Development of a Web Application through a Mobilized Crowdsourcing Platform to Enable Participatory Risk Sensitive Urban Development

Kangana N.[1]*, Kankanamge N.[2], De Silva C.[2], Goonetilleke A.[3], Ranasinghe D.[1] and Mahamood R.[1]

[1]Research Assistant, Department of Town & Country Planning, Faculty of Architecture, University of Moratuwa, Sri Lanka

[2]Lecturer, Department of Town & Country Planning, Faculty of Architecture, University of Moratuwa, Sri Lanka

[3]Professor, Faculty of Engineering, School of Civil & Environmental Engineering, Queensland University of Technology, Australia

nukangana@gmail.com

Abstract

Flooding is the most frequent and destructive natural disaster currently facing Sri Lanka. Rapid urbanization and changing precipitation patterns are exacerbating the situation, leading to extensive socio-economic damage and disrupting countless lives. Despite the availability of technology-based applications that can raise disaster awareness and improve management, these tools are not fully utilized in Sri Lankan communities. The study addresses the critical issue of insufficient awareness and the lack of formal early flood alert mechanisms within Sri Lankan. Although, recent technological advancements offer opportunities for community to engage in sharing early disaster warnings among their networks, they remain underutilized. The community engagement in disaster management is still minimal, reducing the preparedness and resilience of vulnerable communities. To address this, a platform integrating a crowdsourcing-based mobile application with a web application was developed, aiming to make disaster management and response inclusive through community involvement and advanced remote sensing technologies. A flood vulnerability assessment model was created using 30 years of historical flood data and nine conditioning factors, including topographic features, weather-related variables, hydrological networks, land cover, and soil type, with Sentinel-2 satellite imagery for the Kelaniya watershed area enhancing the model's accuracy. The mobile application facilitates real-time data collection from individuals in flood-prone areas, who can report on flood levels, affected locations, and other critical information. This crowdsourced data undergoes rigorous verification to ensure accuracy. Once validated, the information is visualized on a web application, serving as a vital communication tool for both the community and disaster response authorities. The methodology includes developing the vulnerability assessment model, creating the mobile application with integrated crowdsourcing techniques, and conducting trial workshops to engage the community and validate the platform with the contribution of relevant authorities. Mobilization strategies are proposed based on insights from these community interactions. By prioritizing community participation and utilizing cutting-edge geo-information technologies, this research significantly contributes to building resilient and proactive urban communities in Sri Lanka. The findings demonstrate the *substantial potential of combining crowdsourced data with remote sensing to enhance disaster management and community resilience.*

Keywords: Community engagement, Crowdsourcing, Flood vulnerability assessment, Remote sensing

Introduction

Urbanization is an undeniable global phenomenon as of 2021, more than 55% of the world's population resides in urban areas (Geekiyanage et al., 2021) and this figure is expected to rise to over 66% by 2050 (Ni et al., 2019). While urban development is crucial for socio-economic progress, it also presents significant challenges in regard to natural disasters. Moreover, a significant number of cities worldwide, namely those with populations exceeding 500,000, are at a high risk of being affected by various disasters such as floods, droughts, earthquakes, tsunamis, and wildfires (Junhua et al., 2023; Saja et al., 2021). Urban flooding was documented as the predominant natural disaster, which accounts for 44% of all disaster occurrences between 2000 and 2019 Over 2 billion people worldwide are exposed to the risk of flooding (UNDRR, 2021). Over the years, there has been an increase in the frequency of urban flood events in Sri Lanka, resulting in significant socio-economic consequences and posing challenges to countless lives. Urban floods caused the most property damages, with a numerical value of 243,655, between the years 1965 and 2019 (Abeysinghe et al., 2021). According to the World Bank, approximately 50% of Sri Lanka's population is residing in areas that are flood vulnerable, while the economic damage from flooding is estimated at about 1% of the country's GDP yearly (Walsh & Hallegatte, 2019). Colombo, Gampaha, Kalutara, and Rathnapura are districts in Sri Lanka that have seen significant urban flooding. This flooding has been exacerbated by the increased rainfall brought on by the activation of the South-West monsoon (Gunathilaka & Harshana, 2023). The rapid process of urbanization, coupled with the influence of changed precipitation patterns resulting from climate change, are factors that contribute to the escalating occurrence and severity of floods (Xu et al., 2024). The urban population of Sri Lanka is expected to rise to 60% by 2030, up from 14% in 2010 (SerasinghePathiranage et al., 2018). The rapid growth of cities into flood-prone areas without sufficient planning and infrastructure exacerbates the impact of floods. This leads to the formation of informal settlements in vulnerable sites, increasing the risk to lives and property during flood occurrences.

Although there are technology-based solutions available for enhancing disaster awareness and management, they are not widely utilized within Sri Lankan communities. Jayasinghe et al. 2023 emphasize the pressing problem of inadequate awareness and the absence of official early flood alert systems in the country. This gap leads to limited participation from the community in disaster management, which reduces the level of preparedness and resilience of vulnerable populations in the face of disasters. Recent technological breakthroughs provide communities with the opportunity to share early crisis warnings throughout their networks. Mobile applications and crowdsourcing platforms are being recognized as useful means to improve community involvement (Alhaffar et al., 2023; Franco et al., 2019; Leventhal et al., 2024). Ushahidi, a platform that originated in Kenya, enables users to promptly submit and map disaster information, leading to a substantial enhancement in situational awareness and response activities (Krishna et al., 2020). Furthermore, there is a noticeable shift from conventional relief-focused strategies to more progressive methods that highlight Disaster Risk Reduction (DRR) and Community-Based Solutions (CBS). The trend towards more decentralization and participation is facilitated by the use of advanced technological tools like GIS mapping, artificial intelligence (AI), and the Internet of Things (IoT). These tools improve the efficiency of community-based initiatives. These technologies enable the collection and distribution of data in real-time, allowing communities to actively engage in disaster preparedness and response operations (Kaur, 2024; Roy et al., 2023).

To fill this gap, the study develops a platform integrating a mobile application based on crowdsourcing with a web application. The platform aims in promoting inclusivity in disaster management and response by including the community and utilizing remote sensing technologies. A flood vulnerability assessment model has been developed by utilizing 30 years of historical flood data and nine conditioning elements, such as topographic features, weather-related variables, hydrological networks, land cover, and soil type etc. The smartphone application enables the instantaneous gathering of data from persons residing in flood-prone regions, enabling them to report flood levels, impacted areas, and other vital information. The crowdsourced data is subjected to verification using machine learning model to assure its accuracy. After being confirmed, the information is displayed on a web application, which serves as an essential communication tool for both the community and disaster response authorities. The methodology encompasses the formulation of a vulnerability assessment model, the construction of a mobile application including crowdsourcing methodologies, and the execution of trial workshops to involve the community and authenticate the platform with the participation of pertinent authorities. Mobilization techniques are suggested using the knowledge gained from these community contacts. This research makes a substantial contribution to the development of resilient and proactive urban communities in Sri Lanka by placing a high priority on community engagement and leveraging advanced geo-information technology. The results illustrate the significant capacity of integrating crowdsourced data with remote sensing to improve disaster management and community resilience.

