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Analyzing and conceptualizing Pakistan's pioneering disaster risk communication Mobile application: a case study of PDMA Madadgar

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Pakistan's vulnerability to disasters necessitates effective disaster risk communication. This study presents a conceptual model of the PDMA Madadgar Application (hereinafter Madadgar) for subsequent code development and testing. Employing the design science research approach, data were collected through in-depth interviews from the purposefully selected sample participants and analyzed through the content analysis method. Our findings highlight the conceptualization of the app and the strengths it provides in real-time disaster alerts, early warnings and critical information dissemination. The data reveals that the model is highly interactive. A major stake has been provided to the local communities and field-based staff to receive and disseminate early warning messages, locate evacuation centers, report disasters without warning, and digitally conduct damage assessment. This study enhances disaster risk communication in Pakistan and informs the global development of effective mobile-based solutions. Madadgar is Pakistan's pioneer interactive Android-based disaster risk communication app for communities in Pakistan. Madadgar directly contributes to the local implementation of Pakistan's National Disaster Management Act 2010 and National Disaster Risk Reduction Policy-2013 as well as the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals. While the current Madadgar model is specifically designed for use within the Khyber Pakhtunkhwa province of Pakistan, reflecting the decentralization of disaster risk reduction to the provinces following the 18th constitutional amendment, its underlying principles and architecture offer a scalable blueprint for adaptation and replication in other provinces and similar contexts.

1 Introduction

In disaster risk reduction (DRR), timely information communication through multiple means has a greater impact on saving lives and protecting assets. Empirical research shows that the dissemination of information through various platforms in multiple formats such as interactive maps, numerical weather data, advisories, warning messages, etc. has greatly influenced public perception and behaviors and are major component of disaster preparedness (Abunyewah et al., 2020). Information and communication technologies (ICTs) have played a key role in disaster communications and subsequent emergency response by enabling effective communication, data collection, analysis and decision-making (Khan A. et al., 2020; Stute et al., 2020). Technologies collecting data from weather stations, sensors, satellites and subsequent communication in simple understandable language via media, mobile apps, social media, emails, sirens, short message service (SMS), etc., have provided timely and accurate early warnings to vulnerable communities in the path of a disaster (Khan I. et al., 2022; Khan M. et al., 2022; Esposito et al., 2022; Khan A. A. et al., 2021; Khan I. et al., 2021; Khan M. et al., 2021). These technologies have improved the speed and accuracy of early warning systems, support informed decision-making, enable effective communication with affected communities and facilitate data-driven approaches to disaster management (Sarker et al., 2020). The need for employing ICTs in DRR, climate change adaptation (CCA) and sustainable development has been widely recognized, especially in the policies adopted at the United Nations (UN) level (Fan et al., 2021). Sustainable Development Goals (SDGs) Goal 9 "Industry Innovation and Infrastructure," Goal 11 "Sustainable Cities and Communities," Goal 13 "Climate Action," and Goal 17 "Partnership for the Goals" support the domestication of information and communication technologies in achieving these goals (United Nations, 2015). In the context of DRR, the Sendai Framework for DRR supports the use of adaptive technologies to prepare for and mitigate disasters (UNDRR, 2015). Empirical research reveals that technology applications can significantly enhance transparency, public trust and coordination in DRR (Khan A. A. et al., 2021; Khan I. et al., 2021; Khan M. et al., 2021). Transparency through technological application is crucial for achieving sustainability in DRR and is relevant to the long-term viability of comprehensive disaster management systems (Khan I. et al., 2022; Khan M. et al., 2022).

Considering the global significance and welfare outcomes, various streams of research from social science, computer science and information science have been conducted to employ ICTs with artificial intelligence (AI) in DRR (Fan et al., 2021). Within these technologies, mobile phones have proved to be one of the most effective technologies in DRR ensuring timely access to information and its dissemination. More specifically, mobile phones have revolutionized early warning communication by providing timely and reliable information to individuals during emergencies. Their widespread use and accessibility make them an important tool for saving lives and mitigating the impact of disasters. It is a cost-effective and accessible means to enhance DRR efforts, empower individuals, and enable effective communication and coordination during emergencies. A review of some globally accessible disaster apps has been presented in Table 1. Out of these reviewed apps, Disaster Alert is the most widely adopted app due to its global focus and data-sharing feature for each country, followed by the International

Federation of Red Cross (IFRC) First Aid app due to its educational nature.

Pakistan, a low-income country with diverse geographical features, is highly vulnerable to disasters. The increasing risks of disasters and the resultant impacts, in terms of mortality, injuries, infrastructure damage and mass displacement, have greatly affected developmental projects, the investment environment and the overall economy of Pakistan (Manzoor et al., 2022). Pakistan has suffered from multiple earthquakes (Khan et al., 2024; Ali A. et al., 2022; Ali N. et al., 2022), floods (Ali et al., 2024; Shah I. et al., 2020; Shah S. M. H. et al., 2020), landslides (Gardezi et al., 2021; Su et al., 2022), droughts (Khan I. et al., 2020), cyclones (Hussain et al., 2023a), glacial lake outburst floods (Khan I. et al., 2022; Khan M. et al., 2022; Qureshi et al., 2022), forest fires (Ullah et al., 2018), dust storms (Yarmohamadi et al., 2023), avalanches (Saif et al., 2022; Ali et al., 2023) and terrorism (Javeid et al., 2023) etc. Some of the recent disaster data reveals that the 2005 earthquake killed more than 73,000 people and rendered over 2.8 million people homeless (Pande, 2005). The flood of 2010 directly affected 20 million people (Atta-ur-Rahman and Khan, 2013) and the flood of 2022 affected 33 million people (Nanditha et al., 2023). The vulnerability of Pakistan to these disasters is attributed to multiple factors, including climate change and variability (Hussain et al., 2023a,b; Otto et al., 2023; Fahad and Wang, 2020), overutilization of natural resources (Khan A. A. et al., 2021; Khan I. et al., 2021; Khan M. et al., 2021), diverse topographic and temporal dimensions (Hussain et al., 2023a,b), weak implementation of building codes and poor quality of construction (Cheema, 2023; Shaikh et al., 2023), poor governance (Shehzad, 2023; Jan and Muhammad, 2020), rapid and unplanned urbanization (Tayyab et al., 2021; Zia et al., 2023), exponential population growth (Ullah et al., 2019), social inequality and poverty (Memon, 2023), lack of risk assessment (Tayyab et al., 2024; Shah et al., 2023a,b), weak inter-organizational collaboration (Yousefian et al., 2021; Jan and Muhammad, 2020), weak early warning system and its dissemination (Khayyam and Noureen, 2020; Rana et al., 2021; Javed Khan et al., 2019), lack of public awareness (Khan A. A. et al., 2021; Khan I. et al., 2021; Khan M. et al., 2021), weak risk communication (Ali A. et al., 2022; Ali N. et al., 2022; Shah et al., 2023a,b), digital divide, and lack of mainstreaming of ICTs within the domain of DRR (Sajida Tufail and Ainuddin, 2016; Anis and Ashfaq, 2023). Within these causes of vulnerability, the present study attempts to address the problems in disseminating early warning systems, faulty risk communication and weak collaboration between the disaster management authorities and communities in the northwestern province of Pakistan, i.e., Khyber Pakhtunkhwa. Analysis of recent disasters, specifically the 2022 Murree snowstorm, 2022 floods and 2025 Swat floods reveals persistent deficiencies in several key areas including timely risk communication, accessibility of early warning systems, levels of public awareness, effectiveness of information dissemination and the presence of dedicated risk communication platforms for community engagement (PDMA, 2025; Shah et al., 2023a,b; Meo et al., 2022; Asad, 2022). These challenges left people at the mercy of nature causing death tolls and infrastructure damage.

Besides, the Pakistan National Disaster Management Act 2010 (articles 16-2 J, 20-2 K), Khyber Pakhtunkhwa (KP) Emergency Rescue Service (Amendment) Act, 2014 (articles 4c), National

TABLE 1 Comparative analysis of disasters-related mobile applications at the global level.

