Kashf Journal of Multidisciplinary Research
Vol:03 – Issue 04 (2026)
P-ISSN: 3007-1992 E-ISSN: 3007-200X
https://kjmr.com.pk

IMPROVING ACCESSIBILITY IN AGRICULTURE: A USABILITY EVALUATION OF MULTIMODAL INTERFACES FOR LOW-LITERATE USERS IN DEVELOPING REGIONS

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DOI: (*https://doi.org/10.71146/kjmr892*)

Article Info

Abstract

Over the period of time, digital solutions have become an integral part of all sectors, including the Agricultural sector, which is the main livelihood in many developing regions of the country. However, many farmers still face challenges in the utilization of digital technologies because of low literacy levels. Existing conventional systems are all heavily based on text based mobile solutions, which limit the ability usage among illiterate and semi-illiterate farmers. To address these challenges and to fill the gap, this study thoroughly investigates the use of a novel multimodal interaction framework that combines the usability of ICT solutions in low literacy contexts. The proposed framework's efficacy and effectiveness can be evaluated by a mobile application solution that was developed under the name of Zameendar in collaboration with more than 100 farmers from across different communities. The proposed framework assessment was based on the ISO 9241-11 standard for measuring different metrics like user satisfaction level, error rate, efficiency in task performance, and the success rate. The results for illiterate were low as compared to the semi illiterate users like the success rate for illiterate was 53% but the semi illiterate users achieved 82%, the task completion rate was also low as compared to the semi illiterate users which was 68.7 second, and there was greater level of user satisfaction as compared to the illiterate users, who nonetheless showed a 78% reduction in errors with repeated use underscoring the learnability of the approach.

The results and findings of this study demonstrated that the integration of a multimodal interaction framework with a focus on culturally grounded interactions that can improve accessibility for both users who are illiterate and semi-illiterate. The same approach can be followed across the developing regions. Therefore, the main contribution of this work is an evidence-based methodology and is scalable for designing digital solutions targeted towards usability in low-literacy regions.

Keywords: *Low-Literacy Farmers; Accessibility; Participatory Design; ICT4D; Usability Evaluation; Digital Agriculture; Multimodal Interfaces; Urdu-Pashto, Human Computer Interaction, GDP.*

1. Introduction

The agriculture field is considered as the backbone of Pakistan's economy and contributes up to one-fifth to the gross domestic product (GDP) and supports the livelihood of the rural population [1]. Over the past few years, there has been a major difference and an increase in the integration of information and technology in agricultural fields, and in response to it, a substantial effect is visible in the form of improved productivity, strengthening of market access, and increased resilience against climate change [2]. If all of these technologies are designed and implemented properly, they can play a major transformative role in supporting farming communities.

Conversely, the ICT adoption benefits are distributed unevenly, with the marginalized farming communities being unable to effectively utilize or access the digital tools. A growing body of ICT Development (ICT4D) studies focuses on the structural barriers that are being faced by the rural farmers, such as mismatches of languages, low literacy rates, and limited exposure to technologies [3]. These types of structural barriers reinforce the digital divide, leaving the marginalized groups of users excluded from agricultural innovations. Bridging these gaps and limitations requires rethinking about not only the inclusivity of user interfaces but also to meet the technological infrastructure, ensuring that these ICT digital solutions are designed in such a way that they meet the needs of marginalized communities with diverse literacy profiles and linguistics. The adoption and effectiveness of ICT tools in Pakistan remain inhibited by several barriers. Most of the farmers of Khyber Pakhtunkhwa (KP) and other regions primarily communicate with each other in local languages such as Pashto rather than Urdu, making the text-based ICT services inaccessible to them [3]. Moreover, the usability of the tools that already exist is often poor, as most agricultural applications are designed for literate, urban users with little regard for linguistic and cultural diversity [4] face different challenges. Due to these challenges and gaps, low-literate farmers' communities are excluded from the benefits of digital agriculture. Previous studies emphasize three different critical gaps in agricultural ICT design. The first gap is the absence of language adaptive interfaces tailored for low-literate populations [5]. Another is the limited application of participatory design in the field of agricultural technology development, which has resulted in tools that fail to meet user needs [6]. Third is about the lack of real-world usability validation in such resource-constrained environments, which restricts the scalability of proposed solutions [7]. It is necessary to address the limitations and gaps to achieve a highly effective and efficient ICT adoption in agricultural fields. The key gaps and barriers are highlighted in Figure 1:

Low literacy, poor usability, language diversity of existing tools, and lack of inclusive design show how multimodal interfaces integrate culturally relevant icons and localized voice to bridge these gaps. This approach ensures the accessibility mode for the low-level farmer in rural areas of Pakistan aligns with the solution of ICT, with linguistic and cultural contexts. The leading and promising pathways to address these limitations and gaps are being identified as Multimodal interfaces. By integrating the output of the devices and multiple inputs such as iconography, visual navigation, and localized voice prompts helps the system helps to reduce the dependence on text and to make digital tools more intuitive for low literate users [8]. Research in human-computer interaction (HCI) confirms that multimodal solutions not only improve the completion of tasks and comprehension but also foster greater trust among users unfamiliar with text-based systems [9]. Such types of approaches play a vital role in rural areas of KP, where the visual literacy and the oral traditions play a more significant role than the textual comprehension. Moreover, the multimodal systems are integrated with the principles of participatory design, where the solutions are co-created with the users to ensure cognitive, linguistic, and cultural relevance. Studies have shown that the involvement of farmers directly in the designing and evaluation process results in technologies that exhibit higher adoption rates and sustained use [10]. By integrating the principles of participatory methodologies with a multimodal approach, a critical advancement in developing an ICT solution for both social, viable, and inclusive.

