ORIGINAL ARTICLE

LeptoSafe: Integrating Digital Health Tools in Early Detection and Prevention of Leptospirosis

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ABSTRACT

Background: Leptospirosis is a significant zoonotic disease endemic to tropical, flood-prone regions such as Pahang, Malaysia, where limited public awareness, delayed risk recognition, and overlapping symptoms with other febrile illnesses contribute to substantial underreporting and disease burden. Challenges in early detection and prevention necessitate innovative digital solutions to improve public health outcomes. **Methods**: *LeptoSafe*, a mobile health application prototype, was developed through a user-centred, iterative design approach involving collaboration with allied health experts and the Malaysian Ministry of Health. The app integrates evidence-based literature and real-time leptospirosis case data. Key components include a validated ten-item self-screening questionnaire for personalized risk assessment, GIS-enabled dynamic hotspot mapping with push notifications, educational infographics and videos, and a locator for nearby health facilities using Google Maps API. The platform supports bilingual access (English and Malay). **Results**: *LeptoSafe* integrates four core functionalities: (1) interactive self-assessment delivering individualized leptospirosis risk stratification; (2) real-time geospatial visualization of confirmed case clusters enhancing situational awareness; (3) comprehensive multimedia educational content tailored to local epidemiology; and (4) a health facility locator improving care accessibility. The prototype effectively addresses critical gaps in early symptom recognition, health knowledge dissemination, and timely healthcare engagement, particularly among vulnerable populations exposed to environmental and occupational risks. It represents a novel interdisciplinary advancement by integrating mobile technology, geographic information systems, and allied health expertise into a unified digital platform for zoonotic disease management. Moreover, *LeptoSafe* is among the first applications to combine real-time epidemiological data, risk self-assessment, and targeted education for leptospirosis prevention. Its modular and scalable design offers a replicable model for digital health interventions across neglected tropical diseases globally, enhancing surveillance capacity and public empowerment. **Conclusion**: *LeptoSafe* demonstrates the feasibility and impact potential of an integrated digital health platform to enhance leptospirosis control through empowerment, early detection, and prevention. Future directions include field deployment, rigorous evaluation of behavioural and knowledge outcomes, and integration with national surveillance systems to strengthen public health responses.

Keywords:
Leptospirosis; Early detection; Prevention; Digital health; Mobile app

INTRODUCTION

Leptospirosis in Malaysia: Epidemiology, Risk Factors, and Challenges in Diagnosis and Control

Leptospirosis has emerged as a significant public health concern in Malaysia, recognized as an endemic zoonotic disease with a rising incidence and considerable impact (Ab Kadir et al., 2023; Ahmad Zamzuri et al., 2023; Lea et al., 2025; Mohd Yusof et al., 2025). In Malaysia, the disease burden has markedly escalated over the past two decades, with reported cases increasing from 1.45 to 25.94 per 100,000 population between 2005 and 2014 (Ab Kadir et al., 2023; Kamal and Foo, 2023). Despite leptospirosis being endemic in Malaysia, challenges persist in its diagnosis and management due to clinical overlap with other febrile illnesses and the limitations of diagnostic tools. A significant proportion of leptospirosis cases remain asymptomatic, particularly among urban sanitation workers, complicating surveillance and control efforts (Mohd Yusof et al., 2025). The disease is often misdiagnosed as dengue, malaria, or other febrile illnesses due to overlapping symptoms and limited diagnostic capacity in certain regions (Fornazari et al., 2021; Uribe-

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Restrepo et al., 2024, Esteves et al., 2025; Lea et al., 2025). This highlights the urgent need to better understand the dynamics of leptospirosis transmission, at-risk populations, and effective control measures to reduce morbidity and mortality.

Epidemiological data indicate notable spatial clustering in regions such as Sarawak, Kelantan, and Negeri Sembilan, with incidence rates typically peaking after flood events. This underscores the significant influence of hydroclimatic factors on disease transmission (Azman et al., 2025). Surveillance has shown that adult males are disproportionately affected by the infection, with mortality rates varying depending on the severity of the disease and the timeliness of diagnosis (Nazli et al., 2020). High-risk occupational groups, such as town service workers, oil palm plantation labourers, wet market vendors, and urban sanitation workers, exhibit elevated seroprevalence and infection risks due to their frequent exposure to contaminated environments and animals (Hanapi et al., 2021; Rahman et al., 2018; Samsudin et al., 2018; Jeffree et al., 2020; Mohd Yusof et al., 2025; Lea et al., 2025). Additionally, refugee and marginalized communities are particularly vulnerable due to poor living conditions (Hanapi et al., 2021; Azman et al., 2025).