Name of app	Purpose	Features and functionality	Customization and personalization	Accessibility and multilingual support	Cost and sustainability	Rating and downloads on google play	Reference
Disaster alert	To provide critical hazard-related real-time information to communities across the globe to stay informed and safe from disasters.	Updates on eighteen hazards, Early warning, visualized modeled hazard data, and estimated impact reports of the disasters.	The app can be customized according to the geographic area and hazards occurring in the same area.	Accessible to everyone around the globe. The user can use the multilingual login and registration. Available on both Google Play store and App Store.	It is a free app, maintained by the Pacific Disaster Center.	4.1 500 K plus	Pacific Disaster Centre (2011)
Carrington: disaster prediction	To provide access to space weather information and earthquake alerts.	Space weather alerts, earthquake alerts, interactive weather, earthquake maps, and forecasting research tools for earthquakes.	The customization feature is only available to paid users.	Accessible in all regions but can only be used in English. Available on both Google Play store and App Store.	Disaster Prediction App is free but the users have to pay for in-app purchases per item.	50 K 4.5	RESE' LLC (2015)
My earthquake alerts	To provide access to earthquake information locally and globally.	Realtime Live earthquake information, earthquake alerts, earthquake data back to 1970, location, depth of earthquake with distance to the user.	The user can customize the app alert based on the geographic area and magnitude of the earthquake.	Users from the US and worldwide can access earthquake feeds. The app can be used only in English. Available on both Google Play store and App Store.	JrustonApps maintains the app and is available for free to all users.	4.5 5 million	JRustonApps B.V (2015)
First aid-IFRC	To provide information on first aid and safety tips for crises.	Preparedness for emergencies, creation of a personal first aid plan, access to preloaded information without a WIFI and cellular data, Interactive quizzes about life safety knowledge, Linkages to your local Red Cross or Red Crescent, & Connections to emergency numbers.	It is an educational app and there is no push notification etc. The language use can be customized.	Freely accessible and the app is multilingual regardless of the location of the users. Available on both Google Play store and App Store.	Maintained by IFRC and available for free.	3.3 1 million Plus	International Federation of Red Cross and Red Crescent Societies (2018)
Accuweather	To Provide weather information and weather forecasts to 2.7 million locations globally.	Live weather forecasts, local weather, winter cast, daily forecast, advance weather radar view of storms, snow, rain, etc. and, real feel shade temperature.	The app can be customized and personalized as per user requirements and location.	Freely available and can only be used in English. Available on both Google Play store and App Store.	AccuWeather is maintaining the app and it is available for free.	3.9 100 million plus	AccuWeather (2012)

(Continued)

TABLE 1 (Continued)

Name of app	Purpose	Features and functionality	Customization and personalization	Accessibility and multilingual support	Cost and sustainability	Rating and downloads on google play	Reference
Natural disaster monitor	To provide information on the latest disasters.	Information on natural disasters, alert level on color codes, & geographic grids on the maps.	The app can be used and customized to the dark mode settings.	The app is accessible to everyone and can only be used in English.	Available for free and maintained by dominoc925.	3.1 50 K	Dominac925 (2012)
Clime: weather radar live	To provide accurate real-time weather data to stay safe from the impact of various hydro-met hazards.	24/7 Weather forecast, severe weather alerts, radar images, Interactive radar maps of rain, snow, mixed precipitation, AND weather alert with push notification for bookmarked locations.	The app allows users to customize settings, such as temperature units, map types, and notifications.	The app is accessible to everyone and can be used in English, Portuguese, Simplified Chinese, Danish, French, Spanish, Swedish, Italian, Japanese, Korean, Norwegian Bokmål, Russian, Thai, Traditional Chinese, Turkish, Vietnamese, German, and Indonesian languages.	The app is maintained by Mobile Heroes. The majority of the features are available for free but the premium service provides access to more specific information.	4.5 rating with 10 million plus downloads	Mobile Heroes (2016)

Disaster Risk Reduction Policy 2013 and National Disaster Management Plan 2024 have clearly emphasized the use of harnessing information and communication technologies to strengthen early warning capacity and improve resilience through preparedness (Government of Pakistan, 2024a,b; Government of Khyber Pakhtunkhwa, 2014; Government of Pakistan, 2013; NDMA, 2012; I-SAP, 2010). In addition, the Pakistan Social and Living Standard Survey 2019–2020 indicates that 93.15% of the population have access to mobile phones and 11.75% own a laptop or computer (Government of Pakistan, 2021). The latest data further reveal that 193 million Pakistanis are active subscribers of various mobile network operators and the country was ranked 9th on the list of countries with mobile connectivity (Government of Pakistan, 2024a). At the start of 2024, Pakistan had 111 million internet users and 71.70 million social media users (Social and Meltwater, 2023). These statistics portray that due to the limited financial capacity to invest in telemetry stations, weather radars and automatic weather stations, a mobile-based solution can be the best source to scale up the existing early warning information and communication network.

Although Pakistan's DRR system is still in the infancy stage and a paradigm shift from complete reactive disaster management to proactive risk reduction is yet to take place, efforts have been made to develop, harness, and domesticate mobile technologies in the disaster response and preparedness sector. As per Table 2 various app exist and operation for risk communication in Pakistan. These Pakistani apps are mostly static and there is no provision for the citizens to report back about their disaster-related problems. The only Pakistani app, i.e., Citizen Portal App empowers the citizens to report and file complaints about any government department from federal to district levels. In terms of disasters, the app enables local people to file complaints about delayed compensation for relief and cash packages. There is no mechanism to share early warning or any other disaster-related information (Prime Minister's Performance Delivery Unit, 2018).

Because of the given background, we have attempted to understand the current status of the application of mobile-based technologies in disaster risk communication in Pakistan. Similar to the existing apps, we have conducted a landscape analysis of the available mobile apps and identified the best use cases. Based on the landscape analysis and field-based data collection, we have conceptualized Madadgar in the context of the study area. Madadgar covers all disasters and the model is considered a super app for risk communication in KP. This innovative use of a mobile-based app for disaster communication aims to enhance access to real-time information and improve community resilience. The Madadgar is a user-friendly platform for timely risk communication, early warning systems and critical information dissemination. Through the use of this innovative technology, vulnerable communities can be better equipped to prepare for and respond to disasters, ultimately reducing the risk of harm and promoting resilience amid the climate change crisis (Jan et al., 2025). Madadgar only focuses on one province due to the devolution of the disaster, environment and climate change to the provincial level after the 18th Constitutional Amendment of 2010 (Shah I. et al., 2020; Shah S. M. H. et al., 2020). Each province has been empowered to develop and implement projects aimed at reducing disaster risk within its boundaries.

TABLE 2 Comparative analysis of disaster-related mobile applications in Pakistan.

Name of app	Purpose	Features and functionality	Customization and personalization	Data and information	Accessibility and multilingual support	Cost and sustainability	Rating and downloads on google play	Reference
Flood reporting app	To connect flood-affected communities with the disaster management authorities to report their problems following floods.	The app enabled the flood 2022 affected people to report their problems to the authorities. This is the single-function app developed and deployed during flood 2022.	The app is very restricted in nature, with no customization and personalization features available.	The app does not provide information to the user; hence it is not connected to any early warning or information database.	It is accessible to flood victims on the Google Play Store in Pakistan but administratively, the app was developed only for the victims in one province, i.e., Khyber Pakhtunkhwa. Non-Multilingual.	Maintained by the Khyber Pakhtunkhwa Information Technology Board. It is a free app.	4.2 1 K	Khyber Pakhtunkhwa Information Technology Board (2022)
Emergency alert PDMA KP	To communicate to the public about disasters and provide guidelines on how to prepare for disasters.	The app communicates early warning information to the communities about disasters. A feature of COVID-19 reporting was also added during the first wave of the covid. But these days the app does not provide real-time updated information and is outdated.	The app allows users to switch on and switch off notifications.	The app only focuses on information sharing and it is not connected to any scientific organization database directly.	Accessible to the general public in Pakistan but administratively it works only for the people of Khyber Pakhtunkhwa province. Non-Multilingual.	Maintained by PDMA and available for free in KP, Pakistan.	3.9 1 K Plus	Provincial Disaster Management Authority (2018)
PMD weather	To provide the latest city-based weather information and forecast.	Official weather app of Pakistan Meteorological Department (PMD). City Based live weather information and forecast for the next three days., Earthquake and Flood Updates.	Use can customize the Location-specific weather updates.	The app provides data on weather updates, flood forecasts, warnings/alerts drought monitoring, etc. However, the app can be used for one-way communication.	Accessible to all citizens of Pakistan and can be used in Urdu and English.	It is a free app maintained by PMD.	3.7 10 K	Pakistan Meteorological Department (2021)
Locust survey-PDMA Punjab	To enable authorities to do surveillance of locusts in Pakistan.	The app enables local communities and authorities to report about the location-based prevalence of locusts. The app also enables local communities to ask for help to counter locust infestation.	Customization features are not available.	The app is only used for surveys and is not connected to any scientific database.	Accessible to all citizens of Pakistan and can be used in Urdu and English.	Maintained by PDMA Punjab and can be used by any agency in Pakistan.	4.2 10 k	Provincial Disaster Management Authority (2021)

(Continued)

TABLE 2 (Continued)

Name of app	Purpose	Features and functionality	Customization and personalization	Data and information	Accessibility and multilingual support	Cost and sustainability	Rating and downloads on google play	Reference
Pakistan citizen portal	To seamlessly connect citizen with all government agencies and departments and address their concerns and problems as per the vision of the government.	In terms of disasters, the app enables local people to file complaints about delayed compensation for relief and cash packages. There is no mechanism to share early warning or any other disaster-related information.	Customization features are not available for notifications, changing personal data, etc.	The app is directly connected to the government database and verifies each user automatically. Besides, the app creates its database, and data is fully confidential and can only be accessed at a few levels of government.	Accessible to every citizen of Pakistan and can be used in Urdu and English.	The app is maintained by the Prime Minister's Performance Delivery Unit and is free of cost.	3.8 5 million	Prime Minister's Performance Delivery Unit (2018)
Pakistan weather forecast 2023	To provide city-wise weather forecasts and the latest real-time weather updates.	Hourly and daily weather information and weather forecasts. Providing data regarding the approaching heatwave, thunderstorms, wind storms, and snow storms.	Customization features are available for location-specific data.	The app is connected to private sector weather gadgets and international weather information-providing agencies.	Accessible to every citizen of Pakistan and can be used in Urdu and English.	The app is maintained by the private sector weather network called Pakistan Weather Network and is free of cost.	4.2 1 million	Unisoft Apps (2018)
Pak NDMA disaster alert	To disseminate alerts to communities along with the hazard projection and scenario.	The app sends alerts about approaching meteorological and hydrological hazards with hazard projections, safety guidelines, and public service messages.	The app provides user choice in language selection. A new feature for audio listening of the alerts has been added.	The app directly releases information from the NEOC-NDMA and uses government data.	Accessible to everyone across Pakistan and can be used in Urdu and English.	It is a free app and maintained by NDMA Pakistan.	4.3 10 K + download	NDMA (2024)