To bridge these limitations and to respond to the challenges faced, this research paper presents a multimodal interface designed for low-level illiterate users in the agricultural sector of a developing region. The purpose of the study is to integrate the culturally relevant icons with the Pashto-Urdu voice prompts to minimize the dependence on text-based comprehension and navigation. A mixed-method approach for usability evaluation was conducted with different communities of farming in KP to assess the error reduction rate, task success rate, and user satisfaction. The findings from this approach resulted in a significant improvement in accessibility: task completion rate of illiterate users was 82%, semi-literate users achieved 89% rate, and the icon recognition accuracy reached 92%, substantially outperforming the traditional and conventional text-based applications.

This paper's contribution is threefold:

1. **Novel Interface Design:** A multimodal interface is introduced, which eliminates the dependence on the text by integration of culturally relevant icons and localized voice prompts.
2. **Contextual Relevance:** To address the gap present in the agricultural systems for low literate users, the demonstration of the importance of integrating ICT solutions to cultural contexts and linguistics is performed.
3. **Empirical Usability Evaluation:** Results derived from user testing with low-literate farming communities in resource-constrained environments, provide design insights for inclusive agricultural ICT.

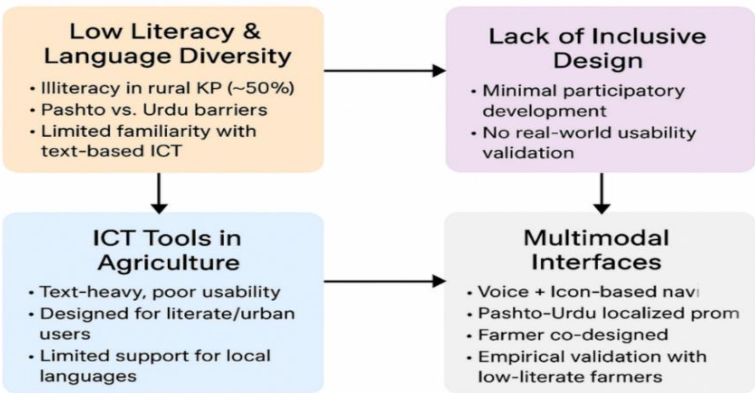

Figure 1: Proposed multimodal interface solution flow diagram and Agricultural ICT barriers.

Organization of the Paper

This paper's remainder sections are organized as follows: Section 2 presents the Literature Review of this paper, which summarizes the main studies related to the multimodal interfaces and ICT accessibility for low-literate farmers in agricultural fields. Section 3 presents the Methodology section, comprising the research framework, evaluation approach, and system design. Section 4 presents the Results and Discussion section, showcasing the main findings in the context of accessibility and usability. Section 5 presents the extended Discussion on the broader implications of the study. Section 6 presents the Benefits of the Study, focusing on the practical contributions and its novel framework design. At the end, Section 8 comprises the Conclusion and Future Work, summarizing the findings and outcomes and suggesting new ways and directions for further research.

2. Literature Review

The core theme in ICT is to improve the accessibility in agricultural fields for Human-Computer Interaction (HCI) and ICT Development (ICT4D), especially in the regions where communities of farmers face multiple challenges [11]. In the developing regions, the farmers lack exposure to standard written languages and rely on the oral and localized dialects and traditions, which makes mainstream agricultural mobile applications difficult to use [12]. So as a result, the farmers cannot take full advantage of the essential services such as pest management alerts, market price updates, and weather forecasts [13]. To address these gaps, researchers have multimodal interaction as a pathway to inclusivity. Multimodal systems combine both input and output channels, such as images, voice, and icons, to reduce dependence on text and to enhance the usability for users who have a low literacy rate [14]. In pilot studies and agricultural prototypes, it is being demonstrated that multimodal approaches improve navigation, comprehension, and trust among farmers with limited literacy skills [15]. Nonetheless, the major gaps remain the same: few systems adopt participatory design methods, most of them remain limited to experimental environments rather than real-world deployment, and usability evaluations in resource-constrained contexts are rare [6]. Bridging these limitations is essential for scaling agricultural ICT solutions that are both society-inclusive and technologically robust.

2.1 The role of ICT in Agricultural development for low literacy populations.

In Pakistan, a large community of agricultural people is illiterate or semi-illiterate, and the skills needed for interacting with ICT systems is limited [16]. Most of the applications are not accessible to users who have a low literacy rate due to their text-heavy design [17]. HCI studies have shown that populations with low literacy rates can effectively interact with multimodal interfaces for ICT technologies. Multimodal interfaces recommend incorporating culturally relevant iconography, integrating voice annotations, and minimizing the text to enhance comprehension [18, 19]. These recommendations highlight and focus on the ICT technologies in the agricultural field for low-level literate users.