Environmental factors, such as proximity to water bodies, flood exposure, inadequate sanitation, rapid urbanization, and rodent infestations, are consistently linked to heightened transmission risk (Pui et al., 2017; Mohd Taib et al, 2023; Suut et al., 2023; Baharom et al., 2024; Azman et al., 2025). Research has shown that specific land use types such as agricultural areas and low-lying regions along with urban features like mixed commercial-residential buildings, play a role in facilitating the circulation of the pathogen (Baharom et al., 2024; Azman et al., 2025; Lea et al., 2025). Rodents, particularly *Rattus* species, serve as primary reservoirs, harbouring pathogenic *Leptospira* spp. in both urban and rural settings (Mohd Taib et al., 2023; Suut et al., 2018; Laun et al., 2019). Recreational activities involving water contact, such as hiking and water sports, have also been linked to leptospirosis outbreaks (Lea et al., 2025). The detection of pathogenic *Leptospira* spp. in recreational waters and soils emphasizes the public health risks associated with these activities (Lea et al., 2025; Mohd Yusof et al., 2025).

Despite advances in diagnostic techniques, early detection of leptospirosis remains a challenge due to its nonspecific clinical manifestations and the limitations of traditional tests such as the microscopic agglutination test (MAT) (Jeffree et al., 2020) and enzyme-linked immunosorbent assay (ELISA) (Samsudin et al., 2018). Emerging diagnostic modalities, including molecular techniques like PCR (Atil et al., 2020) and machine learning models applied to microscopic agglutination images, show promise in improving diagnostic speed and accuracy (Rahmat et al., 2020). Predictive modelling that incorporates meteorological data and stochastic transmission models is also being employed to forecast outbreaks and identify potential hotspots (Rahmat et al., 2020; Rahim et al., 2023; Rahmat et al., 2021; Ramali et al., 2023).

Cross-Platform Mobile Tools for Leptospirosis Education

Research on cross-platform mobile applications for self-assessment and risk education has become a critical area of focus, driven by the growing reliance on mobile health technologies to improve disease prevention and management. Over the past decade, mobile health applications have evolved from basic educational tools to sophisticated platforms that integrate features such as interactive tutorials, symptom checkers, and location-based alerts (Kadir et al., 2025; Mohd Yusof et al., 2025; Suhaimi et al., 2025). This technological progression aligns with the increasing global burden of infectious diseases, including leptospirosis, highlighting the need for accessible and user-friendly digital interventions to enhance public health outcomes. The practical importance of these applications lies in their ability to provide timely risk calculators and customized educational content, empowering individuals to engage in self-directed learning and make informed decisions about their health.

Despite the widespread adoption of mobile health apps, several challenges persist in effectively integrating disease-specific features, such as symptom checkers and location-based alerts tailored to leptospirosis risk. This highlights a significant knowledge gap in the field. While existing literature frequently addresses general mobile health interventions or clinical decision support systems, comprehensive evaluations of cross-platform applications combining interactive educational content with real-time risk assessment tools for leptospirosis remain scarce.

Therefore, this research aims to develop *LeptoSafe*, a mobile application integrating self-screening, real-time hotspot mapping, and educational interventions to enhance early detection and prevention, focusing on its ability to deliver both educational and risk-assessment functionalities for leptospirosis.

METHODOLOGY

Study Design

This project employed a user-centred, iterative development framework to create *LeptoSafe*, a mobile application for leptospirosis early detection, prevention, and education. Design activities were conducted in close collaboration with Ministry of Health and allied health experts from the Kulliyyah of Allied Health Sciences

(KAHS), IIUM.