1.1 Theoretical framework of the study

This research was supported by a multidimensional theoretical framework, drawing on Socio-Technical Systems (STS) Theory, Diffusion of Innovations (DOI) Theory, Actor-Network Theory (ANT) and the principles of Participatory Design (PD). These frameworks collectively enabled a dynamic analysis of the Madadgar's conceptual model, specifically examining the intricate relationship among mobile technology, DRR objectives and key stakeholder engagement within the KP context. STS theory emphasizes the inherent interdependencies between social and technical elements within a system. It posits that optimizing one without considering the other leads to poor outcomes or even system failure (Thomas, 2024; Ahmad et al., 2022; Dell et al., 2021). STS theory in this study's context suggests that Madadgar's success requires optimizing its technical features and integrating it with existing social and organizational structures within the KP disaster management system. This includes aligning with PDMA's procedures, communication protocols among DRR agencies, the target population's digital literacy and public trust. DOI explains how new ideas, practices or technologies spread through a social system over time, identifying factors influencing adoption such as relative advantage, compatibility, complexity, trialability and observability (Mbatha, 2024; Shaw et al., 2022; Frei-Landau et al., 2022; Call and Herber, 2022). The DOI framework allowed for an examination of the Madadgar's perceived attributes, such as its relative advantage over traditional communication methods, its compatibility with existing cultural norms and communication habits, its complexity in terms of ease of use, its trialability (the ability for users to experiment with it), and the observability of its results. ANT offers a perspective by treating both human and non-human entities as "actants" with agency, forming interconnected networks (Ryan et al., 2024). For the PDMA Madadgar app, ANT allowed for a detailed mapping of the heterogeneous network involved in its conceptualization and deployment. Human actants include PDMA officials, app developers, community members, local government representatives, first responders and telecom providers. Non-human actants encompass the Madadgar app itself, smartphones, mobile networks, data, policies and even natural hazards. ANT helped in analyzing how these diverse actants interact, influence each other, and "translate" their interests to shape the app's design, functionality and impact. This includes examining how the app's technical specifications enroll users, how policy decisions facilitate network connectivity, and how user feedback (a form of human actants agency) might lead to app modifications (Lin and Yang, 2021; Singgalen, 2021). While not a singular theory, PD is an approach rooted in theoretical tenets of empowerment and co-creation, emphasizing the active involvement of all stakeholders throughout the design and development process. For the PDMA Madadgar app, this framework posits that the app's relevance, usability and sustainability are significantly enhanced when the end-users and key implementers (stakeholders such as local communities, disaster management authorities and emergency responders) are directly engaged in its conceptualization and refinement (Kistenfeger et al., 2024; Messiha et al., 2023; Steinke et al., 2022; Trettin et al., 2021; Mauka et al., 2021). This approach ensures that the app addresses real-world needs and challenges faced by communities in Pakistan, incorporates local knowledge and communication preferences, and is culturally appropriate. By integrating these theoretical frameworks, this research aims to provide a comprehensive analysis of the PDMA Madadgar app's conceptual model, offering insights into its potential as a ground-breaking tool for disaster risk communication in Pakistan while acknowledging the complex socio-technical dynamics and the indispensable role of stakeholder engagement in its success.

1.2 Research questions

- The present research aims to explore the two basic research questions, i.e.,
- What is the state of the art in mobile apps focused on risk communication and early warning in KP, Pakistan?
- What type of app is required to strengthen vertical and horizontal coordination between communities and disaster management authorities in KP?

2 Methodology

The main objectives of the study are to explore the uses of mobile-based technologies in disaster risk communication, to conduct a landscape analysis of existing DRR apps, conceptualize the idea of a collaborative Madadgar app and to develop an architecture of the Madadgar App. To achieve these objectives and to address the research questions, we primarily relied on using the Design Science Research (DSR) methodology. DSR is a research methodology that can employ both qualitative and quantitative methods, depending on the research goals and context. This approach is typically applied to a range of artifact categories, including algorithms, human-computer interfaces, design methodologies (including process models) and languages. DSR involves a combination of approaches to design, develop and evaluate innovative solutions. DSR effectively redefines reality, addressing human needs and challenges (Venable et al., 2017). In DSR the object of study is the conceptual development, design of an artifact, and evaluation of the artifact (Carstensen and Bernhard, 2019). It prioritizes the design and optimization of artifacts to improve their functional capabilities. There are five phases of the DSR methodology, i.e., construct a conceptual framework; develop a system architecture; analyze and design the system; build the (prototype) system; and observe and evaluate the system (Venable et al., 2017). As shown in Figure 1, we have used the first three phases, i.e., constructing a conceptual framework, developing system architecture and analyzing and designing the system with a qualitative approach in this study. The remaining steps were used in another study on Madadgar (Jan et al., 2025). DSR uniquely distinguishes itself from purely empirical, theoretical or standard software development approaches by proactively designing and constructing innovative, tangible artifacts to solve real-world problems. Unlike empirical studies that describe, theoretical research that models or typical software development that builds without explicit research rigor, DSR integrates systematic research methods, such as extensive literature reviews, stakeholder engagement and rigorous evaluation to create practically useful and theoretically grounded solutions (Jat et al., 2024; Koepp et al., 2024; Lidiawaty et al., 2024; Koepp et al., 2024; Huseynli et al., 2022). This problem-solving focus, particularly in addressing complex socio-technical challenges, like risk communication gaps aligns perfectly with DSR's aim to transform and enhance reality by developing purposeful artifacts. Furthermore, DSR's iterative nature,

demonstrated by the phases covered in the present study and previous study on Madadgar, i.e., Jan et al. (2025) allowed for continuous learning and refinement, crucial for developing adaptable and sustainable DRR tools that evolve with user needs and emerging threats. Following is the description of step wise details:

2.1 Need identification

In the first phase, the discussion on a DRR app for the communities was held at two national-level training workshops on "Flood Management through Flood Early Warning and Forecasting System" under one of our UNESCO-JICA joint-funded projects. Both workshops were attended by 100 officials from various civil protection institutions dealing with DRR at the national and provincial levels. In both workshops, the researchers used "Group Model Building Exercises" to discuss the concept of the early warning system, the existing mechanism of communication of warning messages and how mobile technologies can be used to improve communication and dissemination (Jan, 2018). At this stage, we explored the importance of a dedicated mobile app for the communities. Soon after the workshops, we organized an expo entitled "Technology-Mediated Expo on Disaster Risk Reduction, Climate Change Adaptation and Sustainable Development" at Peshawar (Jan et al., 2019). The researchers invited various tech vendors and agencies to the one-day expo, emphasizing the concept of DRR, Climate Change and SDGs. A total of 30 organizations and tech vendors exhibited their work at the expo. During the expo, it was noted that other types of technologies are being used to reduce disaster risk but there is a serious gap in Pakistan in terms of using mobile technologies for risk communication with the affected people. With the help of both events, we established the need for an interactive mobile app. These events also enable us to identify some of the existing apps that are in use in Pakistan for disaster risk communication (Tables 1 and 2).

2.2 Landscape analysis of identification and review of disaster risk communication app

In the second phase, we conducted a detailed review of the identified mobile apps on the Google Play Store at national and international levels. Apps identified during the workshop and expo were sampled as the majority of the research participants emphasized that they are using these apps to receive disaster-related information and guidance. Apart from these apps, many apps exist at the international level but they are not accessible in Pakistan and are context-specific to their countries. For the review, we established criteria to understand the purpose of an app; features and functionality; customization and personalization; data and information; accessibility and multilingual support; and cost and sustainability. During our review, we explored that the majority of Pakistani apps were static and the app developers or agencies responsible for DRR were able to communicate information to the public but there was no or very little room for the community to share information with authorities.

2.3 Stakeholder consultation (sampling method and sample size)

Both these steps enabled us to draw a list of potential organizations in the KP provincial capital for in-depth interviews to capture the requirements and determine the conceptualization of the PDMA Madadgar App. We prepared a list of potential DRR stakeholders from our previous study on multiagency collaboration for DRR in Pakistan (Jan and Ahmed, 2018), our consortium workshop reports (Mobilise Project Team-Pakistan, 2018), and the expo list (Jan et al., 2019). In total, we selected 10 organizations and 12 research participants through the purposive sampling method. Details of the organizations and research participants are mentioned in Table 3. The selection of participants was not arbitrary but based on specific criteria (1) "minimum of 5 years of experience in DRR," (2) "terminal relevant academic qualifications" and (3) "an understanding of the use of ICTs in DRR." This indicates a deliberate strategy to identify "information-rich cases" individuals who possess deep technical ICTs and DRR knowledge and practical experience directly relevant to the research questions concerning the conceptualization of Madadgar app. Using purposive sampling over other methods like random sampling was essential because the highly specialized nature of the domain necessitated participants with deep, specific knowledge and practical experience to generate relevant and valuable data, optimizing research efficiency and effectiveness. The approach ultimately ensures a robust app design that addresses complex inter-organizational collaboration in DRR.