2.2 Challenges in Delivering Inclusive ICT Solutions Across Regions

Digitalization of the agricultural field has been uneven across various regions of Pakistan, reflecting the discrepancies in infrastructure policies and priorities at the literacy level. Several different initiatives have been initiated by the Punjab government to support farmers by delivering timely updates related to weather, prices that exist in the market and expert advisory content, and government policy notifications [20]. The efforts have shown a promising effect not only in providing farmers with actionable information but also in strengthening agricultural productivity, thereby strengthening resilience and agricultural productivity. But most of the platforms are text-centric, assuming a level of literacy that is not representative of the broader farming population [21]. As a result, the farmers with a high literacy rate take advantage of these services, while the marginalized group of farmers whose literacy skills are low are unable to benefit and take advantage form such interventions. As a result, the accessibility gap is created in such regions where the ICT infrastructure is already advanced. In contrast, the Khyber Pakhtunkhwa (KP) situation highlights more severe challenges. Khyber Pakhtunkhwa province consists of nearly half of the population that is illiterate, and they rely on oral and visual aids rather than written text. Moreover, the conventional ICT tools are also not suitable for this demographic region as they have language constraints and exist in the Urdu and English languages only [22]. Farmers of KP face different barriers, not only in the understanding of the content, language barrier, but also in navigation from one interface to another, designed without considering literacy constraints and linguistics. Without targeted accessibility measures such as multimodal interfaces that integrate localized voice prompts and culturally relevant iconography, these communities' risk being excluded from the benefits of agricultural digitization [23]. This exclusion is really important as agriculture is the backbone of KP's economy, and not limiting this group could deepen the inequalities in income, productivity, and climate resilience.

2.3 Existing Agricultural Applications

Among different digital agricultural tools in Pakistan, Bakhabar Kisan stands out to be one of the most detailed and comprehensive platforms, offering a vast range of services including updates, localized weather forecasts, agricultural advisory content, digital marketplaces for farm inputs, and market price [24]. A great step towards digitalization in the field of agriculture is taken by this digital platform as it integrates multiple services into the two ecosystem and thereby reduces the farmers' dependency on different sources of information. According to the research and study, other multifunctional applications, such as Bakhabar Kisan, shows that they offer a high level of user interaction as compared to a single-feature tool, as they address the limitations and fill the gaps that exist, like diverse farming needs, within a single system [25]. By integrating these, the digital platform shows a potential contribution not only in decision-making but also at the farm level to broader modernization. In spite of the enhancements and advancements made in these systems, accessibility remains a significant challenge. The interface designed is totally text-dependent, which is suitable for illiterate users but limits the usability for low-literate farmers. According to findings 58% of the semiliterate farmers of the KP region still struggle to use the application Bakhabar Kisan effectively, due to text-based navigation menus and interpreting the advisory content [26]. In the regions, where the literacy rate is low, the use of text-based menus disadvantages the farmers, widening the digital divide within the agricultural sectors. These types of challenges underline the need for alternative modalities, such as voice-assistant navigation, relevant iconography, that enable the low-level illiterate population to interact with the agricultural ICT systems. Without these inclusive designs, even the robust and multifunctional platforms risk falling short of their intended purpose, leaving a large group of the farming population excluded from digital agricultural benefits.

Table 1: Accessibility Gaps in Agricultural ICT and Multimodal Opportunities

Category of ICT Solution	**Accessibility Issues**	**Identified Research Gap (with references)**	**Implications for Problem & Objectives**
Market Price Information	Text-heavy interfaces; numeric data difficult for low-literate users	Lack of multimodal systems (voice readouts, icon-based charts) to support comprehension [27]	Justifies the objective of designing voice-icon systems to improve market access for semi/illiterate farmers.
Weather Forecasting	Scientific symbols, technical terms, and reliance on text	Absence of localized voice alerts and culturally relevant weather icons [27]	Supports the problem statement by showing exclusion of KP farmers; the objective is to build multimodal alerts.
Pest and Disease Alerts	Long advisory texts with difficult terminology	Need for image-based pest recognition with voice-supported treatment options [28]	Aligns with design intuitive multimodal alerts that reduce reliance on literacy.
Fertilizer Scheduling	Complex dosage instructions in text form	Gap in step-by-step multimodal guidance using voice and crop-stage icons [29]	Objective reinforced: multimodal design reduces input errors, proves task completion.
Irrigation Management	Numeric-heavy sensor readings; literacy required	Lack of intuitive visual gauges and voice alerts [28]	Objective justified: multimodal dashboards can enhance decision-making efficiency.
Government Policy Notifications	Text-based in Urdu/English; no local adaptation	Missing multimodal interfaces with voice translations and icon summaries [30]	The problem addressed by making policies accessible to low-literate KP farmers.
Digital Marketplaces	Text-based navigation, product search difficult	Lack of voice-enabled search and pictorial catalogs [29]	Directly tied to the objective: improving usability and inclusion through multimodal browsing.
Farm Advisory Services	Technical, text-dense content	Absence of interactive voice-driven decision trees [31]	Helps define the objective of contextualized multimodal advisory systems.
Training and Education Modules	Text-heavy manuals; low engagement	Limited adoption of audio-visual storytelling and localized narration [32]	Objective linked: multimodal Training boosts engagement and knowledge retention.
Record Keeping and Finance	Numeric literacy required; hard data entry	Gap in voice-based transaction input and icon categorization [33]	Reinforces the objective of designing multimodal finance tools for illiterate farmers.