1.1.Objectives of the Study

1. To develop a web application with complementary volunteer crowdsourcing-based mobile application that enables real-time flood data collection and dissemination, enabling Participatory Risk Sensitive Urban Development (P-RSUD)
2. To create a flood vulnerability assessment model using historical flood data remote sensing technologies and Night-time light data to accurately identify and map flood-vulnerable areas

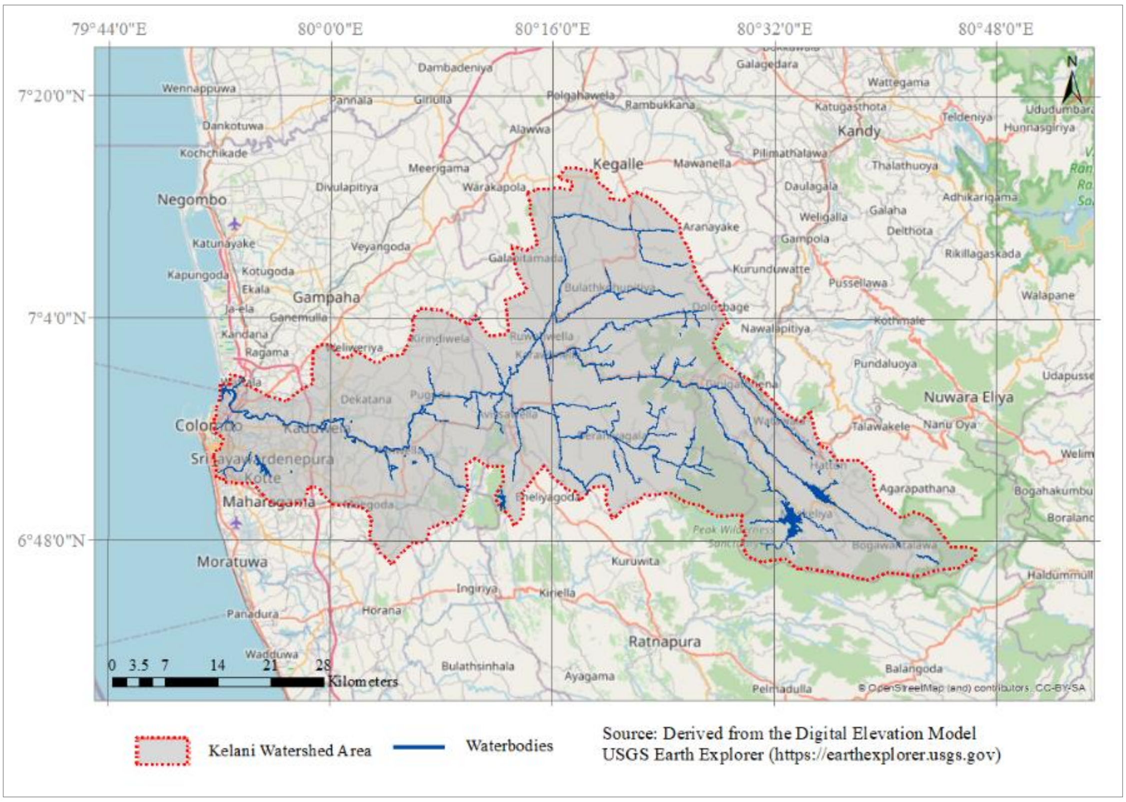
1.2.Research Question

1. How to develop a web application, integrated with a volunteer crowdsourcing-based mobile application, facilitate real-time flood data collection and support effective stakeholder engagement in Participatory Risk Sensitive Urban Development (P-RSUD)?
2. How can historical flood data, remote sensing technologies, and night-time light (NTL) data be integrated to create a comprehensive flood vulnerability assessment model?
3. How to mobilize the developed volunteer crowdsourcing application to efficiently gather reliable, real-time disaster information?

1.3.Study Area

The Kelaniya watershed area has been selected as the case study for this study considering its significant relevance to urban flooding in Sri Lanka. The study area covers approximately an area of 2,298.9 km^2 and is subjected to rapid urban growth and frequent flooding. The Kelani River, across this watershed basin, undergoes annual flooding, mostly during May, and occasionally in February and November, with water levels rising to an average elevation of 3-

4 meters near the two main gauging stations, Nagalagamweediya and Hanwella. The Hanwella station has been identified as the location with the highest risk of flooding in the basin. Over the previous decade, water levels at this station have risen by 19.7 meters, which represents a significant increase of 89.3% (Dushyantha & Ptuhina, 2020) Furthermore, the rapid urban expansion as seen in time-lapse satellite pictures, emphasizes the need to investigate this area to assess the extent of human vulnerability to urban flooding. The study area was defined using the Digital Elevation Model (DEM) generated from the Shuttle Radar Topography Mission (SRTM) data, acquired from the USGS Earth Explorer.



Source: Derived from the Digital Elevation Model, USGS Earth Explorer

Figure 1: Study Area (Kelaniya Waterhsed Basin)

1.4.Limitations

There are few limitations in the study, significantly the technological and logistical limitations. The mobile and web applications were developed in open-source software and platforms that are non-paid, hence with very limited capabilities and scalability. Another challenge is data accuracy and quality issues innate in any crowdsourced data. This can be partially allayed by the development of a machine learning model to further enhance data validation. In Sri Lankan context the community engagement and participation are considerably low. This may be furthered by the different levels of digital literacy among the various communities. Furthermore, the crowdsourcing efforts are carried out inconsistently due to the developing volunteering culture in Sri Lanka itself. Factors that underline the need for further research and development in order to enable the overcoming of the above-mentioned limitations, particularly in data quality, and the diffusion of technological solutions.

Literature Review

Urban areas are increasingly vulnerable to risks stemming from natural disasters, decisive urbanization, and climate change, requiring innovative solutions for addressing these challenges. Conventional disaster management approaches, which typically involve hierarchical decision-making procedures, have faced criticism for their insufficient involvement of local communities in decision-making (Comfort & Dunn, 2023). These approaches typically emphasize hierarchical systems and regulatory frameworks that give more importance to formal institutions rather than grassroots initiatives, leading to inadequate involvement of the community (Mayer, 2019; Mohammad & Huq, 2016).

Recent research during the past decade, highlights the significance of participatory methodologies that actively engage communities in the management of urban hazards, especially in places that are prone to disasters. Singh et al. (2024) and Varsha et al. (2024) have observed an increasing inclination to incorporate modern technology, such as unmanned aerial vehicles (UAVs), Internet of Things (IoT) networks, artificial intelligence (AI), and machine learning (ML), into disaster management techniques. These technologies enable the efficient handling of vast datasets, enhance the accuracy of predictive models, and enhance the ability to make informed decisions. Although these systems are technologically sophisticated, they frequently lack direct community engagement, which is crucial for efficient urban risk management(Teo et al., 2019). The objective of the proposed research is to address this gap by creating a web application that utilizes a mobilized crowdsourcing platform to facilitate participatory risk-sensitive urban development. This strategy is in line with the current trend towards more inclusive and community-centered strategies in disaster management, as emphasized by recent studies. This research proposes an innovative approach to address the difficulties of managing urban risks caused by climate change and increased urbanization. It combines technology-driven strategies with community involvement.

The literature underscores two primary approaches to disaster management. The first approach emphasizes community involvement, whereas the second approach depends on data-driven solutions without direct community involvement. The initial strategy, commonly referred to as Community-Based catastrophe Management (CBDM), prioritizes the involvement of local communities and their expertise in the management of catastrophe risks. Nevertheless, this approach may be inadequate in addressing intricate, extensive disaster situations that necessitate advanced data analysis and real-time information (Comfort & Dunn, 2023). During the past decade the second approach, which emphasizes data-driven approaches such as remote sensing, historical event analysis, and AI-based predictive modeling, has become increasingly prominent. According to the literature survey done over two-thirds of the case studies on disaster management (20 out of 30) have focused on the implementation of innovative technology through smart technological approaches. These techniques facilitate quick data processing and identification of patterns, which are crucial for prompt and efficient disaster response. Nevertheless, they frequently exclude community input, hence restricting their pertinence and efficacy in local contexts (Paton, 2019; Raja & Thomas, 2019).

The use of crowdsourcing platforms for disaster management have been increasingly popular because they may effectively mobilize community resources and improve data integrity by utilizing collective input. Ushahidi and similar applications utilize crowdsourced data to offer immediate awareness of the situation, showcasing the potential of this method in disaster management(Raja & Thomas, 2019). Similarly, the use of mobile applications that employ accelerometers to detect seismic activity (such as MyShake) or or GPS data to monitor user locations have proven effective in improving disaster preparedness and response (Krommyda et al., 2019). However, the exploration of integrating these technologies into a cohesive platform for participatory urban risk management is still limited.