2.4 Investigation of the research problem: primary data collection

Based on the prompts and attributes identified during the literature review, we prepared an in-depth interview (IDI) checklist for primary data collection. The tool was designed to capture information about the app features as well as the interactive aspect to engage communities across the province. The tool consisted of various questions, including questions on the current use of ICTs, use of any mobile app for communication with communities, interest in the development of the dedicated mobile app, the purpose of such an app, basic features, modules/tabs to embed into the app, information the app should capture or disseminate, nature of the app (static or interactive), app language, color scheme, linking the app to external services like website and social media, architecture and any available domain to host both the frontend and backend of the app. Interviews were conducted in a face-to-face environment. For easy communication, the native language of Pashto and where required national language Urdu was used to conduct the interview. Word-to-word transcription of each interview was conducted soon after the conduction of the interview. Informed consent from each participant was taken before the interview.

2.5 Data analysis strategy

Employing the content analysis strategy, qualitative data analysis followed a rigorous process beginning with the meticulous
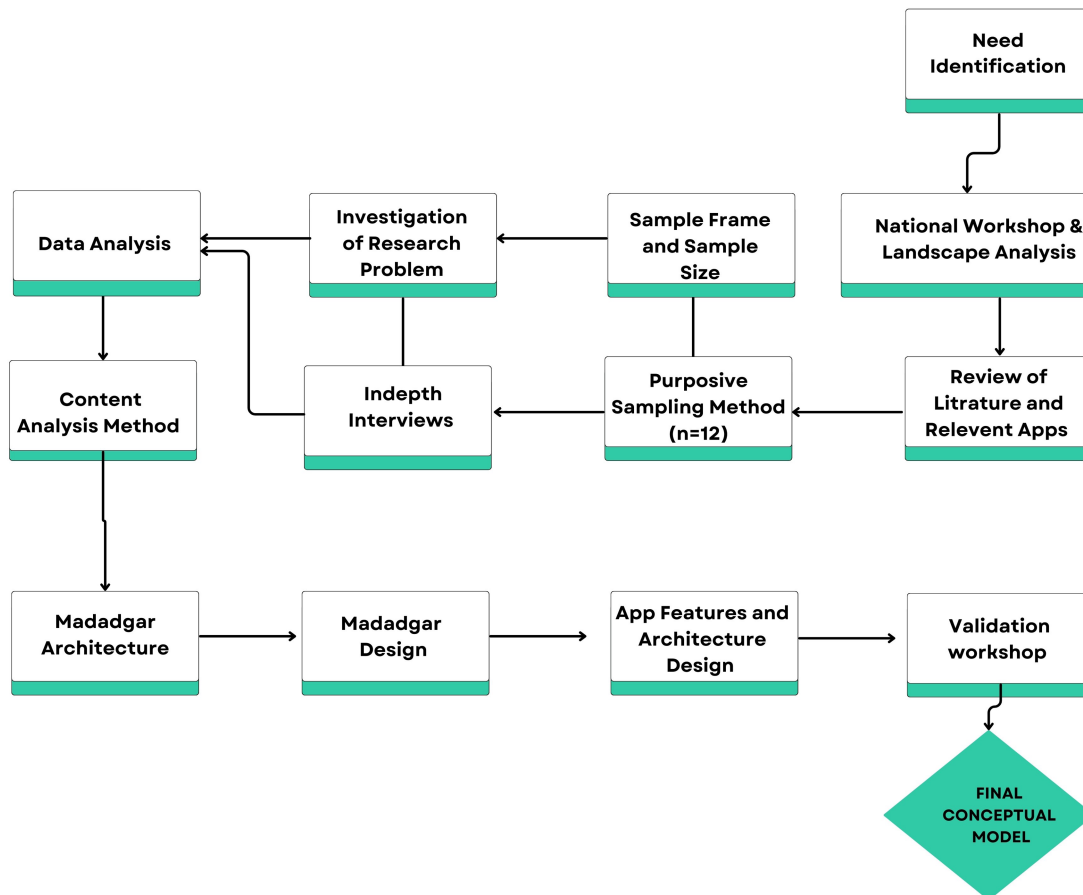
FIGURE 1
Design Science Research (DSR) steps followed for architecture development and conceptualization of the PDMA Madadgar App.

transcription of each interview to convert spoken words into a systematic textual format. Subsequently, an inductive coding approach was employed, allowing codes and categories to emerge directly from the interview data through a process of text reduction, ensuring themes were grounded in participant perspectives. The content analysis employed a mixed-methods approach, integrating both deductive and inductive coding to systematically analyze interview data and inform the PDMA Madadgar App's conceptual design. Deductive coding began with pre-defined categories and themes derived from our research questions, an initial landscape analysis of existing DRR apps (as detailed in Tables 1, 2) and the comprehensive in-depth interview checklist. This checklist was specifically developed based on prompts and attributes identified in the methodology's second step, covering aspects like the app's purpose, essential features, modules, information capture vs. dissemination, interactivity, language, design elements, external service linking, login services, architecture and hosting domains. These pre-established areas provided a structured framework for organizing the qualitative data. Conversely, inductive coding allowed specific codes and patterns to

emerge directly from the primary interview data. Through a process of text reduction, we applied codes to specific words or patterns, identifying trends that ensured the app's conceptualization was deeply grounded in the real-world experiences and needs of DRR experts and stakeholders. For instance, while "General Features of the App" was a deductive category, the concept of a "super app" integrating multiple components emerged inductively from participant feedback. Similarly, detailed functionalities within each tab (e.g., specific early warning types or disaster reporting mechanisms) were inductively derived from the interview content. This interplay between deductive and inductive approaches ensured our analysis was both systematic and flexible, effectively capturing emergent insights crucial for a comprehensive and responsive app design. This iterative coding scheme was continuously re-examined, including explicit checks for errors, typos or misspellings, to ensure consistent code application by the researchers. The codes were then organized into broader categories and patterns, forming the empirical basis for the app's conceptualization, technically known as Software Requirement Specification (SRS) (317 to 360).

TABLE 3 IDI's Respondents' Profiles.

Respondent #	Experience in years	Agency/ organization
R1	12⁺ Years	Provincial Emergency Operation Centre, PDMA
R2	9⁺ Year	Disaster Risk Reduction Section, PDMA
R3	13⁺ Years	Relief Section, PDMA
R4	24⁺ Years	Relief Rehabilitation and Resettlement Department
R5	6⁺ Years	Emergency Rescue Services 1,122
R6	5⁺ Years	Civil Defence Department
R7	16⁺ Years	Centre for Disaster Preparedness and Management
R8	23⁺ Years	Khyber Pakhtunkhwa Information Technology Board
R9	26⁺ Years	National Humanitarian Network
R10	22⁺ Years	Disaster Resilience Forum
R11	19⁺ Years	Pakistan Metrological Department
R 12	5⁺ Years	Pakistan Red Crescent Society

3 Results

The final conceptual model of the PDMA Madadgar App is presented here. During our investigation, we found that a few apps existed for communication with the communities but these were static. The concept of the PDMA Madadgar App empowers local communities to report incidents of disasters to PDMA-PEOC and conduct post-disaster Rapid and Damage Need Assessments. At present, the early warning system is based on the linear paradigm, where the authorities can only send information to the public but there is no mechanism to report an incident of disaster to the authorities. The PDMA Madadgar App provides access to real-time early warning messages, data related to damages from disasters, daily weather and daily situation reports, etc. The app enables the local communities to access location-based dedicated evacuation centers during times of emergencies. Authorities can send updates and news with push notification services to the public about any approaching threatening event. The risk assessment studies currently lying on shelves have been made accessible to the public. Besides, the public can file complaints to authorities about their disaster-related problems. Madadgar also serves as a dedicated platform to create awareness amongst the general public about disaster risk reduction. Lastly, Madadgar serves as a social media platform for the PDMA. All social media pages of the PDMA and different websites can be accessed from the app. The app provides access to all emergency helplines and office numbers of the district disaster management authority. The final concept through the content analysis strategy has been presented in Tables 4, 5, whereas the PDMA Madadgar App architecture can be seen in Figure 2 and a visual overview of the Madadgar App has been presented in Figure 3.

2.6 Reliability check, triangulation and validation

The study rigor was further maintained through expert validation via a "Validation Workshop." In this critical step, we presented the app's architecture and proposed concept to research participants for their validation and refinement. This member checking ensured the conceptual design accurately reflected the experts' insights, thereby enhancing the trustworthiness of our conclusions and serving as a crucial form of code validation. The validated model was recommended for software-based development of Madadgar. Madadgar as an app is available on the Google Play Store for the use of both authorities and communities (Jan et al., 2025) and the algorithms/codes can be openly accessed on GitHub (Syedpg, 2025).