Table 1 summarizes the challenges of accessibility associated with existing ICT solutions in the agricultural field and highlights the research gaps reported in prior studies. While the other initiatives, such as weather forecasting services, advisory systems, pest alerts, and market price platforms remains inaccessible to low low-literate population of farmers due to their heavy reliance on technical terminology, numerical data, and dependence on text [34]. To address the shortcomings like integration of voice, icons, and simplified visuals, multimodal approaches have been called [35]. The final column of the table establishes a direct relation of implications of these gaps for the present objectives and study problem. It shows that the lack of culturally contextualized, language-adaptive, and usability-validated multimodal interfaces continues to exclude marginalized farmers' communities in the KP region. This issue reinforced the need for evaluating and designing a multimodal approach framework that improves task success, inclusivity, and user satisfaction rate for the population with a low literacy rate in agriculture [36].

Methodology

The methodologies adopted a user-centered field-driven approach that is being tailored to the socio-technical realities of farmers with low literacy rates in developing regions of Pakistan [37]. It is the combination of ethnographic participant election with participatory design principles to ensure that accessibility of multimodal interfaces addresses real-world challenges of agricultural needs. The study was based on the clear distinction between farmers from different regions of Pakistan, based on the literacy rate, to evaluate the usability [38]. The approach of multimodal was designed and developed through the incorporation of interactive workshops, voice guidance, cultural symbols, and local languages integration, which covered the limitations that exist in conventional systems and studies [39]. Each designing phase consists of farmers' input, ensuring the intuitiveness, ease of use, and relevance. The architecture of the multimodal interface illustrates the integration of several services, like backend services, cloud infrastructure, farmer mobile interfaces, and admin web portals. The architectural design emphasized the voice icon-driven interaction for low-literacy rate farmers, real-time feedback loops to optimize agricultural decision making, and offline caching for connectivity challenges user as shown in Figure 2.

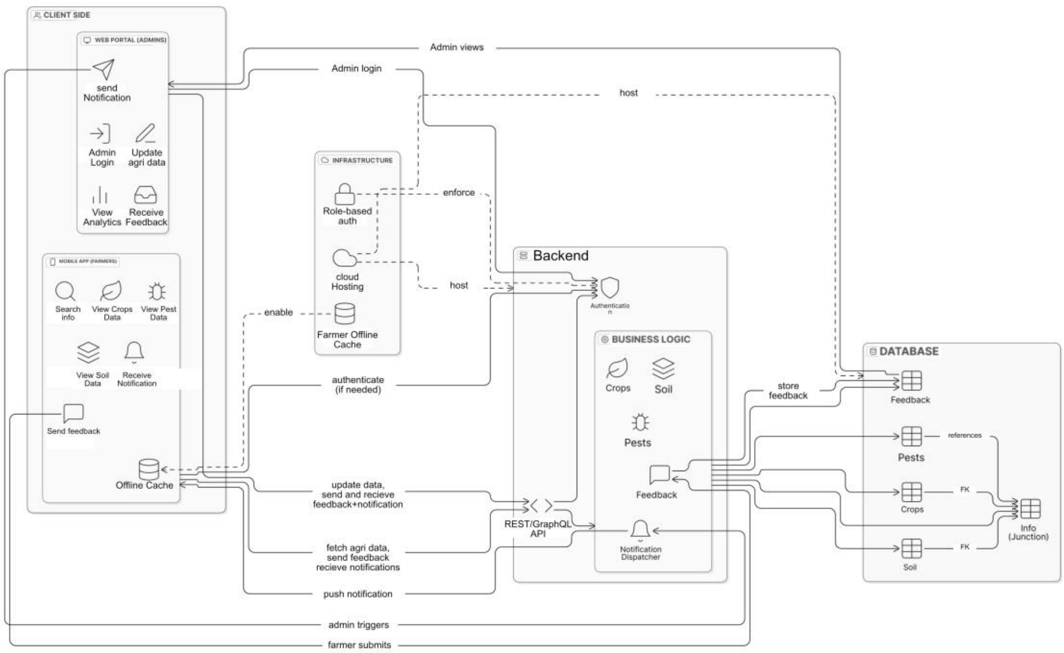

Figure 2: Multimodal interface System Architecture with mobile, web, cloud, and backend integration.

3.1 Participant Selection

Table 2 shows the distribution of participants according to five different study regions (R1-R5), with a total number of 100 farmers, equally divided between different groups, like illiterate (n=50) and literate (n=50). Each region is further categorized into 20 participants (10=literate and 10=semiliterate), ensuring the diversity and balance in the sample. Agricultural understanding was persistently high, ranging from 70% in R3 to 100% in R1 and R4, reflecting strong domain expertise among the participants. Moreover, all the farmers reported basic family and access to mobile technologies, which provided a practical foundation for the evolution of multimodal interfaces in low literacy contexts [40]. The distribution focuses on both the strengths and variations within the sample, ensuring that usability findings reflect a broad spectrum of agricultural knowledge and literacy across different regions of Khyber Pakhtunkhwa (KP) [41].