Application Development Approach

A Rapid Application Development (RAD) model guided the system's creation, emphasizing prototyping and incremental refinement under a six-month timeline (Pereira et al., 2022). Flutter is used for the frontend development of the prototype. It is a cross-platform mobile app framework that enables building iOS and Android apps from a single codebase. Backend services such as Firebase provide real-time database and authentication, while the Google Maps API is integrated to display leptospirosis hotspot locations. The development involves four phases described below:

Phase 1: Requirements Planning

–Open-ended interviews with allied health experts were conducted to elicit core functional requirements (self-screening, hotspot alerts, educational content, facility locator) and data sources.

– The project scope, success criteria, and technical constraints (data availability, geospatial accuracy, multimedia performance) were defined in this phase.

Phase 2: User Design

– This phase involves designing the low- and high-fidelity wireframes in Flutter, drawing on Material Design principles to ensure cross-platform consistency and accessibility.

Phase 3: Construction

– The frontend modules and backend services were implemented using Flutter in this phase. Firebase is also used for authentication, real-time database updates, and push notifications.

– We integrated QGIS for hotspot geoprocessing and the Google Maps API for facility lookup.

– Construction of content such as infographics and video resources, sourced from peer-reviewed literature and Ministry of Health reports was performed in this phase.

Phase 4: Cutover Preparation

– This phase involves finalizing the prototype, including automated data synchronization, user risk-scoring algorithms, and multilingual support (English, Malay).

– However, technical documentation, user guides, and test scripts for pilot deployment will be prepared in the next phase.

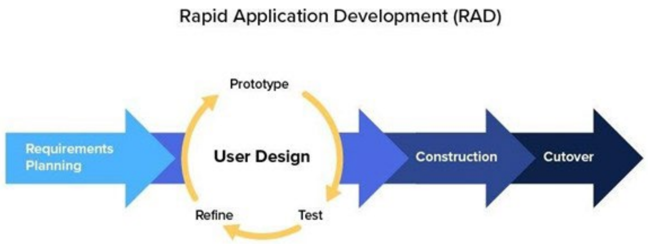

Figure 1: *Rapid Application Development Model*

Data Sources and Content Criteria

Leptospirosis Case Data

Aggregated from Malaysia's Ministry of Health for hotspot mapping. Cases older than one year were excluded to ensure timeliness.

Literature-Based Content

Educational materials (infographics, videos) were curated from PubMed, Web of Science, and Google Scholar; only content describing clinical symptoms, transmission routes, or preventive measures was included.

Self-Screening Survey Design

A ten-item questionnaire was designed to assess recent exposure history, symptom presence, and behavioural risk factors. Each response is scored and mapped to one of four risk levels (low, moderate, high, critical), triggering personalized recommendations ranging from self-monitoring advice to immediate clinical referral.

Hotspot Mapping Module

Geospatial Processing

QGIS workflows aggregate confirmed case coordinates into dynamic risk layers.

Real-Time Updates

A Firebase cloud function imports new case reports daily, refreshes map tiles, and issues location-based push notifications when users enter areas with elevated case density.

Logical Design

The use case diagram of *LeptoSafe* is designed as shown in Figure 2. User shall be able to login or register if there is no existing account, view hotspot location, do self-checking survey and view risk level along with personalized recommendation. Additionally, user can view leptospirosis symptom, treatment, and educational awareness content, find out nearby health facilities, and change language settings. The admin is responsible to manage hotspot location by updating the database.

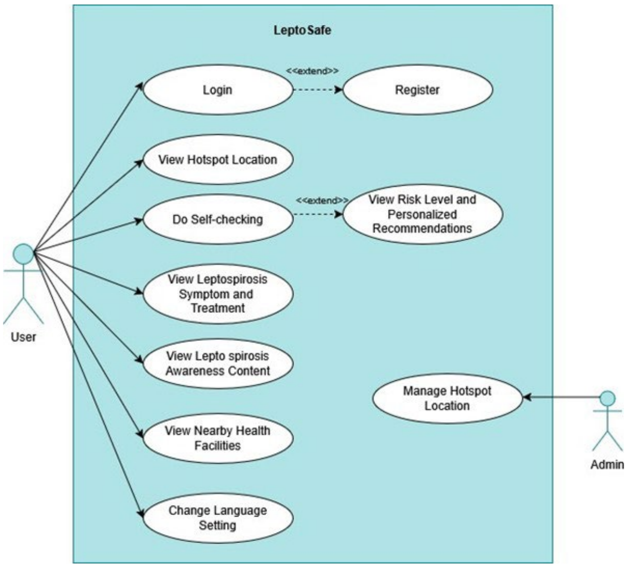

Figure 2: Use Case Diagram

Figure 3 shows the activity diagram of the user login and registration process. A user can either register by completing a form or log in by entering their credentials. The system then verifies the login details, if the information given is correct, the app dashboard will be displayed, or otherwise, the user is prompted to try again.