Complementing this, the study used both data and methodological triangulation. Data triangulation was achieved by comparing insights from a comprehensive literature review, an analysis of existing DRR apps and in-depth interviews, providing a richer understanding of app requirements. Methodological triangulation combined landscape analysis (document review) with in-depth interviews (primary data collection) and the validation workshop, offering a multi-faceted exploration of the problem space and potential solutions.

3.1 Material design, user Interface, language, and information sharing

In this section, the User Interface (UI), User Experience (UX), color scheme, language support, general features of the app and nature of the app has been discussed. The UI and UX were the technical aspects and only people from the IT section understood the questions related to it. The UI refers to the tabs, icons, screens, color palettes, fonts, dropdown menu, text fields, layout, and other visual elements of the Madadgar. UX is about the interaction one might have with the product, i.e., Madadgar app. It was recommended that the user interface must be adaptable as per the industry's latest requirements. Data in Table 4 indicates that the majority of the research participants recommended using the color scheme of the PDMA logo ($n = 9/12$). Additional language support, i.e., Urdu along with English was highly recommended ($n = 9/12$). Research participants emphasized that the app must be interactive ($n = 10/12$). The interactive app allows the community to report back about a problem, the occurrence of a disaster, evacuation support, relief items needed, assessment of damages at both individual and community levels and engaging volunteers in times of need. Regarding the general features, the participants recommended that people are getting annoyed with too many apps for each aspect of DRR. Therefore, it was recommended to develop an app by integrating multiple components to make it easy for the community to use a single app with multiple functions ($n = 10/12$).

3.2 Recommended features, functionalities, and major tabs in the PDMA Madadgar app

Based on the data presented in Table 5, the results highlight several key features and functionalities recommendations for the Madadgar app. The feature with the highest number of participants' support was the inclusion of an Early Warning tab ($n = 11/12$). Respondents emphasized the need for real-time data integration from the Pakistan Meteorological Department (PMD) and PDMA, including graphical and textual information on weather advisories, flood bulletins, GLOF alerts, earthquake updates and drought alerts. This underscores the critical importance of timely and accurate dissemination of early warning information for effective disaster preparedness and response.

Following closely, the Volunteer Engagement feature was supported by a significant majority of the research participants ($n = 10/12$). The research participants highlighted the availability of a large volunteer pool and the necessity of a platform to register and mobilize them during emergencies through geolocation mapping and notifications. Several features received support from 9/12 research participants, including Report a Disaster and Damage Need Assessment. The emphasis on the "Report a Disaster" feature centered around empowering local communities and PDMA field teams to report disaster occurrences to the Provincial Emergency Operation Centre (PEOC) for swift response and evacuation. For "Damage Need Assessment," respondents recommended digitizing the process to ensure transparency and accountability in relief provision and cash

compensation, with the ability for both field teams and the general public to conduct and report damages.

Other notable features and their support levels include User Registration and Language Selection ($n = 8/12$), Community Outreach ($n = 8/12$) and Rapid Need Assessment ($n = 8/12$). Seven out of 12 research participants supported the PDMA News, Daily Situation Report and Register Complaint sections. Six out of 12 research participants supported the Locate Nearby Evacuation Centre and sharing risk assessment results. Table 5 presents the data on the features of each function of Madadgar as well as the associated functionalities.

3.3 PDMA Madadgar App architecture

Figure 2 shows the architecture of the PDMA Madadgar App. During the validation workshop, the architecture was thoroughly discussed. Participants emphasized the interactive nature of the app. As per architecture, the app sends the data to the main server hosted on the database of the KP provincial government to ensure data privacy. A web dashboard of the backend is displayed at the PDMA-PEOC for quick response. Entries to the app are made by volunteers, district-level field teams, and the general public. Through APIs, data from other platforms have been integrated into the app. Public awareness messages, sharing any news, advisories, and volunteer engagement are administered from the web dashboard at the PEOC-PDMA. The app ensures two-way communication between users and PDMA. A push notification service has been enabled on the News and

TABLE 4 Material design, user interface, language, and information sharing.

Feature	Recommendation	Respondents	Respondents number	Comments
User interface	The user interface and experience (UI/UX) may be designed to be user-friendly and aligned with industry standards, ensuring ease of use.	R1, R3, R8, R11	4	"An adaptable user interface design must be used for this app"
Color scheme	The user interface must be developed on the color scheme of the PDMA logo	R1-R3, R6, R8, R9, R11, R12	8	"People are familiar with the PDMA social media pages and it would be better to use the colour scheme of the Disaster Management Authorities logo"
Languages Support	The app must be available in at least two languages, i.e., Urdu and English. If possible, include a Pashto version also.	R1-R5, R7-R8, R11-12	9	"Multilingual support is highly recommended, particularly Urdu version is most important for community level use"
General features of the app	The app should not be very restricted to sharing one type of information. It must have multiple types of tabs with sub-tabs.	R1-R6, R8, R10, R11-R12	10	"Multiple apps for different types of uses mostly annoy the user. It is recommended that a super app must be prepared on the pattern of the Citizen Portal"
Interactive or static	The app must be collaborative and must curtail the existing linear paradigm in risk communication.	R1-R4, R7-R8, R9, R12	8	"The App shall be interactive to ensure community participation in information sharing"

TABLE 5 Recommended features and functionality required in the PDMA Madadgar mobile application.

Tab type	Features and functionality	Respondents	Number of respondents	Comments
User registration and language selection	Upon installing the app, users are prompted to select their preferred language from the available options. This selection can be modified later via the settings menu. Next, users are presented with the option to register. Although registration is not mandatory, it is recommended to unlock the full functionality of the app. The registration process is divided into three distinct categories: 1. PDMA User: This type of user requires approval from the Web Dashboard. 2. Citizen: A standard user account for citizens. 3. Volunteer: An account type for individuals wishing to contribute to disaster response efforts.	R1, R4, R 5, R6, R7, R9, R11, R12	8	*"Users division into various categories will help PDMA verify data and engage them meaningfully in DRR…."*
Early warning	The Early Warning tab will provide users with both graphical and textual information regarding the latest weather advisories and early warnings issued by the Pakistan Meteorological Department and PDMA. Through seamless API integration, the PDMA data management platform and Disaster Information Management System are linked with the app, enabling automatic synchronization of uploaded weather advisories. This tab also features a range of essential functions, including daily weather forecasts for the province, weather advisories, flood bulletins, GLOFs alerts, earthquake updates, and drought alerts. By providing end-users with accurate, real-time information, this tab enables informed decision-making and timely action.	R1-R6, R8-R10, R11, R12	11	*"The app shall have exclusive tabs for early warning. It should have a feature for integration of real-time data from PMD and PDMA regarding early warning…."*
Report a disaster	This tab empowers the local communities in KP province and PDMA field teams to report the occurrence of a disaster to the Provincial Emergency Operation Centre (PEOC) for quick response and evacuation. Data sent through this tab can be viewed on the Web Dashboard of the app at the PEOC. As soon as the report is received, PEOC officials directly assign the report through their Disaster Management Information System to the concerned District Disaster Management Authority for response. The backend/web dashboard of the app creates logs of any action taken on the report, thus regulating the behaviors of the responsible officials to take action on time.	R1-R4, R6-R7, R10, R11, R12	9	*"Provide a feature to remote communities to report about the occurrence of a disaster. Many times, such disasters are reported very late and negatively affect emergency response operations"*
PDMA news	The public information and media team of PDMA keeps close coordination with local communities and shares disaster-related news with the general public. Through this tab, PDMA sends any vital information in the form of a news report to the app user. Keeping in view the significance of the information, the user gets notified on their mobile. Within a second, PDMA reaches all users of the app. Push notification services have been acquired for notifying the app users.	R1-R5, R8, R11	7	*"We face problems in mass notification of information related to the onset of a disaster, evacuation order, emergency response management, etc. A feature for mass notification is recommended"*

(Continued)

TABLE 5 (Continued)