The literature highlights an increasing acknowledgment of the necessity for inclusive disaster management solutions that integrate technical innovation and community involvement. Nevertheless, there are still substantial obstacles to overcome in order to achieve this integration. An example of a significant obstacle to effective community participation is the limited digital literacy and lack of access to technology experienced by vulnerable and marginalized communities (Madhavaram et al., 2017; Zangana, 2022). Furthermore, the presence of cultural and linguistic variety can provide additional challenges when attempting to engage local populations in disaster management (Teo et al., 2019).

The literature examined demonstrates a distinct evolution in the discourse of risk-sensitive urban development, with a growing emphasis on technology, data-driven approaches, and community involvement. Prior to 2000, the main focus of talks revolved around social geography and the synchronization of urban development, with little attention given to technology innovation (Mayer, 2019). Starting from 2018, there has been a clear change towards more advanced and interrelated ideas in urban risk management. These include concepts like "feasibility," "socio-economic considerations," "stakeholders," and "preparedness." This movement reflects the increasing complexity of the field (Comfort & Dunn, 2023; Paton, 2019).

Recent research emphasizes the growing significance of technological advancements in urban risk management, with concepts such as "crowdsourcing," "cloud computing," "AI," and "gamification" gaining prominence in scholarly literature (Singh et al., 2024; Varsha et al., 2024). This trend highlights the necessity for inventive solutions that can efficiently incorporate these technologies into participatory risk management systems. The online application being proposed addresses this requirement by providing a platform that utilizes crowdsourcing and real-time data analytics to boost community involvement and enhance urban resilience.

The proposed research offers many substantial contributions to the realm of urban planning and disaster management. Firstly, it fills a significant void in the existing body of knowledge by combining community involvement with novel technology tools inside a unified platform. This technique provides a comprehensive answer to the issues of managing urban risks by combining the advantages of both classic and contemporary methodologies. Furthermore, the research emphasizes the capacity of activated crowdsourcing platforms to support participatory urban development, offering significant perspectives.

Methodology

This study employed an inductive research approach, starting with the identification of practical flood management issues in Sri Lanka and progressing through the iterative development of technology-driven solutions based on empirical data and stakeholder input. The research was structured into three primary phases (Figure 1: Research design):

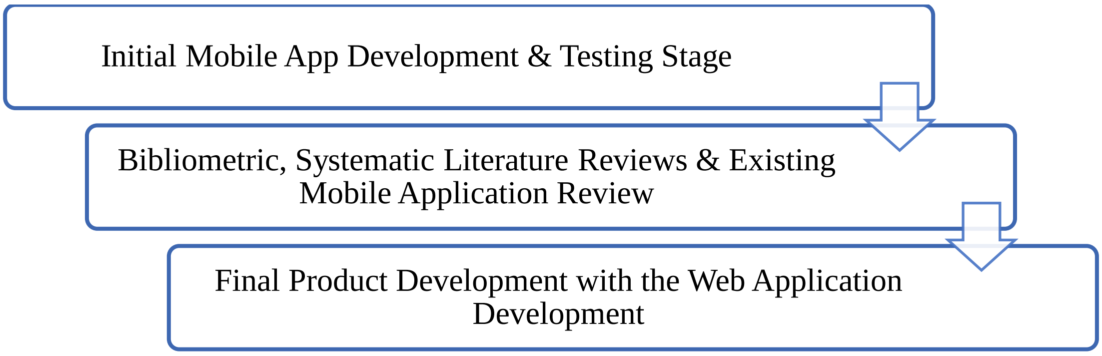


Figure 1: Research Design

I. Phase 1: Initial Mobile App Development and Testing

The first phase involved developing and testing a prototype mobile application to collect real-time flood data using crowdsourcing techniques. The app was designed using web-based, open-source platforms to facilitate cost-efficient deployment (Figure 2: Initial Mobile App Design). Thirty participants from the Kelaniya watershed basin area, representing diverse demographic backgrounds, were selected randomly to test the app's functionality and usability, significantly to test the functioning of a crowdsourcing based mobile application in Sri Lankan context.

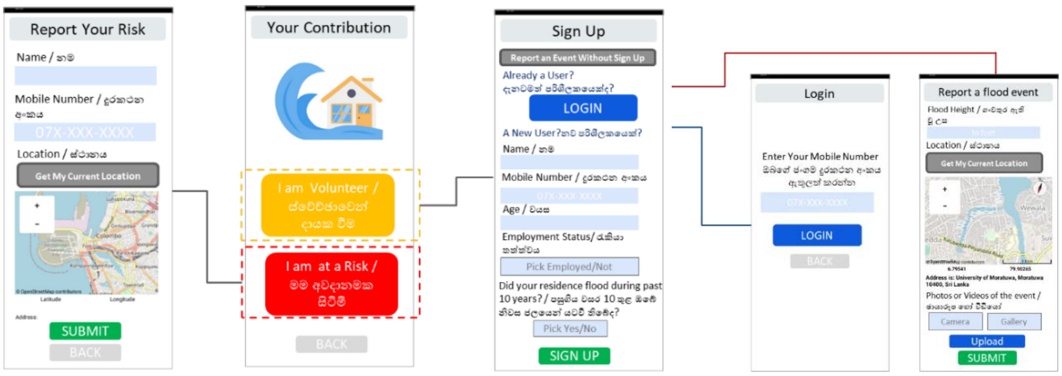


Figure 2: Initially Developed Mobile App

Participants engaged in practical trials to evaluate the app's performance, including tasks related to data input, navigation, and overall user experience. Feedback was collected via a structured questionnaire, focusing on usability, willingness to contribute to crowdsourcing, and volunteer activities. The feedback identified key areas for improvement, such as user interface complexity and the need for an emergency contact feature. Based on this input, the app underwent iterative refinement to align with technical and user engagement requirements (Figure 3: Photographs of Initial Testing Session).

Figure 3: Photographs of the Initial Testing Session

II. Phase 2: Bibliometric, Systematic Literature Review, and Existing Mobile Application Review

A comprehensive bibliometric study was conducted using academic databases like Web of Science and Google Scholar to understand trends in risk-sensitive urban development. A total of 525 articles were retrieved using keywords like "Risk Sensitive Urban Development." A systematic review followed, using PRISMA guidelines to refine the dataset to 56 relevant articles that provided the basis for the study's conceptual framework (Figure 4: PRISMA Flow Diagram).