Table 2: Participant Selection

Sample Taken Regions	Total users=100		Agriculture Understanding(%)	Technology Access & Usage Knowledge
	Illiterate	Semi-literate		
R1	10	10	100	Yes
R2	10	10	80	Yes
R3	10	10	70	Yes
R4	10	10	100	Yes
R5	10	10	90	Yes

The term R denotes the region of the farmer.

3.2 Participatory Design

A user-centered approach was needed to design the multimodal interfaces for low-literate and semiliterate farmers. A Participatory Design (PD) methodology [42] was adopted for engaging the local farmers, community representatives, and local experts through the process, as shown in Figure 3.

There were four groups of participants: (i) Users: Farmers, having direct interaction with the interfaces, (ii) Proxies: local advisors or family members who articulated user needs, (iii) Experts: specialists of agricultural fields who contributed to domain-specific content, and (iv) NGO staff and design team members who documented sight and guided sessions.

Stage 1: Understanding Farmers' Needs

Different visits to the field and interviews were conducted to identify the farming challenges. The tasks were prioritized by the farmers, such as the identification of crop diseases, checking the prices of the crops, and assessing the fertilizer schedules. Different sticker-based picture cards were used in it to capture the needs of the farmers without relying on the text. The most critical feature that emerged was the pest control and weather updates [43].

Stage 2: Designing Icons and Voice Features

With the help of the farmers, culturally relevant icons were co-created, like depictions of fertilizer bags or infected crops. For the enhancement of accessibility, all the contents were recorded in both Urdu and Pashto by using local voices with accents, ensuring the usability for farmers with no or limited literacy rate.

Stage 3: Testing Prototypes and Gathering Feedback

Low-fidelity prototypes in mobile screens and paper were tested through tasks like pest management advice, fertilizer scheduling, and market price checking. Feedback revealed a strong preference for icon-driven interfaces and voice over the text-based designs, confirming the effectiveness of multimodal interfaces for this group of users [44].

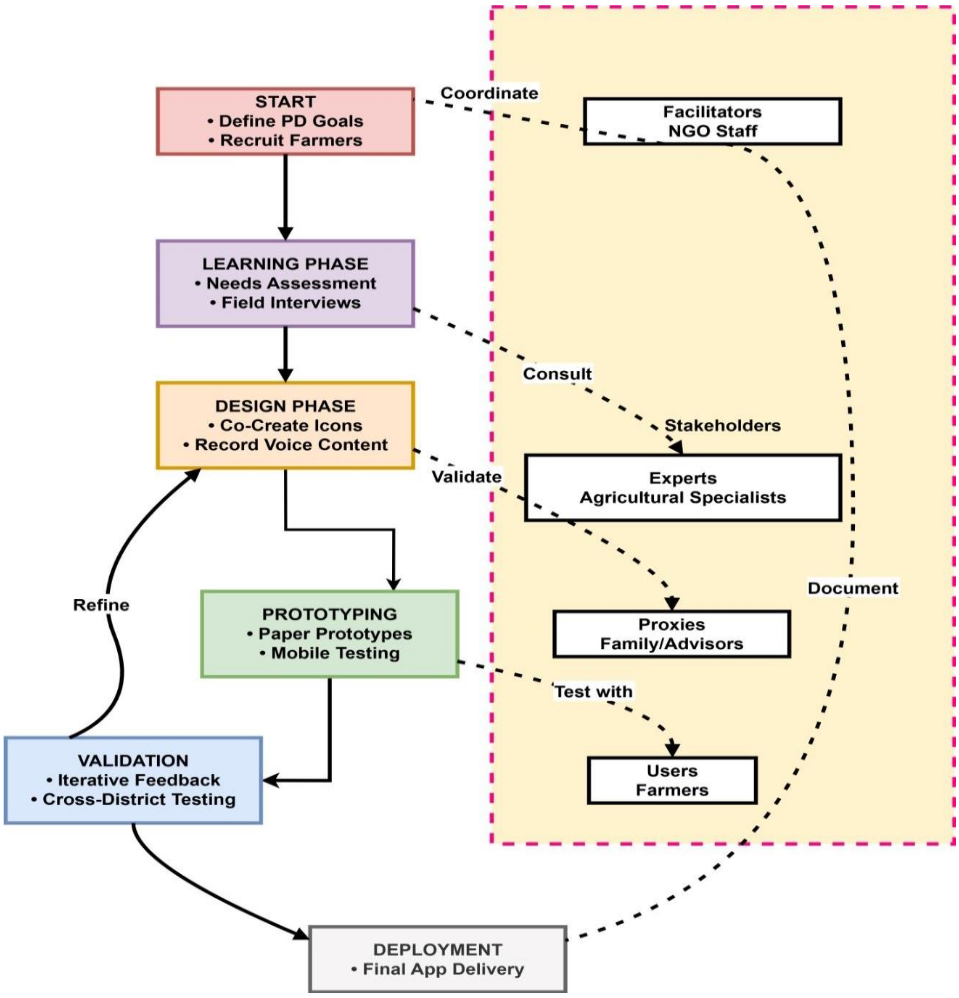

Figure 3: Flow diagram of the participatory design

Implementation of Application

The multimodal interface was designed and developed as a mobile solution known as the Zameendar Application, with the main focus on localized content, simplicity, and accessibility. The mobile application was deployed in Android Studio using Java as the main programming language with backend services provided by Firebase, real-time data synchronization, and cloud storage. The incorporation of voice annotations both in Urdu and Pashto with culturally familiar icons minimized the reliance on text, thereby supporting low-level literate users in performing critical tasks of agriculture. The user interface system architecture is illustrated in Figure 2, while the implementation of features such as cloud-based messaging and audio input is depicted in Figure 4.