Tab type	Features and functionality	Respondents	Number of respondents	Comments
Locate nearby evacuation centre	PDMA has declared dedicated evacuation centers in all Districts of the province. Each of the evacuation centers has been numbered and coordinates have been recorded. All these evacuation centers have been added to the app through their Geo Coordinates. Communities can locate a nearby government evacuation Centre and the app directs the people to reach the Centre through safe and fastest evacuation routes.	R2, R4-R6, R9, R11, R12	6	*"The existing identified evacuation centre must be geo-tagged in the app to guide the community in the time of need"*
Daily situation report	PDMA through its dedicated web-based platform publishes Daily situation reports twice a day. This report covers all types of natural hazards and associated damages. The situation report provides information on any small-scale and or large-scale disaster and sex-wise disaggregated damages data. During emergencies, the media and general public usually want to get access to real-time daily situation reports. This tab provides access to the officially verified disaggregated disaster damages data for humanitarian purposes. Besides, this repository can also be used by DRR researchers, reducing the time and cost of disaster-related data acquisition.	R1-R4, R9, R11, R12	7	*"The Daily Situation Report section from the DMIS must be made public through the app to the general public"*
Community outreach	Visual and textual information and awareness messages with the local community on DRR can be shared via this tab with further access to the PDMA YouTube Channel, PDMA official Twitter, Facebook, and LinkedIn pages.	R1-R5, R7, R9, R12	8	*"A section for public awareness must be added"*
Volunteer engagement	As per the Relief Department, the province has 35,000 Civil Defence Volunteers. Through this feature, all those volunteers who are using smartphones will be mapped with their geolocation. The disaster management and rescue agencies can directly engage them during times of need. Through a message, the volunteers in each district can be mobilized to assist authorities in response and early recovery. The active volunteer data can be shown on the dashboard.	R1-R2, R5-R6, R7, R9-R12	10	*"We have a rich source of volunteers but we lack a platform to engage them in emergencies. The app must include functions to register volunteers and also to engage them through a notification when and where needed"*
Damage need assessment	Immediately after a disaster, authorities want to know the level and types of damages. This information is required for initial relief assistance and post-disaster rehabilitation and recovery. Through this feature, both the field teams (DDMUs) and the general public can conduct and report damages caused by disasters to PEOC-PDMA. Data will be directly submitted to the web dashboard, reducing manual data compilation efforts. The data can be extracted in the form of CSV and the PDMA GIS team can visualize the damages on Maps for information and geo-spatial distribution of damages. Many times, the affected people are left out of assistance just because the Assessment Teams have ignored them in the post-disaster need assessment phase. Madadgar enables these people to conduct their assessment of damages and submit the information within seconds to the PDMA. If meticulously used, this feature can ensure transparency and accountability in relief provision and cash compensation.	R1-R4, R6-R7, R11-R12	9	*"Digitization of post-disaster damage needs assessment is highly recommended to shift the system from analogue assessment to digital assessment"*

(Continued)

TABLE 5 (Continued)

Tab type	Features and functionality	Respondents	Number of respondents	Comments
Rapid need assessment	Through Rapid needs assessment basic needs (i.e., medicine, food, NFIs, Shelter), etc. of the survivors are identified and sent within no time. Through this tab, the local community asks authorities about their immediate requirements following a disaster. PDMA team sends the most needed items to different areas as per the Rapid Need Assessment report submitted by field teams or communities.	R1-R4, R6, R9, R10, R12	8	*"A section for emergency analysis and assessment of immediate needs of the survivors will be good to enable authorities to send the most needed items to the affected sites"*
Risk assessment results	The latest risk assessment results conducted by PDMA and other scientific agencies are made accessible to the general public for information and humanitarian use. Data can be shown in the form of maps, infographics, and tables. PDMA regularly publishes updated data on its website and it can be easily integrated here for information of the general public.	R2, R4, R7, R9, R10, R12	6	*"Access must be provided to the latest risk assessment data through the app for the community"*
Register complaint	This tab can be used to report complaints to PDMA, Khyber Pakhtunkhwa regarding issues with faulty risk assessment, problems in post-disaster damage need assessment, delayed receipt of relief items from district authorities, and/or delay in compensation payment against damages caused by natural or anthropogenic hazards, etc. This section serves as a digital grievance redressal system for the communities.	R1-R4, R7, R10, R12	7	*"Right now, we do not have a DRR-related grievance redressal system at the government level. A dedicated redressal system is needed and recommended"*
Emergency contacts	All emergency contacts are added to this section where communities can directly contact civil protection institutions in their respective Geographic area in times of crisis. PDMA control room number 1700 has been providing 10 different services since covid19 emergency declaration.	R1, R3, R6, R9, R12	5	*"Control room numbers of Emergency Services 1,122, Police 15, and PDMA 17 must be made accessible"*
Quick links	This table provides access to websites of agencies at the government, humanitarian, academic, and United Nations levels.	R1, R4, R8, R11, R12	5	*"Add a feature to provide accessibility to the websites of various government and nongovernmental organizations"*

Early Warning tabs for sending any critical information to the user. Each entry from the app is sent to the dashboard via the server. A notification setting/siren on the web dashboard is catching the attention of PEOC staff for new entries. The web dashboard is also integrated with the Disaster Management Information System of the PDMA. This allows for real-time assignment of the reported problem to the concerned officers at the district level. The system creates logs for each report and action initiated on the information received from the users. This feature serves as a monitoring tool for the reports received from the communities and actions initiated. This regulates the behavior of the PEOC staff to respond to the concerns of the communities in time; otherwise, they can face disciplinary actions. During the validation workshop, concerns were raised regarding data protection and confidentiality and it was recommended to ensure a Secure Sockets Layer (SSL) certificate to secure communication and protect information from interception and eavesdropping.

4 Discussion

The data indicates that there are thirteen tabs in the Madadgar App, whereas some of the tabs are further divided into sub-tabs (Figure 3). For example, the early warning tab provides seven different types of information for different hazards and other atmospheric phenomena. As per the data, soon after the app installation, the user is prompted to language selection from the options of languages, i.e., English and Urdu. The user can change the language selection from the app settings. After language selection, the app directs the user to the user registration section. Although a user can be able to use the app without registration. But this restricts access to four functions of the app, i.e., Report a Disaster, Damages Need Assessment, Rapid Need Assessment, and Register Complaint. Through these tabs, communities can share information with PDMA and the authenticity of such data can only be assured when a user provides all personal relevant information. Three categories of users, i.e., PDMA users, Citizens, and Volunteers can log in and log out from the app in the app settings section. Registration is necessary for information sharing and the laws of Pakistan have punishment for people who circulate false warnings, share fake information, or claim compensation without damages (Ali and Iqbal, 2021).

The existing early warning system lacks a mechanism of feedback from society and a stake in information sharing. The information is usually generated at the federal level, whereas the disasters start at the local level (Rana et al., 2021). Besides, the country does not have meteorological stations in all districts, weakening the reliability of data to model the forecasts and issue advisories. During the flood of 2022, the authorities failed to communicate critical climate forecasts, including predictions of extreme summer 2022 rainfall in Pakistan, leaving the public uninformed and unprepared (Dunstone et al., 2023). In such a situation, Madadgar provides a comprehensive suite of features to augment response initiatives (Shafiq and Ahsan, 2014). The PDMA Madadgar App's "Early Warning" tab provides access to early warning/advisories, daily weather reports, flood bulletin, GLOF alerts, the latest earthquake events and drought information. According to Jan et al. (2025), Madadgar empowers people across Khyber Pakhtunkhwa with crucial disaster information and communication. Users readily engage with its "Early Warning" feature, which delivers timely alerts, weather forecasts and hazard-specific

advisories, enhancing their preparedness. The "Report a Disaster" tab in the Madadgar app empowers communities to directly report incidents to the PDMA-PEOC. This feature serves as a crucial counter-strategy to the traditional linear communication model, moving beyond unilateral announcements by authorities. It enables communities to add local, real-time information, including photos and location data to early warnings or disaster occurrences. This direct channel facilitates a rapid and precise emergency response, filling a critical gap where no prior digital mechanism for community-led reporting existed (Shah et al., 2023a).

The "PDMA News" section enables authorities to quickly disseminate any critical information to the app user. People also use the "PDMA News" section for essential updates on hazards and humanitarian aid. Another critical aspect of the app is the "Locating Nearby Evacuation Centres." In emergencies, evacuation centers and routes serve as vital lifelines, providing a secure haven for individuals to seek refuge. By offering a protected environment, these centers ensure the safety and well-being of those affected, shielding them from harm (Suhardi et al., 2023). During the recent disasters in Pakistan, the existing early warning system remained irrelevant for many people and people faced serious evacuation challenges. For example, during the Murree snowstorm, the Punjab Disaster Management Authority did not convey the message to the public. The majority of the tourists were stranded in their vehicles and 22 precious lives were lost (Asad, 2022). The post-disaster investigation report of the government revealed that there was no evacuation mechanism, defined routes and/or evacuation centers (Geo News, 2022). A similar pattern was observed during the flood 2022 in the study area. The PDMA Madadgar App provides a list of all evacuation centers during an emergency, and with one click it directs people to the nearest evacuation centre using Google Maps services. The government has identified 179 evacuation centers in KP and it has been integrated with the Madadgar through their geo coordinates (Government of Khyber Pakhtunkhwa, 2022). The "Volunteer Engagement" section of Madadgar offers significant benefits. While the spirit of volunteerism is strong in the study area, a centralized platform to mobilize this crucial human resource has been lacking. The PDMA Madadgar app addresses this by enabling authorities to develop a roster of volunteers, assign tasks and communicate with them directly during times of need. All information shared through the app, including volunteer data and task assignments, seamlessly integrates with a web dashboard, ensuring efficient communication and response coordination between communities and the PDMA. The "Damage Need Assessment and Rapid Need Assessment" components enable the local people and local authorities to conduct these assessments with rapid submission to the authorities. The "Complaint Registration" section enables vulnerable people to file complaints in a digital mechanism and will serve as a grievance redressal system. Lastly, the emergency contacts of all critical social protection institutions are added to the app and the user can easily access these contact numbers when and wherever needed. According to Jan et al. (2025), Madadgar beta testing and evaluation results reveal that the key feature of the Madadgar received very positive ratings from its users (Early Warning 86.7%; Report Disaster 86.3%; PDMA News 66.6%; Evacuation Centres 73.3%; Register Complaint 76.6%; Damage Need Assessment 80% and Risk Assessment 66.7%).