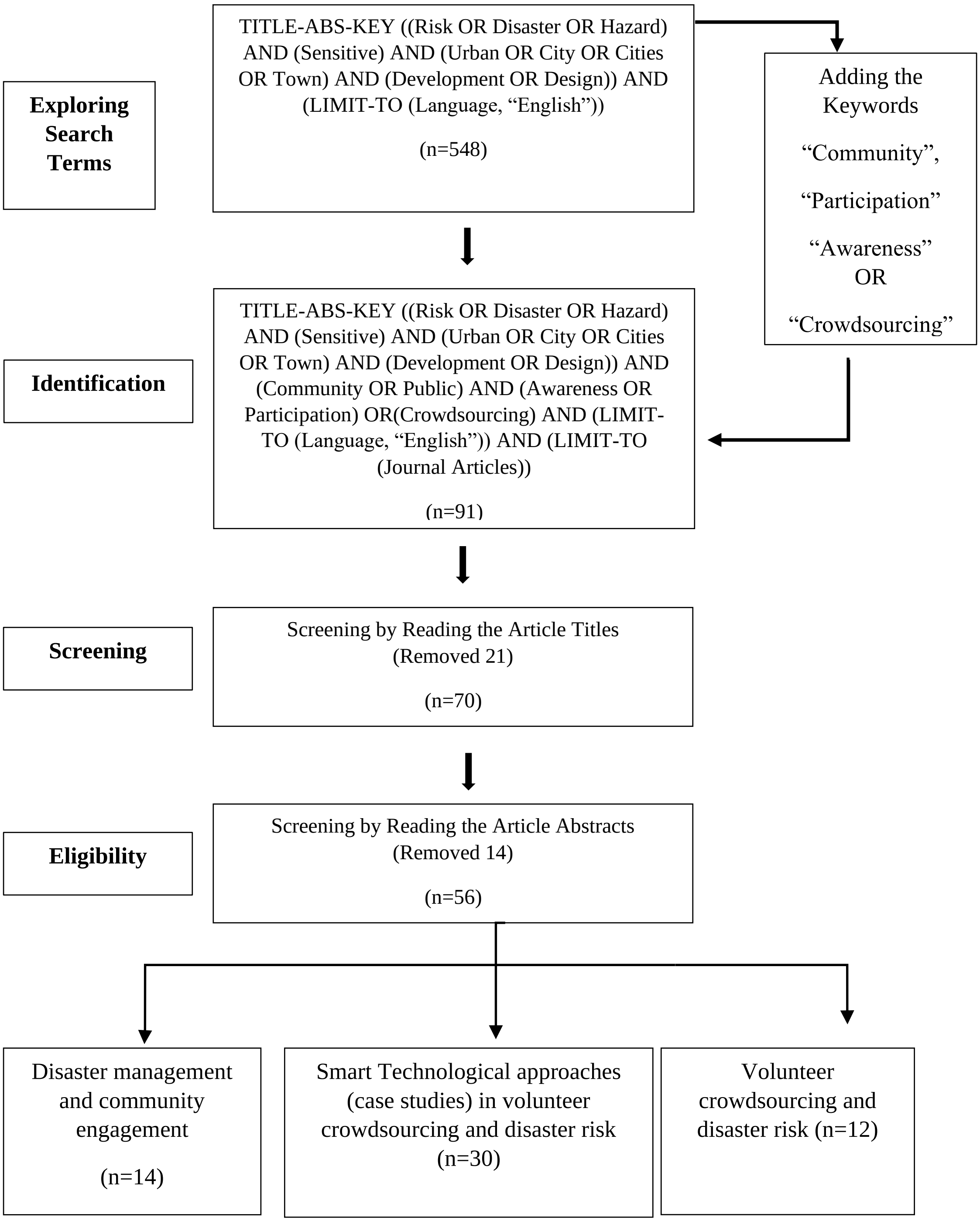


Figure 4: The PRISMA Flow Diagram (Adapted From Pérez-Gañán et al., 2023; Kankanamge et al., 2019)

An additional review of existing mobile applications related to disaster management was performed, focusing on those available on the Google Play Store due to data extraction constraints. Seventy-eight apps were identified and categorized based on their type and functionality, including crowdsourcing disaster management apps, general weather apps, and flood-specific apps. The review highlighted successful features and gaps in existing disaster management apps, such as the integration of sensors (e.g., accelerometers in MyShake) and GPS data for real-time monitoring, which were adopted for the subsequent development phases (Habib et al., 2023; Krommyda M et al., 2019)

III. Phase 3: Final Product Development and Web Application Integration

The final phase involved refining the mobile app and developing an integrated web application to assess urban flood vulnerability and human exposure. The mobile app was enhanced based on user feedback and insights from the literature, focusing on optimizing user experience, ensuring data accuracy, and incorporating current technologies in disaster management. Key features added to the refined app include multilingual support, a simplified user interface, data validation mechanisms, and emergency contact functions to enhance community engagement and participation.

The web application, developed using Google Earth Engine (GEE) and Java programming language, is designed to monitor real-time human exposure to urban flooding (Figure 5: Web Application Development Methodology). The application integrates various geospatial datasets, such as night-time light (NTL) data and satellite images, to dynamically map flood vulnerability in the Kelaniya watershed area. Two key dynamic variables critical to assessing flood vulnerability were identified: precipitation and past flood occurrences. These variables are known to change rapidly over time and significantly impact the flood risk profile of urban areas. Real-time precipitation data is vital in predicting flood risk, as the magnitude and duration of rainfall are directly correlated with flooding events while Accurate historical flood data is essential for predicting future flood risks and understanding flood patterns (Khosravi et al., 2018; Manandhar et al., 2010).

The innovative aspect of this approach lies in the utilization of crowdsourced data for these two dynamic variables. The mobile app enables users to report real-time observations related to local precipitation levels and any recent flood events. This data is then continuously fed into the web application, allowing for near-instantaneous updates to the flood vulnerability models. By incorporating real-time crowdsourced data, the web application provides a more accurate and up-to-date representation of flood risk.

While static variables, such as topography (slope, elevation, and curvature), land cover, hydrological network characteristics, and soil type are already integrated into the GEE platform, these datasets do not require frequent updates as they represent relatively stable, long-term conditions(Rahmati et al., 2016; Tehrany et al., 2014). The static datasets, sourced from reliable repositories like the USGS Earth Explorer and local meteorological and survey departments, form the foundational layers of the web application's flood vulnerability assessment framework. By combining these stable datasets with dynamic, real-time data on precipitation and past flood occurrences sourced directly from community members, the web application offers a more comprehensive and current analysis of flood vulnerability. This integrated approach also facilitates stakeholder collaboration in validating data accuracy, enhancing trust in the platform's findings, and encouraging ongoing community engagement.

By incorporating these real-time, crowdsourced inputs, the web application dynamically adjusts its analysis to reflect the latest conditions, thereby offering a robust tool for disaster preparedness and response. The integration of these data points ensures that urban planners and disaster management authorities have access to the most current information, enabling them to make informed decisions and take proactive measures to mitigate flood risks. This model demonstrates how leveraging community-sourced data can bridge gaps in traditional disaster management frameworks and enhance the resilience of urban areas to climate-related hazards.