Figure 4: Screenshots of the Multimodal Interfaces for low-literate users

The major and core features of multimodal interface include a scheduling system for fertilizers, a real-time crop market price viewer, and voice-guided crop disease identification module. The scheduler for fertilizer provides timely recommendations based on the type of crop and growth stage, using a voice prompt to alert users. Crop price feature pulls the updated rates from the locally present markets and presents them through simple voice menus, enabling farmers to make informed selling decisions without needing to read [45].

Each module was being tested in the real environments across five different cities in Pakistan. Special attention was given to low-bandwidth support and offline functionality, ensuring that the farmers in remote areas could access key information even with limited connectivity.

Quantitative Performance Metrics for Usability

The multimodal interface, like the Zameendar Application usability evaluation, aligns with ISO 9241-11 standard, which defines usability as the extent to which a system can be used by some specified set of users to achieve specific targets with efficiency, effectiveness, and satisfaction in a specified context of use [46]. Table 3 shows the four main metrics that were selected in accordance with the framework to assess the suitability of applications for both the illiterate and semi-illiterate farmers. **Task Success Rate**, as defined by ISO-9241, is a direct indicator of *effectiveness*, i.e., the accuracy and completeness with which users achieve specified goals [47].

This metric was used to assess whether users, particularly the illiterate farmers, can independently complete tasks like identification of crop diseases or check the market price without external assistance for the Zameendar Application. **Time on Task** serves as a measure of *efficiency*, indicating the resources expended in relation to task accuracy. The time was being tracked, which they took to complete each task, and from that it was evaluated the navigational complexity and cognitive loads faced by the illiterate users were evaluated. A high time on task often correlated with interface confusion or lack of intuitiveness. The **Error Rate** shows both the efficiency and effectiveness by focusing on the frequency of the unintended and incorrect sections. The higher frequency of error rate for illiterate users showed the recognition of ICMPs, misunderstanding of voice commands misleading voice cues. Error management is critical for system learnability, according to ISO-9241, especially when the literacy rate or level of users is very limited. The third core pillar of ISO-9241 is **User Satisfaction,** which was assessed using a 5-point Likert Scale to capture users' subjective comfort, perceived confidence, and usability in using the application.

This response is especially momentous when the application targets people who rely more on instinctual and multimodal interaction (e.g., icon + voice), as is the case with illiterate agricultural users.

Table 3 shows the metrics that were selected deliberately to reflect usability goals ISO-9241, which showed that the Zameendar Application was not only serviceable but also acceptable and accessible to all the farmers who have no formal background education. These configurations proved the formats of inclusive digital architectural tools that meet the needs of marginalized user groups.

Collectively, all these metrics provided a composed and inclusive assessment of both user experience and system performance.

Results and Discussion

Overview of Usability Metrics

In this section, the multimodal interface usability (Zameendar Application) between two different user groups is shown, both the illiterate and semi-illiterate farmers across three core tasks. The findings are based on four different metrics, such as Time on task (seconds), Error Count, User Satisfaction (1-5 Likert Scale), and Task Success Rate (%).

Table 3: Identified Quantitative Metrics for Usability Evaluation

Metric	Definition	Purpose	Formula	Measurement Method	Ref.
Task Success Rate	Measures how many users' complete tasks correctly without assistance	Critical for evaluating if users can access vital information like crop prices or disease info independently	# Successful Tasks / # Attempted Tasks × 100	Observational study during field testing	[46]
Time on Task	The duration taken by users to finish a specific task	Reflects app navigation efficiency and user effort	Total Time / # of Users	Stopwatch or screen recording	[47]
Error Rate	Number of incorrect interactions or task missteps	Highlights interface usability flaws and cognitive load	# Errors / Total User Actions	Count incorrect taps, misinterpretations	[46]
User Satisfaction	Feedback scale (1–5) using Likert	Indicates user confidence and comfort, crucial for continued usage	Sum of Ratings / # of Users	Post-task Likert questionnaire	[47]

Task 1: Identify Crop Disease

A relative review of particular Agricultural Applications can be shown in Table 4, focusing on the functionalities, interface features, limitations, and targeted groups. Through this evaluation, the development of the Zameendar Application was contextualized, such as lack of voice or icon-based navigation and reliance on text-based interfaces and icon-based navigation, considered the most critical features that support the low literacy users in rural KP.