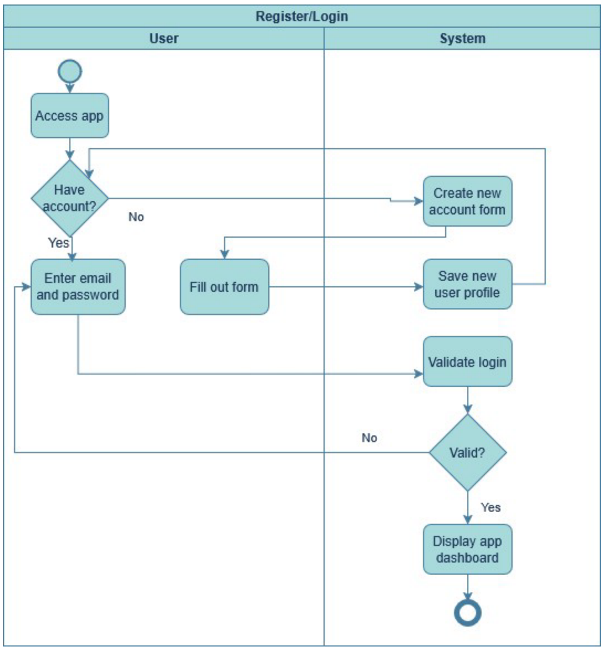

Figure 3: Register/Login Activity Diagram

The activity diagram in Figure 4 shows the activity when a user performing a self-check. The user navigates to the self-checking page, clicks "Self-checking," answers a questionnaire, and clicks "Submit." The system then displays the questionnaire, evaluates the user's responses, generates and saves a health record, and finally displays the health record to the user.

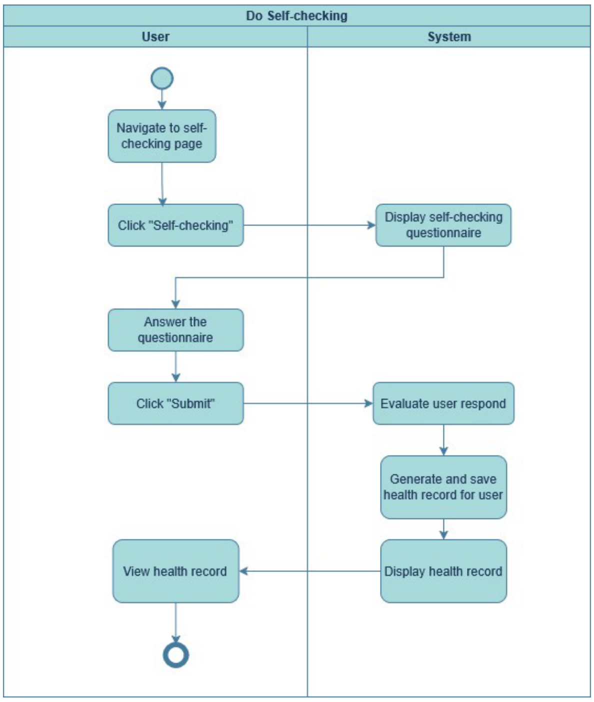

Figure 4: Do Self-checking Activity Diagram

The activity diagram shown in Figure 5 depicts the process of a user accessing their health records. When the user clicks "Health Record", the system retrieves and displays the available records. The user then selects a specific record, after which the system presents a personalized recommendation for the user to view.