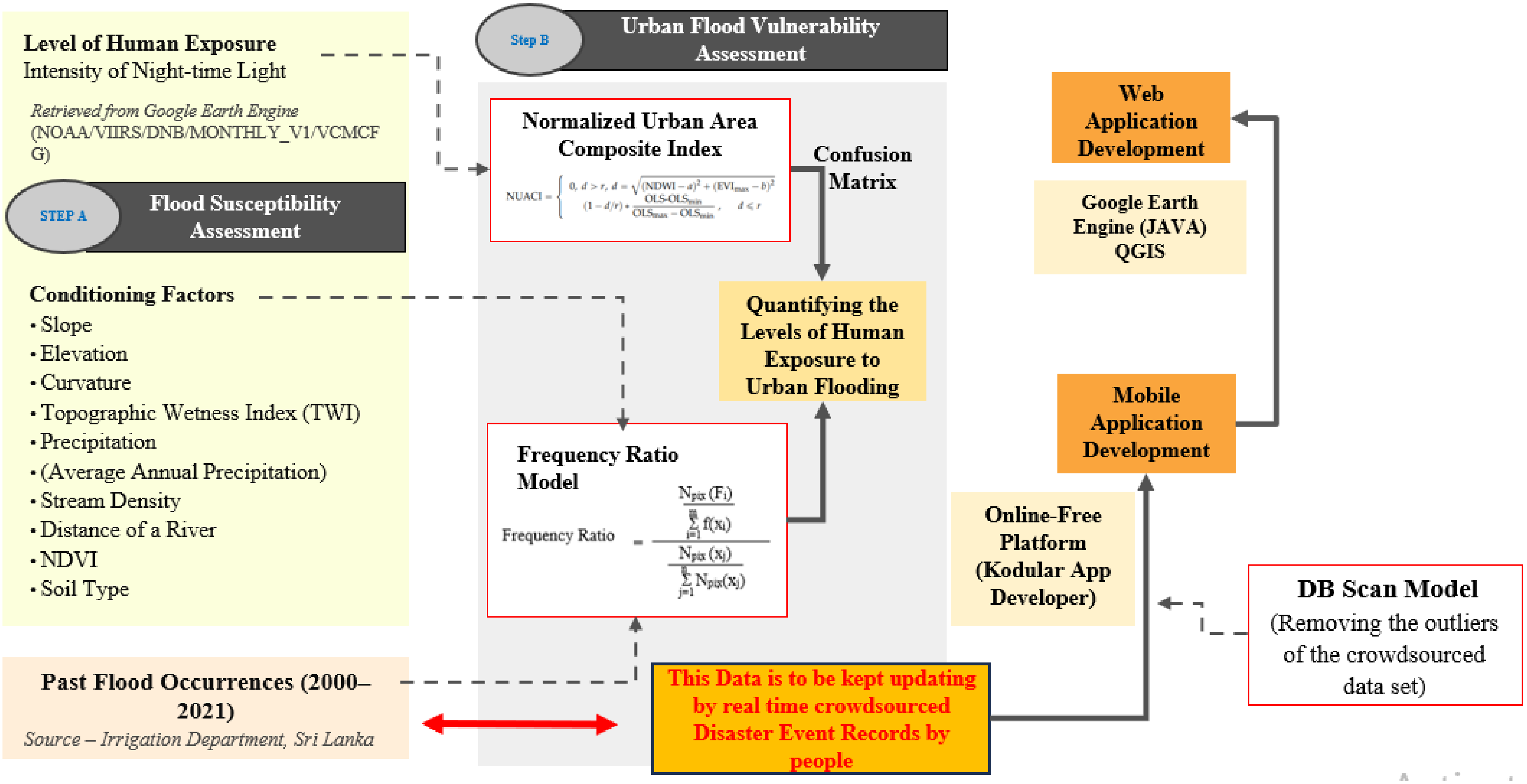


Figure 5: Web Application Development Methodology

Results and Discussion

The first stage of the study focused on the development and initial testing of a mobile application designed to collect real-time flood data using a crowdsourcing approach. The app was tested by a diverse sample of 30 individuals from the Kelaniya watershed basin region, including three-wheeler drivers who are highly mobile and familiar with the local flood-prone areas. This sample represented a broad range of demographics, including various age groups, income levels, and educational backgrounds, to ensure a comprehensive assessment of the app's usability and functionality (Figure 6: Age Groups of the Respondents).

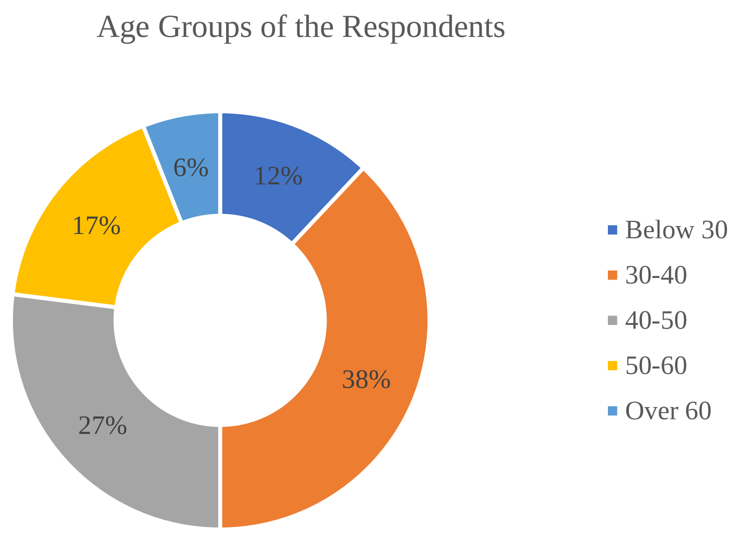


Figure 6: Age Groups of the Respondents

The initial feedback from the testing phase revealed that 90% of respondents highlighted the absence of an effective early warning system for floods in their locality. Many respondents relied on traditional indicators, such as observing rising river levels or continuous monsoon rains, to gauge flood risks. This lack of formal warning systems underscored the need for a digital platform that could provide timely and accurate flood alerts.

During the testing period, participants were asked to use the mobile app to report flood occurrences and precipitation data over ten days of monsoonal rainfall in September 2023. The results showed that users found the app's primary functions—data input, navigation, and reporting—to be generally effective. However, some concerns were raised regarding the app's complexity and the need for additional features, such as emergency contact options and real-time communication channels with local communities.

Based on the feedback received from initial testing, finding from the systematic review of literature and existing mobile app review several key refinements were made to enhance the usability and functionality of the mobile application, transforming it from a basic crowdsourcing tool into a comprehensive platform for flood data collection and community engagement.