Table 4: Usability Metrics for Task 1: Identify Crop Disease

Metric	Illiterate Users	Semi-Literate Users
Task Success Rate %	62%	82%
Time on Task (sec)	148	112
Error Count	18	6
User Satisfaction (1-5)	3.1	4.0

A significant performance was shown by the semi-literate users over the illiterate users in this task. The semi-literate users (82%) showed a strong understanding of the image/icon recognition supported by the voice prompts. In contrast to semiliterate users, illiterate users struggled (62%) and took substantially longer. The error count was high (18 vs 6), which reflected the difficulty in associating the disease symptoms with icons. In spite of it, satisfaction among illiterate users was moderate (3.1), suggesting that feedback of audio aided task completion in some context.

Task 2: Check Market Prices of Crops

Table 5 demonstrates the usability evaluation for Task 2, a significant performance difference between the illiterate and semi-illiterate users was revealed through checking market prices of crops. 86% of semi-illiterate users completed tasks successfully with a higher level of satisfaction and few errors, while only 56% of illiterate users succeeded, focusing on the need for further simplification of the interface and more audio guidance to bridge this gap.

Table 5: Usability Metrics for Task 2: Check Market Prices of Crops

Metric	Illiterate Users	Semi-Literate Users
Task Success Rate %	56%	86%
Time on Task (sec)	172	90
Error Count	22	5
User Satisfaction (1-5)	2.9	4.3

A prominent gap between the two different groups of users, both the illiterate and semi-illiterate, is shown in Table 5, the time taken for task completion by semi-illiterate users was nearly twice faster that of the illiterate user group, and the errors were also fewer. The illiterate user group performance was (56%, 22 errors), suggesting that the multistep navigation remains a barrier despite the voice support. A (2.9) user satisfaction score shows that the interface complications and user hindrance.

Task 3: Smart Fertilizer Scheduler

Table 6 shows Task 3, which is of usability results, including the usage of the Smart Fertilizer Scheduler feature. The rate of success among the semi-illiterate users was high (78%) as compared to the illiterate users (48%), who required more time and made significantly more errors. These results show the importance of the intuitive design and multimodal feedback for low literacy users to interact effectively with advanced features.

Table 6: Usability Metrics for Task 3: Smart Fertilizer Scheduler

Metric	Illiterate Users	Semi-Literate Users
Task Success Rate %	48%	78%
Time on Task (sec)	190	102
Error Count	26	8
User Satisfaction (1-5)	2.7	4.1

The task consisted of complex inputs like soil data and crop types. Semiliterate users performed better than the illiterate users, but the success rate was 78% and there were several difficulties faced by the illiterate users in interpreting scheduling instructions, which led to the lowest task rate (48%) and high error count (26). The findings suggest the need for more interaction and contextual support.

Cross-Task Comparison

Table 7 highlights that there exists a clear usability gap between both the user groups, illiterate and semi-illiterate, across all the tasks. While semi-illiterate user groups achieved a faster completion time (q101.3 seconds) and higher success rate (82%) and a few errors (6.3), illiterate users still faced the challenges, specifically in tasks requiring multiple interactions or symbolic interpretation. Despite the incorporation of a multimodal interface, further enhancements were needed to accommodate farmers with no literacy background.

Table 7: Cross-Task Average Usability Comparison

Metric	Illiterate Users	Semi-Literate Users
Task Success Rate %	55.3%	82%
Time on Task (sec)	170	101.3
Error Count	22	6.3
User Satisfaction (1-5)	2.9	4.13

Figure 5 shows a grouped bar chart comparing the usability performance of both the literate and semiliterate users using four metrics across three evaluated tasks: Task Success Rate, Time on Task, Error Count, and User Satisfaction. It can be seen that semi-illiterate users showed faster task completion, higher success rates, greater satisfaction, and fewer errors across all tasks. These visual patterns align with the tabulated results discussed in Tables 4 – 7, reinforcing the observed usability gap between user groups. The graph illustrates how a multimodal interface, though beneficial for future use, still requires adoption and simplification to meet the requirements of illiterate users.

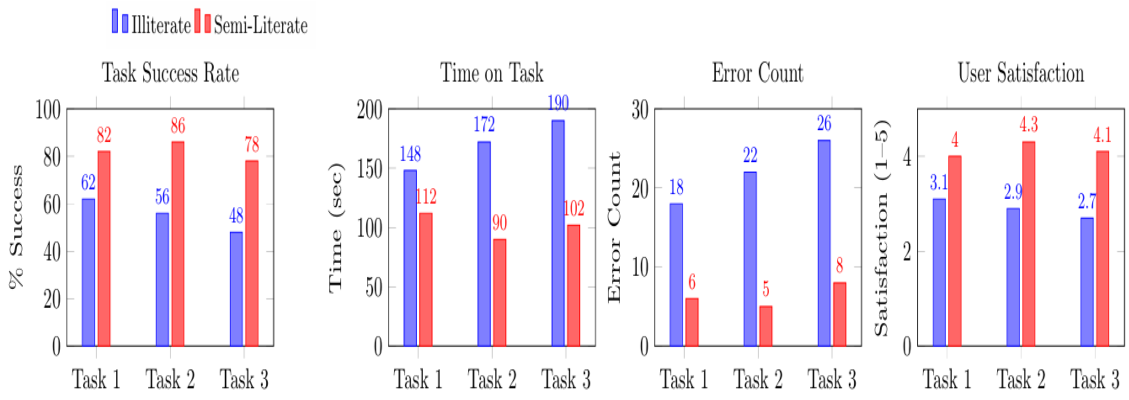

Figure 5: Usability metric comparison between illiterate and semi-illiterate users across tasks