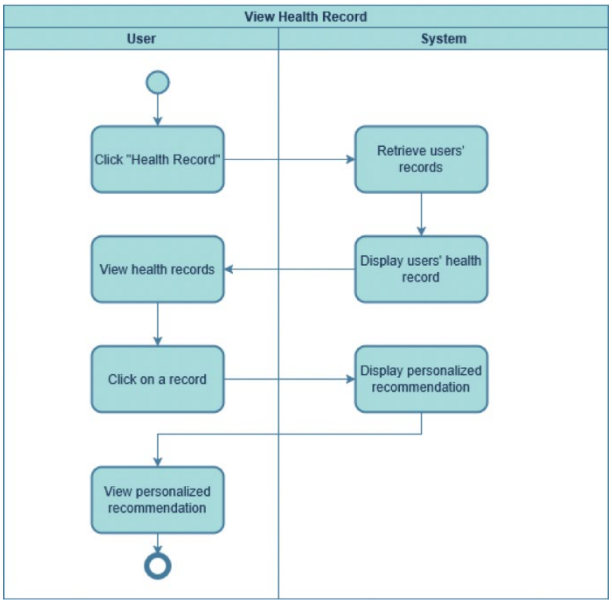

Figure 5: View Health Record Activity Diagram

The activity diagram in Figure 6 illustrates how a user accesses leptospirosis hotspot information. The user selects "Hotspot", prompting the system to display the hotspot page. After the user enters a desired location, the system presents nearby leptospirosis hotspots for viewing.

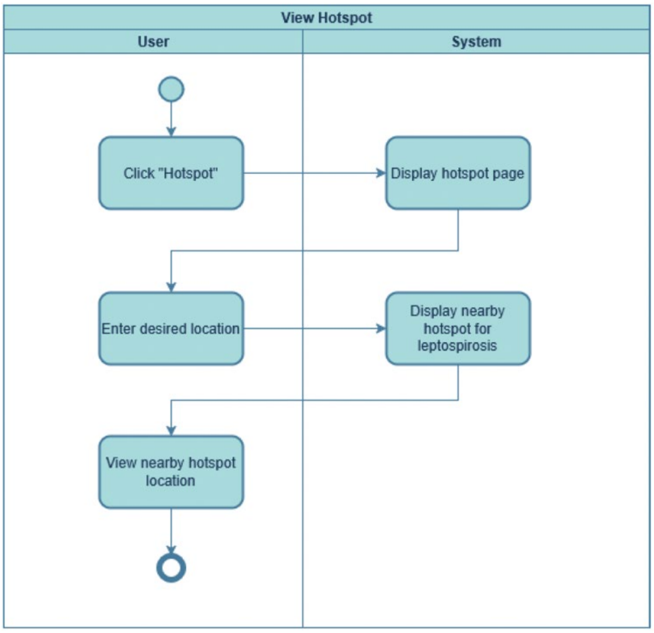

Figure 6:: View Hotspot Activity Diagram

The activity diagram in Figure 7 illustrates the process of viewing awareness content. When the user clicks "Awareness", the system displays the awareness page. The user then selects either the "Infographic" or "Video" tab, prompting the system to retrieve and display the selected content for the user to view.

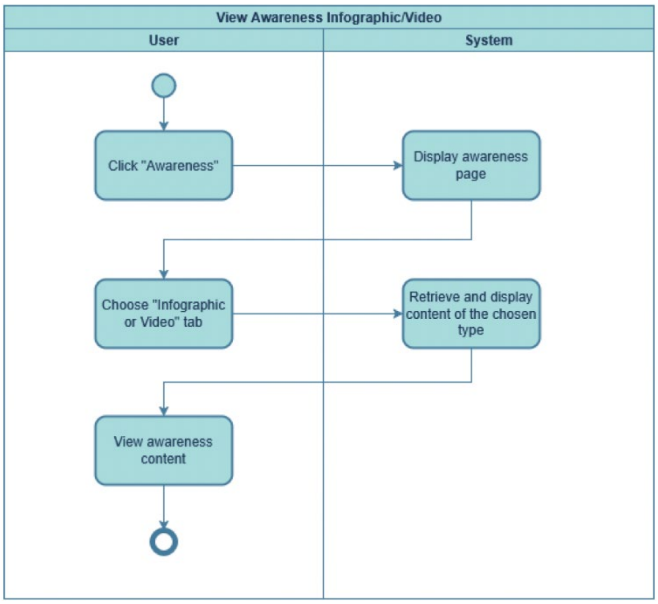

Figure 7: View Educational Awareness Content Activity Diagram

A sequence diagram is a type of interaction diagram that visually represents how objects in a system interact over time (Booch et al., 2005). It shows the order of messages exchanged between objects, typically illustrating the flow of a specific scenario or use case. The sequence diagram in Figure 8 shows the self-checking process. A user starts self-checking via the app, answers a questionnaire, then the app evaluates responses, generates then saves a health record in the database, and displays it. The user can then view health records and click one to see risk level and personalized recommendations.