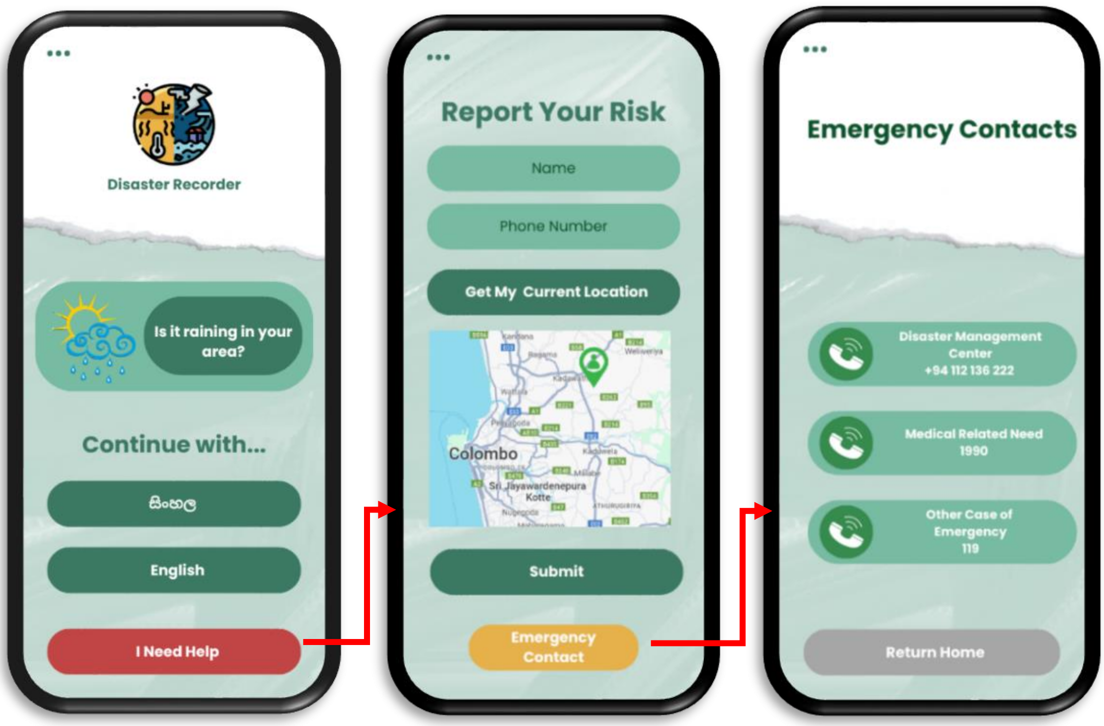


Figure 7: Welcome screen, reporting risk & emergency contact

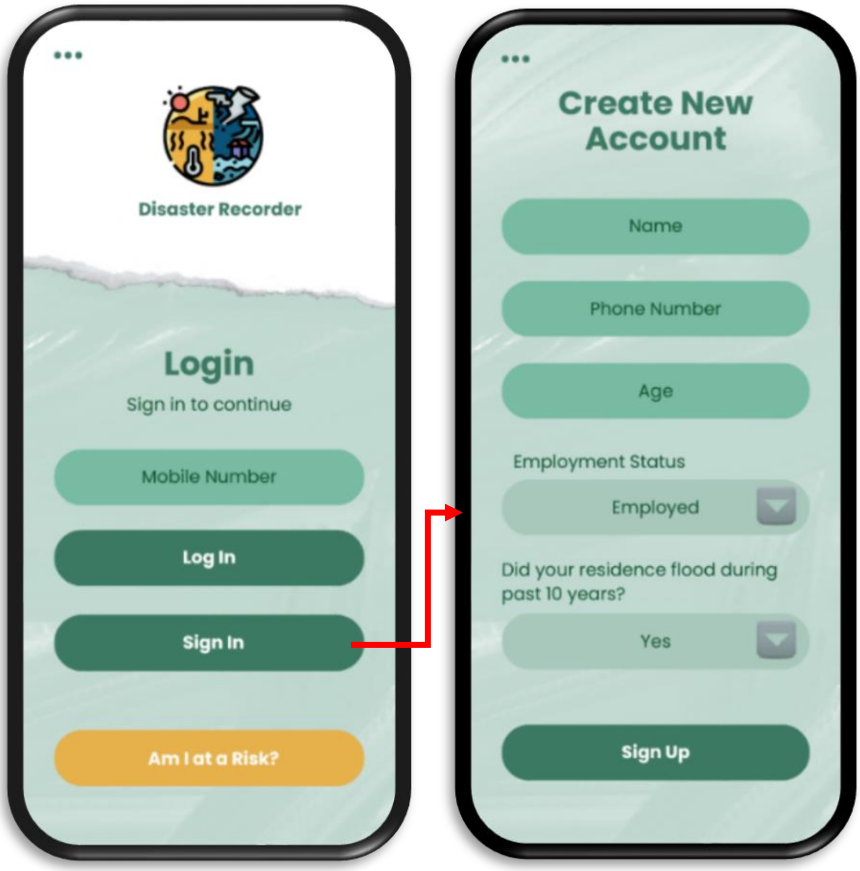


Figure 8: Login & Sign In Screen

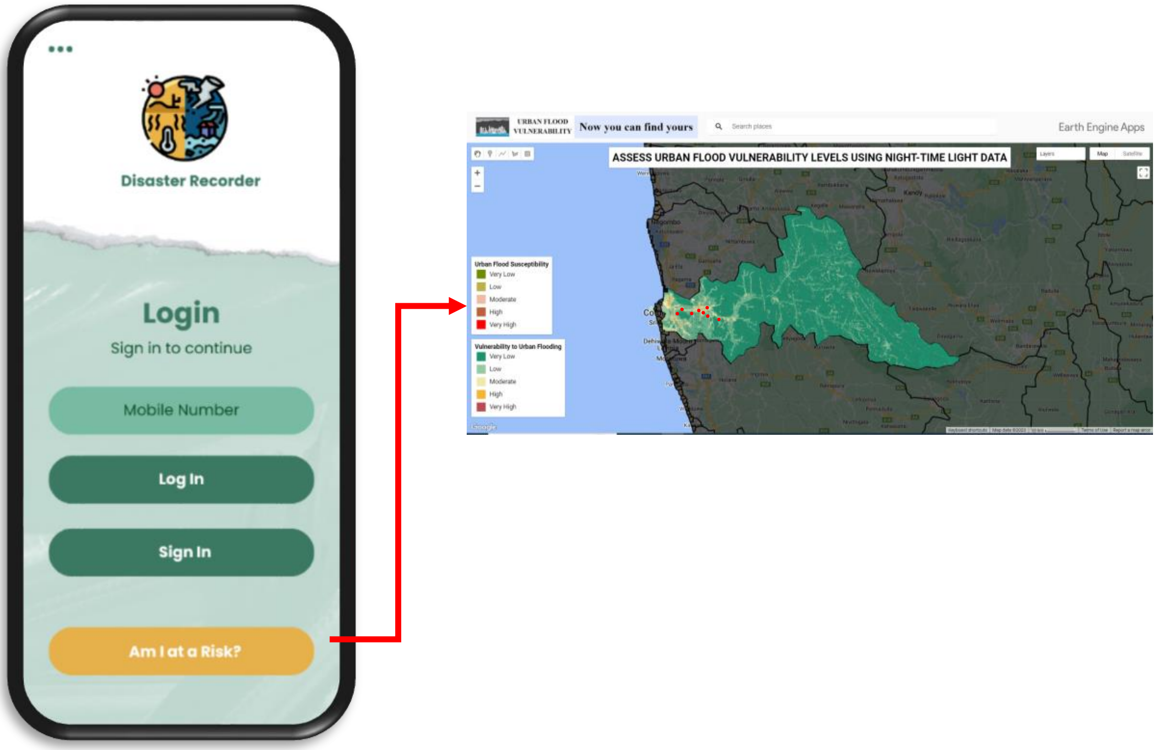


Figure 9: Am I at a risk option linked to Web Application

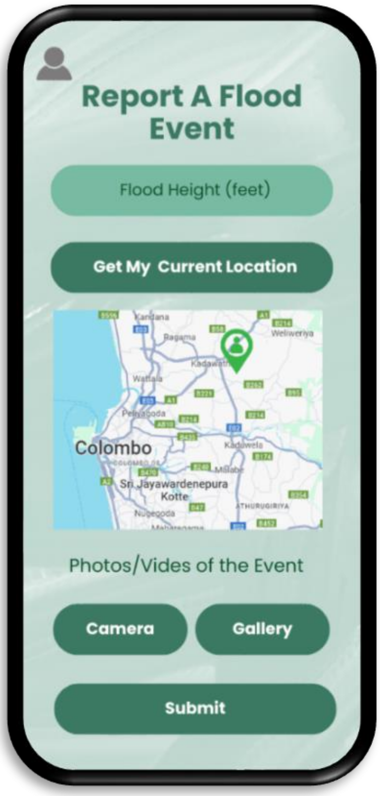


Figure 10: Reporting a Flood Event

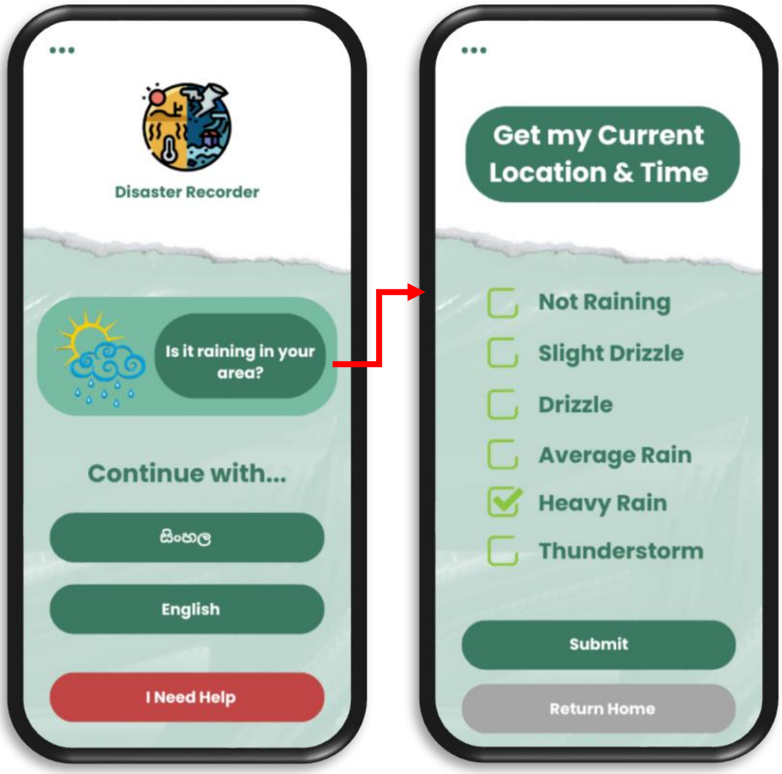


Figure 11: Precipitation Data Crowdsourcing Function

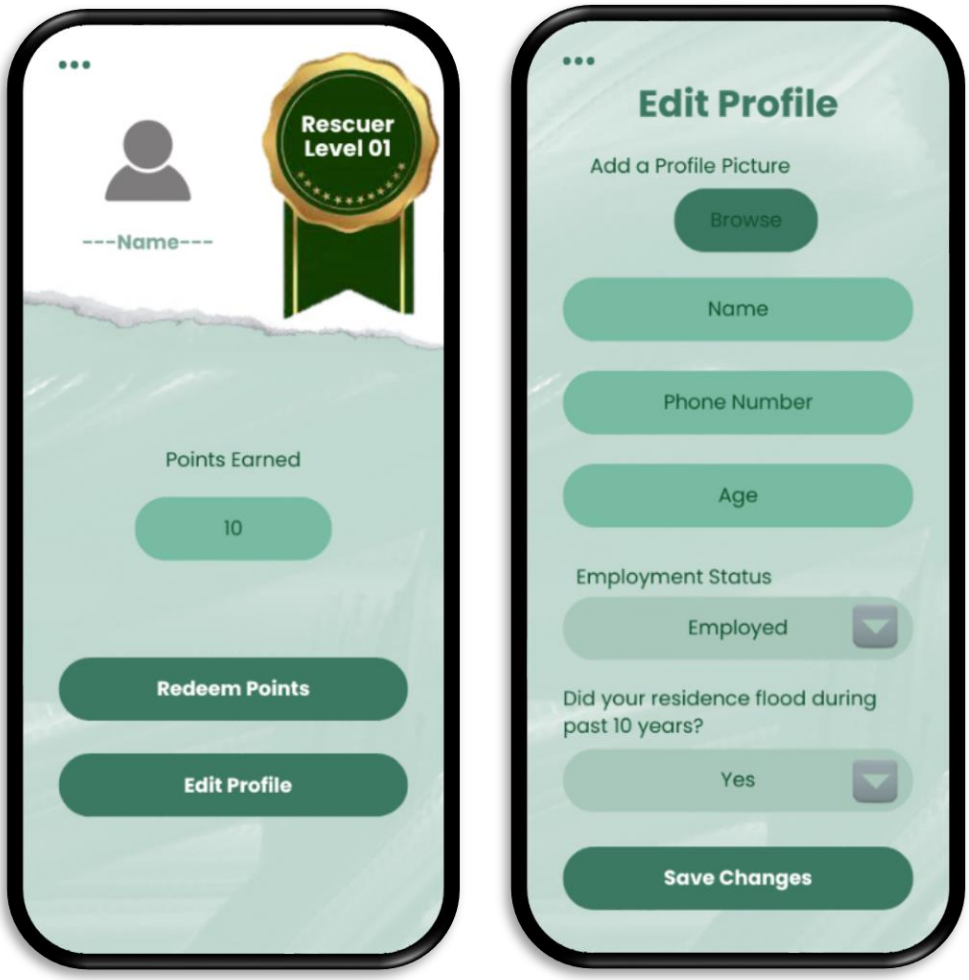


Figure 12: User Profile and Edit Profile and Incentivization

One of the primary improvements was the introduction of **multilingual support**, enabling the app to function in both Sinhala and English. This adjustment was crucial in addressing the digital divide and enhancing accessibility for a wider audience, particularly for users who may be less proficient in English or possess limited digital literacy (Figure 7: Welcome screen, reporting risk & emergency contact). By offering language options, the app's usability was expanded to accommodate the diverse linguistic needs of the community, thus ensuring broader participation.

To further enhance the user experience, the app underwent a redesign of its user interface to make it more intuitive and user-friendly. This refinement involved simplifying the navigation process and ensuring that critical functions, such as flood reporting and emergency contacts, were easily accessible. These changes significantly improved user engagement by reducing complexity and minimizing potential barriers to participation, allowing even less tech-savvy users to interact with the app seamlessly.

Additionally, the app incorporated **data validation mechanisms** using a machine learning model, specifically the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm. This model was integrated to enhance data accuracy by identifying and filtering out outliers or erroneous data entries. By ensuring that only reliable and valid data is used for analysis, the app improved the credibility of the crowdsourced information and the effectiveness of flood risk assessments.

