatory research approaches in risk prone diverse environments. Presented at the Deutscher Tropentag 2000 Session: Farming Systems and Resource Use. Hohenheim.

Rupnik, R., Kukar, M., Vračar, P., Košir, D., Pevec, D., Bosnić, Z., 2019. AgroDSS: a decision support system for agriculture and farming. Computers and Electronics in Agriculture, BigData and DSS in Agriculture 161, 260–271. https://doi.org/10.1016/j.compag.2018.04.001.

Saiz-Rubio, V., Rovira-Más, F., 2020. From smart farming towards agriculture 5.0: a review on crop data management. Agronomy 10, 207. https://doi.org/10.3390/agronomy10020207.

Senapati, A.K., 2020. Evaluation of risk preferences and coping strategies to manage with various agricultural risks: evidence from India. Heliyon 6, e03503. https://doi.org/10.1016/j.heliyon.2020.e03503.

Sharma, U., Chetri, P., Minocha, S., Roy, A., Holker, T., Patt, A., Joerin, J., 2021. Do phone-based short message services improve the uptake of agri-met advice by

farmers? A case study in Haryana, India. Climate Risk Management 33, 100321. https://doi.org/10.1016/j.crm.2021.100321.
Shore, J., Warden, S., 2021. The Art of Agile Development. O'Reilly Media, Inc.
Siegrist, M., Connor, M., Keller, C., 2012. Trust, confidence, procedural fairness, outcome fairness, moral conviction, and the acceptance of GM field experiments. Risk Anal. 32, 1394–1403. https://doi.org/10.1111/j.1539-6924.2011.01739.
Spiegelhalter, D., Pearson, M., Short, I., 2011. Visualizing uncertainty about the future. Science 333, 1393–1400. https://doi.org/10.1126/science.1191181.
Steinke, J., van Etten, J., Müller, A., Ortiz-Crespo, B., van de Gevel, J., Silvestri, S., Priebe, J., 2021. Tapping the full potential of the digital revolution for agricultural extension: an emerging innovation agenda. Int. J. Agric. Sustain. 19, 549–565. https://doi.org/10.1080/14735903.2020.1738754.
Steinke, J., Ortiz-Crespo, B., van Etten, J., Müller, A., 2022. Participatory design of digital innovation in agricultural research-for-development: insights from practice. Agric. Syst. 195, 103313. https://doi.org/10.1016/j.agsy.2021.103313.
Steinke, J., Schumann, C., Langan, S., Müller, A., Opola, F.O., Ortiz-Crespo, B., van Etten, J., 2024. Fostering social inclusion in development-oriented digital food system interventions. Agric. Syst. 215, 103882. https://doi.org/10.1016/j.agsy.2024.103882.
Stienen, J., Bruinsma, W., Neuman, F., 2007. How ICT can make a difference in agricultural livelihoods. The Commonwealth Ministers Reference Book. International Institute for Communication and Development.
Tarfe, O.S., Bagul, M., 2024. Linguistic diversity of Marathi in Maharashtra: review article. IRE J. 7, 91–96.
Vroman, K.G., Arthanat, S., Lysack, C., 2015. "Who over 65 is online?" Older adults' dispositions toward information communication technology. Comput. Hum. Behav. 43, 156–166. https://doi.org/10.1016/j.chb.2014.10.018.
Wawire, A., Wangia, S., Okello, J., 2017. Determinants of use of information and communication technologies in agriculture: the case of Kenya agricultural commodity exchange in bungoma county, Kenya. J. Agric. Sci. 9, p128. https://doi.org/10.5539/jas.v9n3p128.
Young, S.L., 2021. Viewpoint: the measurement of water access and use is key for more effective food and nutrition policy. Food Pol. 104, 102138. https://doi.org/10.1016/j.foodpol.2021.102138.
Zipkin, D.A., Umscheid, C.A., Keating, N.L., Allen, E., Aung, K., Beyth, R., Kaatz, S., Mann, D.M., Sussman, J.B., Korenstein, D., Schardt, C., Nagi, A., Sloane, R., Feldstein, D.A., 2014. Evidence-based risk communication. Ann. Intern. Med. 161, 270–280. https://doi.org/10.7326/M14-0295.