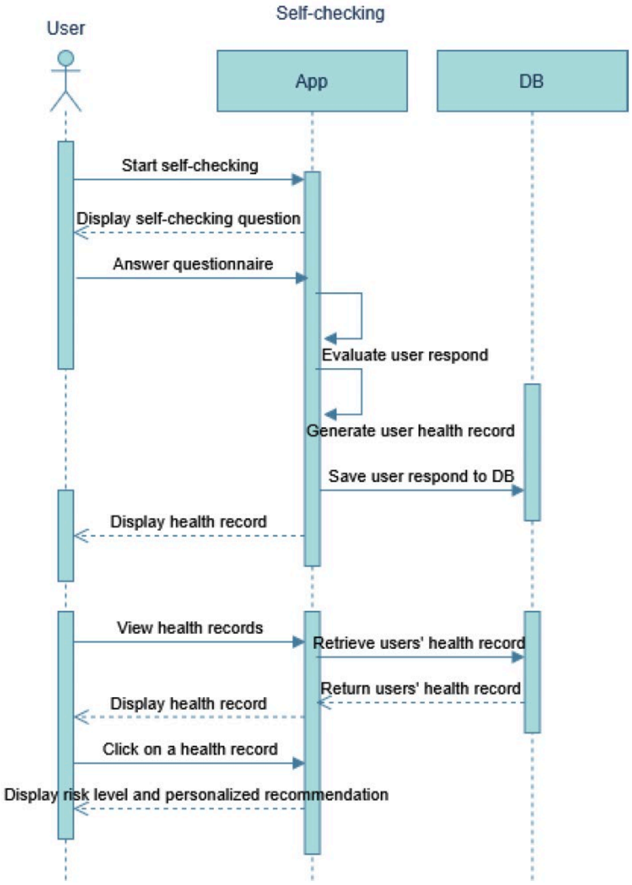

Figure 8: Self Checking Sequence Diagram

RESULTS

In this Section, a high-fidelity prototype of the mobile application (*LeptoSafe*) is presented. Figure 9 shows the landing page that will be displayed when *LeptoSafe* prototype is executed. User is then required to sign in using their registered email.

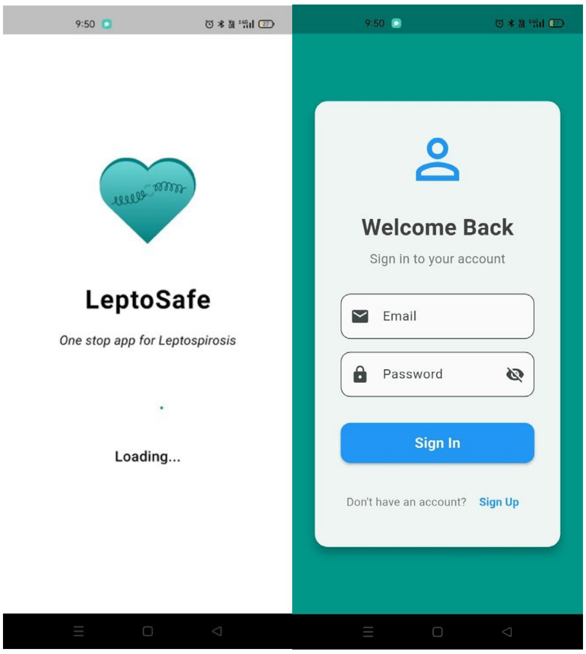

Figure 9: Landing and welcome page

Once the user has logged in, the dashboard page shown in Figure 10 will be displayed. It shows the main features that user can benefit from. For example, when clicking on the "Health Record" icon, their health information will be shown.