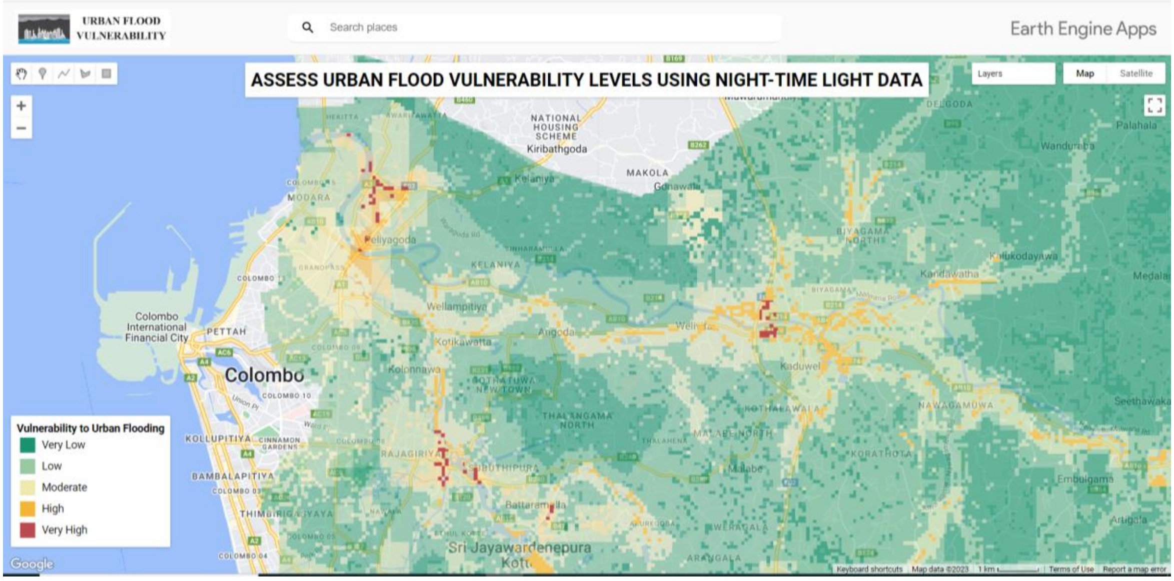
The inclusion of an **emergency contact feature** was another critical enhancement, allowing users to seek immediate help during flood situations (Figure 7: Welcome screen, reporting risk & emergency contact). This feature was developed in response to feedback from participants who had experienced direct impacts of flooding and identified it as a crucial addition. By enabling real-time communication with emergency services, the app's practical utility during disasters was significantly enhanced, making it a more valuable tool for users in crisis situations.

To sustain user engagement over the long term, an **incentivization mechanism** was introduced (Figure 12: User Profile and Edit Profile and Incentivization), where users earn points for providing flood-related data. Collaborations with private enterprises were established to offer tangible rewards, such as discounts or vouchers, which helped to motivate continuous participation. This points-based system not only encourages users to contribute data regularly but also encourage the sense of community involvement and ownership over the data collection process.

The web application, developed using Google Earth Engine (GEE) and Java programming language, was designed to dynamically assess urban flood vulnerability and human exposure by integrating both static and dynamic data layers. The web app is available at, https://ee-researchnuwani.projects.earthengine.app/view/floodexposure. The core functionality of the web application revolves around the integration of static geospatial data—such as slope, elevation, land cover, and hydrological network characteristics—with dynamic, crowdsourced data on precipitation and past flood occurrences.