Discussion

The study showed enhancement in the ICT usability and accessibility for low-level illiterate farmers by integrating culturally grounded multimodal interfaces in developing regions. By integrating the different modules like the simplified navigation, intuitive icons, and voice-over commands, faster completion times are achieved through this approach as compared to a conventional text-based system. The results from this study showed that the integration of cultural adoption and multimodality, improves user confidence, fosters comprehension, and reduces the cognitive load on users. During the recent research and studies where multimodality was just used as a technical aid, this study and approach work as a socio-technical bridge connecting cultural identity and digital inclusion. The results guided the design of agricultural ICT systems and supported the broader goal for equitable technology in rural areas.

Benefits of the Study

This study presents an innovative approach of a culturally grounded multimodal interface framework that is designed to augment the ICT user friendliness for low-literate farmers in the developing regions of the country. By integrating different modules such as simplified interaction flows, localized voice commands, and intuitive visual cues, the proposed approach advances the inclusive design beyond different barriers of language and literacy. The contribution is done through this research on the new evidence that is based on ISO 9241-11 usability principles, that by the integration of multimodal approach there is a significant increase in the task efficiency task accuracy and user satisfaction among low level literate populations, the novelty lies in the combination of cultural contextualization with multimodal usability engineering to create an adaptable scale solution in different rural areas of the country. The results and findings derived from this study provide insight for developer's policymakers, and digital inclusion advocates, supporting the equitable access to the IT sector and promoting the sustainable socio-economic empowerment through culturally sensitive ICT innovation.

Limitations

There are three main limitations of this study. The first limitation is that the evaluation was conducted in Khyber Pakhtunkhwa (KP) rural areas, which limits the generalizability of findings to other cultural contexts and geographic areas. The second limitation is about the participants' pool, which was quite smaller and did not represent the demographics, such as gender, which could influence the adoption patterns. Third, the study also assessed the term usability across a limited set of agricultural tasks, without examining the broader behavioral changes and long-term adoption.

Conclusion and Future Work

Agriculture is considered as the main backbone of Pakistan's economy, yet the digitalization of this field remains unsatisfactory due to persistent illiteracy and accessibility barriers. A multimodal interface tailored to low and semi-illiterate levels can address these gaps and challenges by focusing on the local content, accessibility, and cultural relevance. The proposed interface minimizes the textual interface dependence, unlike other conventional text-dependent agricultural ICT solutions; it integrates different voice prompts of the Urdu and Pashto languages that supports low offline connectivity environments and relevant iconography. A design process was concluded with the involvement of the farmers, representatives of different agricultural communities, and experts in agricultural fields. This co-creation strategy during the design phase not only improved the technical requirements but also enhanced the linguistic needs, practical realities, and cultural needs of its users. During the co-creation and studies phase, the direct involvement of farmers' interaction contributed a lot to defining the task priorities, validation of audio prompts, and meaningful development of iconography. During the design cycle, the embedding of user perspectives not only ensured the strong ecological validity but also addresses the historical exclusion of marginalized farming communities. The evaluation process included 100 farmers from five different regions of Khyber Pakhtunkhwa, which was followed by the ISO 9241-11 standard to assess different metrics like error rate, task success rate, and efficiency rate. The results showed a success rate of (82-86%) with faster task completion time (average 68.7 seconds faster) of semi-illiterate farmers, with a higher satisfaction as compared to illiterate farmers. But one of the important and most noticeable things was of that the 78% reduction in errors by the illiterate users, which highlighted the learnability of multimodal interaction even among non-readers. The conclusions derived from the results, highlighted the usability gains achievable through the multimodal system while also revealing challenges faced during the multitasking execution and abstract icon recognition.

This research study should be extended in the future to assess the broader impact of multimodal interface integration, to assess the learning curves of the farmers, and long-term adoption in agricultural productivity. Expanding the evaluation across the diverse user groups of farmers and various regions of the country will help to test the inclusivity and scalability. In addition, interaction with emerging technologies such as gesture-based interaction, AI-driven pest recognition, and personalized voice support can further enhance the usability. Sustained collaboration with technology providers, experts of the agricultural field, and policymakers are essential to scale and refine the multimodal solutions in real-world scenarios.

Declaration

Author Contributions

The authors confirm contribution to the paper as follows: Conceptualization, methodology, and writing original draft preparation, Imran Maqsood; data curation, formal analysis, and validation, Sadeeq Jan; investigation, resources, visualization, and writing review and editing, Mareena Karim; supervision, project administration, and funding acquisition, Umm E Rubab. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Data Availability

All relevant data and supporting material used in this study are in the manuscript.

Conflict of Interest

The authors state that none of the work described in this study could have been influenced by any known competing financial interests or personal relationships.

Ethics Approval

The 1964 Helsinki Declaration and its subsequent amendments, as well as the ethical guidelines set forth by the national and institutional research committees, were followed in the conduct of this study. The Institutional Review Board (IRB) of UET Peshawar granted ethical permission for this study.

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