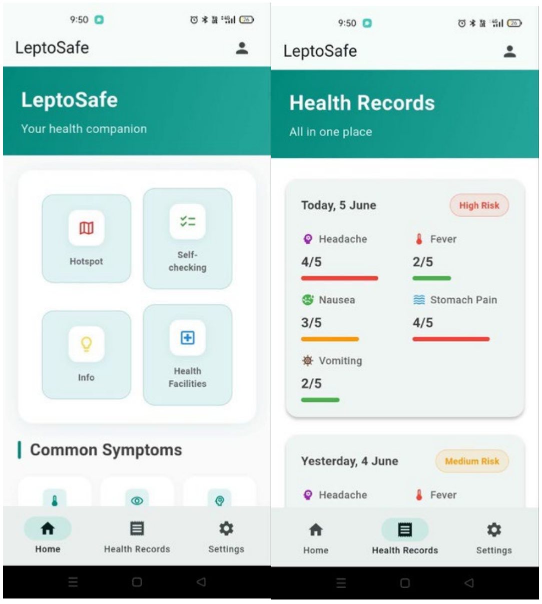

Figure 10: Dashboard and health record page

The self-screening can be done by user to rate the severity level of Leptospirosis symptoms. User will be prompted with a total of ten questions using 5-point Likert Scale (see Figure 11). From the dashboard, user is also allowed to update their profile page.

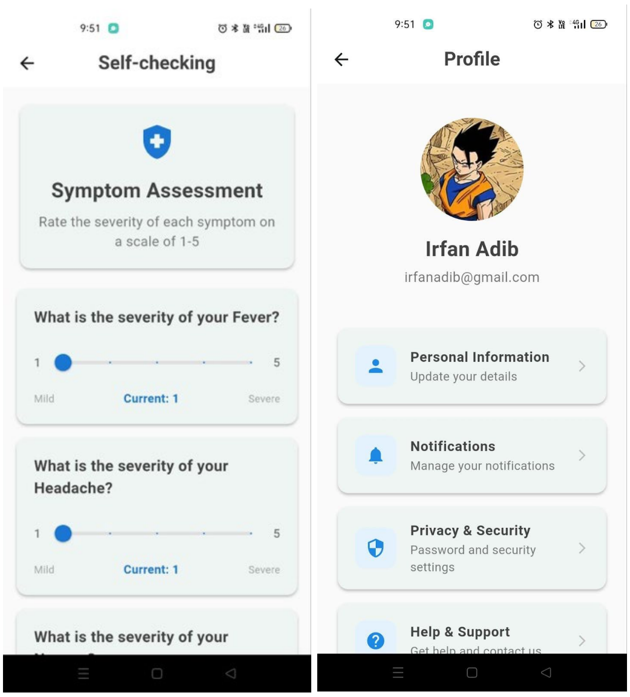

Figure 11: Self-screening and Profile page

Another main feature of the prototype is to show the hotspot location for the user to check the location of leptospirosis cases. They can also view the available health facilities as can be seen in Figure 12.

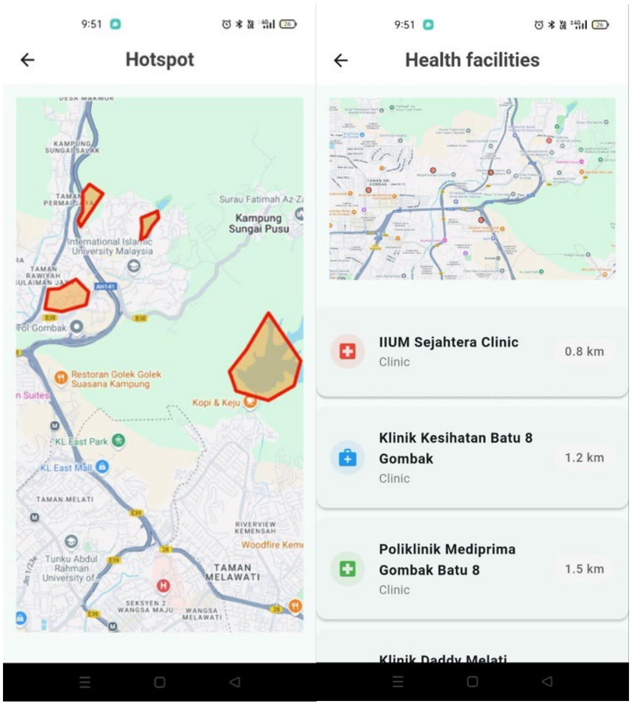

Figure 12: Hotspot map and Health Facilities

System Implementation

LeptoSafe's core modules were implemented in a cross-platform Flutter application with Firebase and QGIS integration. Table 1 summarizes the features. For the prototype development, we focused on development of three modules: i) User Authentication; ii) Self-Screening Survey, and iii) Educational Content.