Keeping in view gender sensitivity and inclusivity in Pakistan, Madadgar has been designed to incorporate features that empower

vulnerable groups. This includes gender-sensitive reporting mechanisms that enable women in remote locations to actively participate in DRR operations, receive and disseminate early warnings and file complaints. The app also offers child-friendly content, such as age-appropriate alerts and visual guides in the public awareness section. Furthermore, accessibility features for the disabled, including multi-modal communication, screen reader compatibility and simplified navigation have been integrated. To address the digital divide, low-bandwidth optimization and extensive multilingual support ensure the app effectively reaches and empowers all segments of the population.

The results of the study strongly align with the multidimensional theoretical framework. The emphasis on features like two-way communication, community-led incident reporting and damage assessments directly reflects the principles of STS and PD frameworks. This highlights the crucial interplay between the app's technical functionalities and the social structures, user engagement and local needs (Thomas, 2024; Kistenfeger et al., 2024; Messiha et al., 2023; Ahmad et al., 2022; Dell et al., 2021). The integration of various DRR components into a single app, along with the focus on user-friendly interfaces and multi-language support demonstrates an understanding of DOI theory, aiming to increase the app's relative advantage, compatibility and trialability for broader adoption (Mbatha, 2024; Shaw et al., 2022; Frei-Landau et al., 2022; Call and Herber, 2022). Furthermore, the detailed architecture which outlines the roles of various "actants" ranging from PDMA officials and app developers to community members, smartphones and hazards shows the practical application of ANT in mapping the complex network essential for Madadgar's successful conceptualization and deployment, ensuring all elements, human and non-human

contribute to its functionality and impact (Lin and Yang, 2021; Singgalen, 2021).

The PDMA Madadgar app stands apart from conventional disaster-related applications by offering a comprehensive, interactive, and localized operational tool for DRR. Unlike global monitoring platforms, specialized weather apps, first-aid guides or national alert systems, Madadgar uniquely integrates multi-hazard early warnings with extensive localized support services (like evacuation center directories, volunteer management and grievance redressal). Its deep integration with the PDMA's operational backend via a web dashboard creates an actionable framework for disaster risk reduction, response and recovery, bridging the citizen-authority gap by empowering communities with bidirectional reporting capabilities and facilitating coordinated institutional responses. A detailed comparative analysis of the Madadgar with other such apps has been presented in Table 6.

Madadgar conceptual model also has a few major limitations, i.e., data privacy, connectivity issues and user adoption. The data privacy and security limitations were effectively mitigated through stakeholder engagement and participatory design to embed user-centric privacy features. The clear privacy policy and robust technical measures like data minimization, informed consent, SSL/TLS encryption, strong authentication, secure storage and regular dependency updates has further reduced the privacy concerns (Jan et al., 2025; PDMA, 2023). The inherent challenge of connectivity in remote disaster-prone areas is also recognized; while the app optimizes digital communication where infrastructure exists, Madadgar next next-generation model will explore complementary solutions such as offline capabilities or integration of alternative communication channels to bridge this digital divide. To achieve widespread and sustained user adoption and accessibility considering varying literacy and digital skills, an ongoing
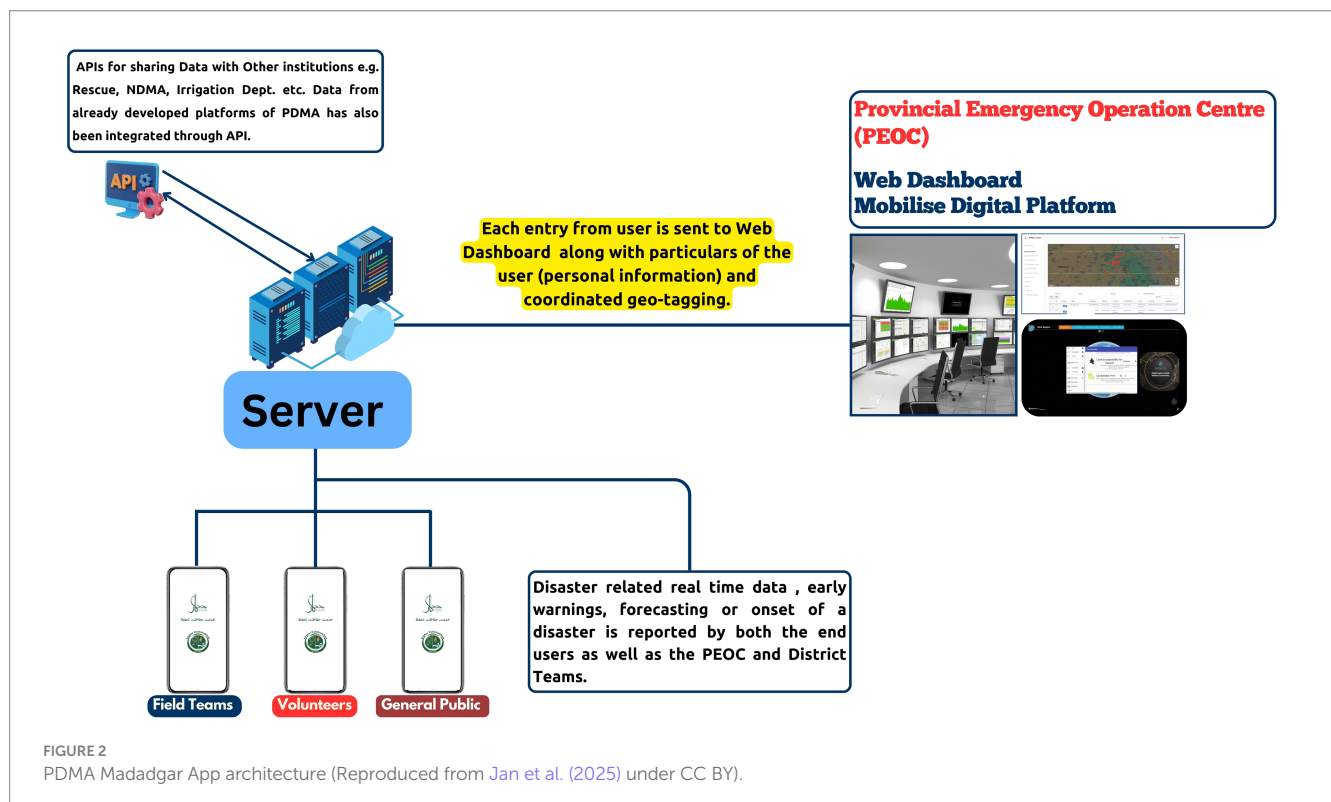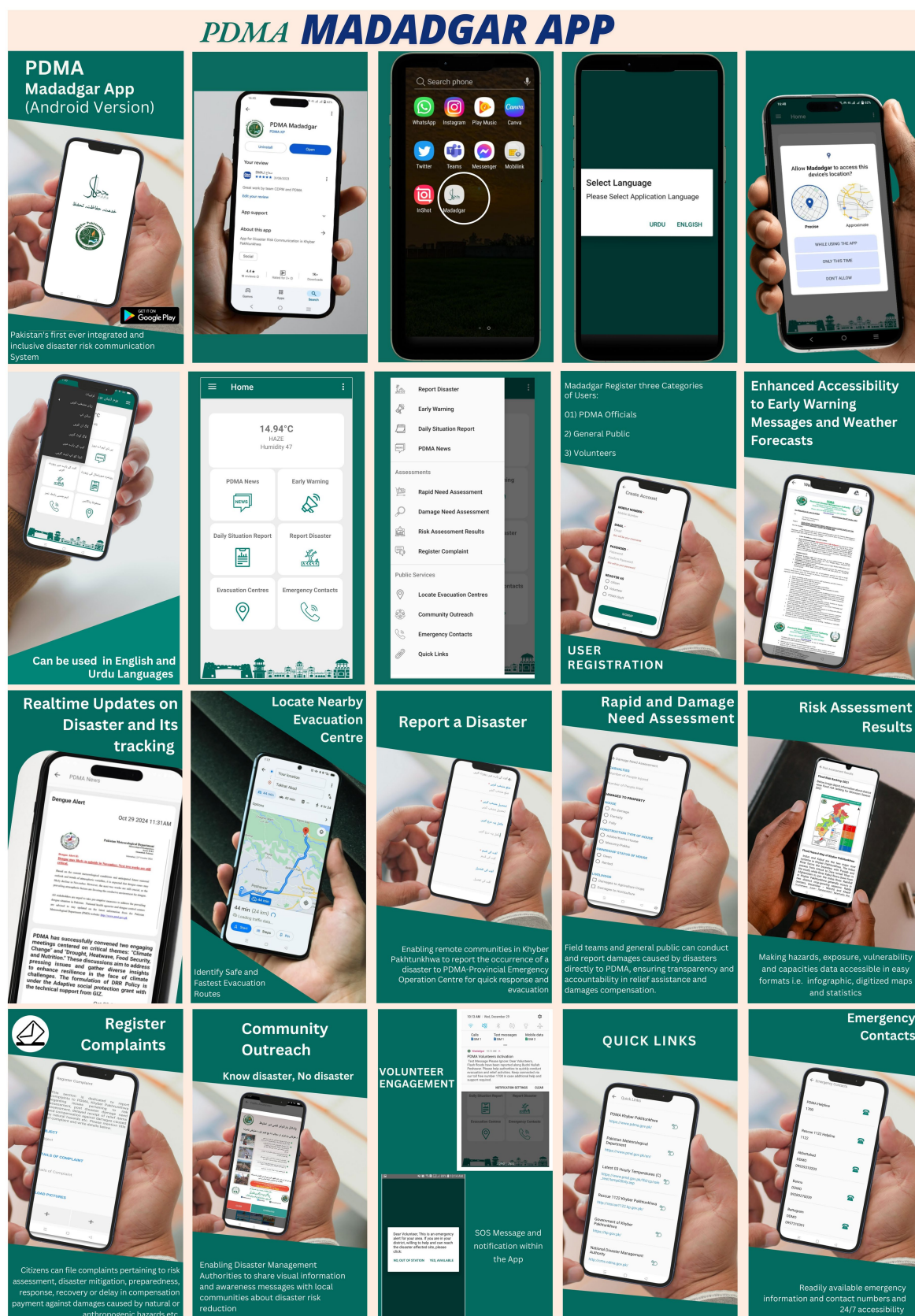

FIGURE 2
PDMA Madadgar App architecture (Reproduced from Jan et al. (2025) under CC BY).