Table 1: Modules and Descriptions

Module	Description
User Authentication	Registration and login with email/password, Firebase Authentication integration
Self-Screening Survey	Ten-item questionnaire with algorithmic risk scoring and personalized recommendation output
Hotspot Mapping	Real-time GIS visualization of confirmed case clusters via QGIS; push notifications for alerts
Educational Content	Infographics and short videos on symptoms, transmission, and prevention
Nearby Health Facility Locator	Google Maps API integration to display clinics and hospitals within 5 km of user location
Multilingual Support	English and Malay language options for all user interface elements

DISCUSSION

LeptoSafe represents a promising advancement in integrating digital health tools for leptospirosis early detection, prevention, and education. Its core features—self-screening survey, real-time hotspot mapping, and educational content—address key challenges in leptospirosis management, especially in resource-limited and flood-prone areas where healthcare access may be limited (Mohd Yusof et al., 2025; Kamal & Foo, 2023). The personalized risk assessment facilitated by the self-screening survey empowers users to make informed healthcare decisions, which is vital in settings where delayed diagnosis often worsens outcomes (Fornazari et al., 2021; Jeffree et al., 2020).

The dynamic hotspot mapping with push notifications aligns with recent advances in using geospatial data to predict and monitor leptospirosis incidence, thereby improving situational awareness (Ab Kadir et al., 2023; Ramali et al., 2023). Such spatial epidemiology tools have been shown to enhance public health responses by identifying high-risk areas and facilitating targeted interventions (Rahim et al., 2023). The integration of a health facility locator further supports timely access to care, complementing existing gaps in healthcare infrastructure within endemic regions (Ahmad Zamzuri et al., 2023).

Educational modules utilizing multimedia formats engage diverse users effectively, closing knowledge gaps that contribute to the underreporting and misdiagnosis of leptospirosis (Lea et al., 2025; Baharom et al., 2024). This is particularly crucial in tropical settings with overlapping febrile illnesses such as dengue and malaria, where confusion in symptom recognition complicates clinical management (Esteves et al., 2025; Uribe-Restrepo et al., 2024).

Importantly, *LeptoSafe* exemplifies the benefits of interdisciplinary collaboration between computer scientists, allied health experts, and public health authorities, a model advocated in other digital health interventions for zoonotic and neglected tropical diseases (Suhaimi et al., 2025; Mohd Yusof et al., 2025). Its modular, scalable architecture offers potential adaptability to other infectious diseases, enhancing its value beyond leptospirosis.

While the prototype demonstrates technological feasibility and aligns with epidemiological evidence, field validation is essential. Future work should rigorously assess user engagement, knowledge gains, behaviour changes, and epidemiological impacts in diverse populations. Furthermore, integration with national surveillance and reporting systems could transform *LeptoSafe* from a standalone tool to a critical component of Malaysia’s leptospirosis control strategy (Kadir et al., 2025; Kamal & Foo, 2023).

CONCLUSION

LeptoSafe presents a feasible and innovative solution for the early detection, prevention, and education of leptospirosis. The app's integrated features—self-screening, real-time hotspot mapping, and educational content—demonstrate its potential to address key public health challenges associated with the disease. While the initial prototype has shown positive usability and user engagement, further research is needed to evaluate its impact on health behaviour and its integration into national surveillance systems. The continued development and testing of *LeptoSafe*, informed by field data, will be crucial in ensuring its effectiveness and scalability in the fight against leptospirosis.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the author(s) used Perplexity AI to draft the manuscript text and format the citations. The author(s) subsequently reviewed, revised, and approved all content, and accept full responsibility for the final manuscript.

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