TABLE 6 Comparative Analysis of PDMA Madadgar with Other Apps.

App name	Primary focus	Geographic scope	Key differentiator from Madadgar
Disaster alert	Global multi-hazard monitoring	Global	Primarily a top-down information dissemination tool for a broad range of global hazards. Lacks localized citizen reporting and an integrated backend for direct governmental response like Madadgar.
Carrington: disaster prediction	Predictive analytics for natural disasters	Global	Focuses on forecasting and modelling potential future events (e.g., floods, wildfires). While important for preparedness, it does not offer real-time citizen reporting or integrated local response mechanisms like Madadgar.
My earthquake alerts	Real-time earthquake notifications	Global/ Regional	Niche focuses on seismic activity. Provides alerts, maps, and information on past earthquakes. Lacks the multi-hazard scope, citizen reporting, and comprehensive local disaster management features found in Madadgar.
First aid-IFRC	First aid guidance	Global	Educational and guidance-focused. Offers step-by-step instructions for medical emergencies. It's a critical preparedness tool but does not involve disaster monitoring, reporting, or large-scale coordination, which are Madadgar's core functions.
Accuweather	Weather forecasting and alerts	Global	Primarily a weather app providing forecasts, radar, and weather-related alerts (e.g., storms, heat waves). While essential for pre-disaster awareness, it does not facilitate incident reporting, evacuation centre information, or integrated disaster response workflows like Madadgar.
Natural disaster monitor	Aggregated disaster news and information	Global	Acts as a news aggregator for natural disasters worldwide. Offers a broad overview of ongoing events but lacks the interactive, real-time reporting and localized operational integration that defines Madadgar.
Clime: weather radar live	Live weather radar and forecast	Global/Regional	Similar to AccuWeather, its main function is to visualize weather patterns through radar. Valuable for immediate weather awareness, but does not extend to the comprehensive disaster management and citizen engagement functionalities of Madadgar.
Comparative analysis of PDMA Madadgar with disaster-related apps in Pakistan			
Flood reporting app	Incident reporting specifically for floods	Khyber Pakhtunkhwa	Niche focuses on flood incidents only. While it facilitates reporting with images and location, it lacks the multi-hazard early warning, comprehensive localized services (evacuation centres, volunteer management), and integrated DMIS backend of Madadgar.
Emergency alert PDMA KP	Alerts and information from PDMA KP	Khyber Pakhtunkhwa	Focused on one-way dissemination of official alerts and information from PDMA KP. The multi-faceted services of Madadgar have replaced this app and no longer in use.
PMD weather	Official weather forecasting	Pakistan	Purely a weather forecasting app by the Pakistan Meteorological Department. Provides detailed weather data but does not include disaster incident reporting, localized emergency services, or direct coordination with disaster management authorities for response.
Locust survey-PDMA Punjab	Survey and reporting for locust infestations	Punjab (specific)	Highly specialized for agricultural disaster management (locusts). It's a data collection tool for a specific hazard in one province. Lacks the broad multi-hazard scope and comprehensive disaster management features of Madadgar.
Pakistan citizen portal	General public grievance redressal	Pakistan	A broad complaint management system for various government services. While it can be used for disaster-related complaints, it's not a dedicated, real-time disaster management and communication platform with specific emergency response features like Madadgar.
Pakistan weather forecast 2023	General weather forecasting (third-party)	Pakistan	Another general weather app, often providing basic forecasts and alerts. Lacking official data sources and depth of PMD Weather, and certainly does not offer any disaster reporting or management functionalities like Madadgar.
Pak NDMA disaster alert	National-level disaster alerts and information	Pakistan	National-level alerts and general guidelines from NDMA. It serves as a warning communication tool. While important, it generally lacks the localized, bidirectional citizen reporting, granular localized services (e.g., specific evacuation centers), and direct provincial agency integration that Madadgar provides at the KP level. It complements, rather than duplicates, Madadgar's function.

user experience study has already been initiated along with localized training, social media content, videos and targeted strategies to ensure inclusivity. Based on the results of the upcoming adoption potential study with a large sample size in all seven administrative divisions of KP, we will provide a concept of a next-generation model of the Madadgar. In the next generation, we will move beyond real-time alerts and explore predictive analytics (Machine Learning), automated risk assessments (Artificial Intelligence) and personalized notifications for a more proactive and intelligent app aligning with the long-term vision for the Madadgar App.

The Madadgar app has significant policy implications, serving as a practical model for strengthening disaster risk communication in Pakistan and other developing countries. The app directly contributes to the Pakistan National Disaster Management Act 2010 (articles 16-2 J, 20-2 K), which explicitly emphasizes the use of information and communication technologies to enhance early warning capabilities and build resilience through preparedness (Government of Pakistan, 2010). By providing a platform for real-time alerts, two-way communication and citizen reporting, the app operationalizes these policy directives at the grassroots level, transforming abstract policy goals into actionable tools. Madadgar closely aligns with the Pakistan National DRR Policy by operationalizing its focus on enhancing early warning systems, promoting community participation and utilizing technology for effective communication and information sharing to build national and local resilience against disasters (Government of Pakistan, 2013). Furthermore, Madadgar aligns with global agendas like the Sendai Framework for DRR 2015–2030 and contributes to SDGs 11, 13, and 17 (IPU and UNDRR, 2021; UNDRR, 2015) (573–586).

The Madadgar App presents a robust, scalable blueprint for enhancing disaster risk communication in developing countries due to its ability to address common vulnerabilities like weak early warnings and the digital divide. Madadgar transforms passive users into active DRR participants through two-way communication, integrates multiple DRR functions into a user-friendly app, prioritizes local context and language, and boosts governance and accountability via integration with official systems like PDMA's DMIS. Madadgar codes and algorithms have been made public for replication in other areas on a humanitarian basis and can be reached at Syedpg (2025).

5 Conclusion

The conceptual model of the PDMA Madadgar App indicates that it is a critical tool for enhancing disaster resilience in KP, Pakistan. Featuring an intuitive and user-friendly interface, the Madadgar enables local communities to report disaster incidents in real-time, access timely early warning messages, and conduct comprehensive post-disaster assessments. The app's multifaceted features, including instantaneous incident reporting, proactive early warning systems, volunteer mobilization, evacuation centers localization, and assessment and complaint registration effectively address the challenges in Pakistan's early warning system and disaster response mechanisms. Specifically, it addresses the limitations of Pakistan's early warning system, which often fails to communicate critical information to the public. The app enhances disaster

preparedness, response, and resilience in Pakistan. Its impact will be crucial in saving lives and reducing damage during disasters. By facilitating useful information dissemination and effective response, the app strengthens disaster risk communication in Pakistan, expediting widespread adoption through its bilingual language options. The development and implementation of the PDMA Madadgar App have the potential to transform the way disasters are managed in KP, Pakistan. By leveraging technology and community engagement, the app can help mitigate the impact of disasters, save lives, and foster sustainable development. PDMA Madadgar App is accessible on the Google Play Store via https://play.google.com/store/apps/details?id=com.mobilisepakistanirfan.pdma.

Data availability statement

The datasets presented in this article are publicly available on GitHub and can be accessed via Frontend (App) Code: https://github.com/irfansyedpg/AndroidCP Backend (Dashboard) Code: https://github.com/irfansyedpg/madadgar. Further inquiries can be directed to the corresponding author.

Ethics statement

The study adhered to all applicable local legislation and the ethical guidelines. All research participants provided their written informed consent, having been fully apprised of the study's purpose, procedures, potential risks and their right to withdraw at any time.

Author contributions

MJ: Conceptualization, Writing – original draft, Formal analysis. SIU: Writing – original draft, Data curation, Methodology. WU: Writing – review & editing, Visualization, Investigation, Funding acquisition. SU: Investigation, Writing – review & editing, Formal analysis. HT: Supervision, Writing – original draft, Validation. TF: Writing – review & editing, Project administration, Funding acquisition. AA: Supervision, Resources, Writing – review & editing, Investigation. ZR: Visualization, Validation, Writing – review & editing.

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The authors declare that no Gen AI was used in the creation of this manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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