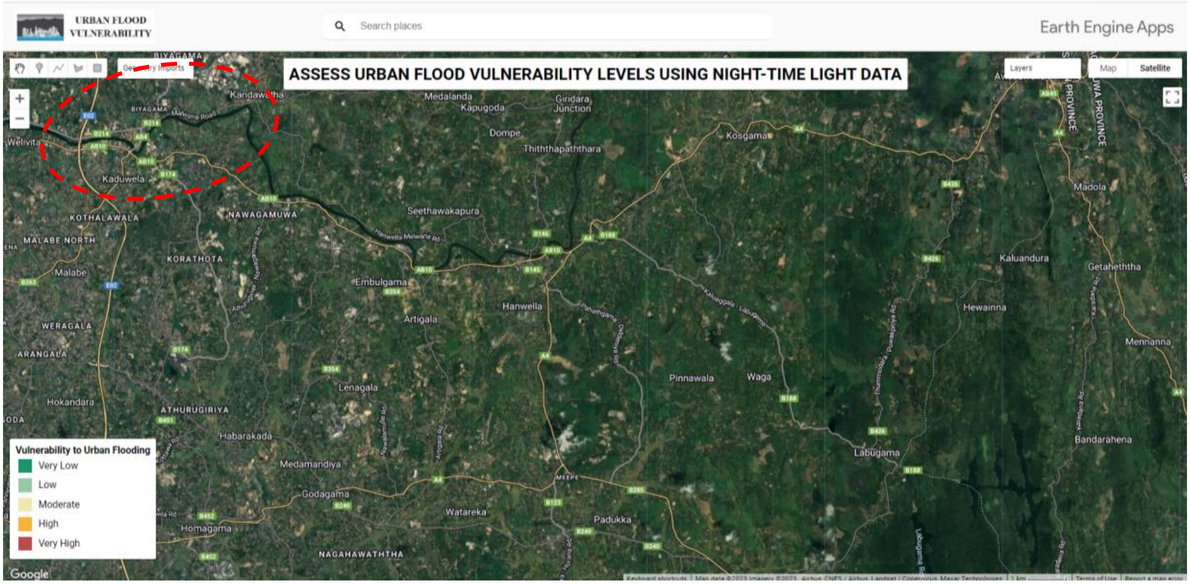
A significant innovation in the web application is its use of crowdsourced data to update two critical variables in real-time: precipitation levels and recent flood occurrences. These two factors are highly dynamic and can change rapidly, significantly influencing flood vulnerability assessments ((Khosravi et al., 2018; Manandhar et al., 2010). The mobile app collects this data from users, which is then transmitted to the web application, allowing for continuous updates and more accurate flood risk modeling. While static datasets such as topographic features and soil types provide foundational information and do not require frequent updates, the integration of real-time crowdsourced data on precipitation and flood occurrences allows for a current and precise assessment of flood risks. This capability is particularly crucial in urban areas where flood risk can change rapidly due to sudden weather events or changes in land use patterns.

The web application successfully produced dynamic flood vulnerability maps for the Kelaniya watershed area by overlaying static conditioning factors with real-time crowdsourced data. The results provided several key insights into the nature of flood risks in this region. Firstly, the application identified three highly vulnerable urban hotspots: Kaduwela, Kelaniya-Peliyagoda, and Kolonnawa-Koswatta corridors (Map 1: Areas with Very High Urban Flood Vulnerability). These areas are characterized by a high concentration of human activities, significant infrastructure development, and frequent flood events. For instance, Kaduwela, which has experienced rapid urbanization and infrastructure development, is highly susceptible to flooding due to increased runoff and reduced natural drainage (Ranaweera & Ratnayake, 2017).



(Map 1: Areas with Very High Urban Flood Vulnerability)

The study further demonstrated a clear link between urban growth and increased flood risk. Areas with significant infrastructure development, such as the Kaduwela-Malabe corridor and the Kolonnawa-Koswatta economic centers, were shown to have higher vulnerability to urban flooding. This finding aligns with previous studies that have highlighted the impact of urban sprawl and impervious surfaces on flood risk (Pradhan & Youssef, 2010; Tehrany et al., 2014). Moreover, the web application enabled a more nuanced understanding of human exposure to flooding by integrating night-time light (NTL) data. For example, areas like Hanwella were identified as having varying levels of flood vulnerability depending on the concentration of human activities (Map 2: Human Exposure to Urban Flooding - Hanwella Area). This finding emphasizes the importance of considering both flood susceptibility and human activity levels when assessing flood risk.



Map 2: Human Exposure to Urban Flooding - Hanwella Area

By continuously updating precipitation and past flood occurrence data, the web application can dynamically adjust flood risk assessments to reflect current conditions. This capability ensures that the information provided to urban planners, disaster management authorities, and the public is always up-to-date, facilitating timely and effective responses to changing flood risks.

The integration of crowdsourced data into flood risk assessment models represents a significant advancement in disaster management strategies. The study demonstrates that real-time, community-sourced data can effectively fill gaps in traditional flood management approaches, which often rely on static datasets and delayed information. By leveraging local knowledge and real-time observations, the web application offers a more comprehensive and adaptable tool for urban flood risk management. However, challenges remain in ensuring data quality and encouraging sustained user engagement. While the DBSCAN model effectively filtered out anomalous data points, maintaining data accuracy requires continuous monitoring and validation. Furthermore, the incentivization mechanisms implemented in the mobile app—such as rewards and gamification—proved effective in encouraging user participation, but long-term engagement may require additional strategies, such as community outreach and education programs.

The findings of this study have several important implications for urban flood risk management. Firstly, the real-time integration of dynamic data provides urban planners and disaster management authorities with timely and accurate information, enabling more informed decision-making and proactive flood mitigation measures. Secondly, by involving local communities in data collection, the crowdsourcing approach empowers residents to take an active role in disaster preparedness and response. This participatory approach fosters greater trust and collaboration between the public and authorities.

Furthermore, the design of the web application allows for easy adaptation to different geographic locations with minimal input data layers, making it a scalable solution for other urban areas facing similar flood risks. Lastly, the study highlights the potential of integrating advanced technologies, such as machine learning and artificial intelligence, to further enhance the accuracy and effectiveness of flood risk assessment tools. Future research could explore the use of additional data sources, such as social media feeds and IoT sensors, to complement crowdsourced data and provide an even richer dataset for analysis.

Conclusion and Recommendation

This study marks a significant progress in utilizing crowdsourced data along with flood vulnerability analysis developing a platform with a mobile and a web application. By utilizing 30 years of past flood data and Sentinel-2 images of the identified flood occurrences, along with up-to-date crowdsourced data, the platform offers a comprehensive tool for monitoring and evaluating the level of human exposure in flood susceptible areas. The mobile application effectively involves in crowdsourcing disaster data and, disseminating disaster alerts, while the web application provides robust visualization and analytical features, allowing users to gain a deeper understanding of and respond more effectively to flood hazards.

The platform highlights the capacity of crowdsourcing as an efficient approach for collecting specific, real-time information. By integrating historical data, this approach greatly improves the precision and significance of flood vulnerability evaluations. By integrating machine learning techniques, such as DB SCAN, to verify crowdsourced data, the reliability of the acquired information is significantly enhanced. In addition, the mobile app's inclusive design caters to a diverse user base, including individuals with less sophisticated devices. This approach helps bridge the digital gap and promotes wider engagement.

However, the study highlights a significant obstacle: the need to continually motivate people to actively participate on the site. Although the program is technically strong and provides significant advantages, enhancing long-term user engagement is a crucial aspect that needs to be further strengthen. The results indicate that while a significant number of users value the effort, there are individuals who do not possess the drive to consistently provide data. This is frequently attributed to the presence of pre-existing local knowledge or a strong inclination towards self-reliance in managing flood hazards.

In order to address this obstacle, the study suggests the implementation of focused mobilization techniques. These could involve forming alliances with local government and private companies to provide concrete incentives and acknowledgment for individuals who actively contribute, thus motivating their engagement. Furthermore, increasing community awareness regarding the platform's wider societal advantages, such as its ability to enhance early warning systems and safeguard vulnerable populations, could serve as an additional incentive for active participation. To achieve continuous mobilization, it is crucial to implement community-based outreach activities, incorporate educational content within the app, and ensure that the platform stays user-friendly and responsive to criticism. Ultimately, the effectiveness of this platform in participatory flood risk management is on its ability to effectively mobilize and retain user engagement. By tackling these difficulties, the platform may fully realize its promise as a crucial instrument for improving disaster resilience and promoting a proactive culture of flood risk management.

References

Abeysinghe, A. A. S. E., Bandara, C. S., Siriwardana, C. S. A., Haigh, R., Amarathunga, D., & Dissanayake, P. B. R. (2021). *Incorporation of Disaster Risk Reduction Mechanisms for Flood Hazards into the Greensl® Rating System for Built Environment in Sri Lanka* (pp. 573–587). https://doi.org/10.1007/978-981-15-7222-7_47

Alhaffar, M. B. A., Joury, E., & Eriksson, A. (2023). Community engagement and crowdsourcing for effective disaster response and rescue operations during the earthquake in Syria. *International Journal of Disaster Risk Reduction*, *98*, 104096. https://doi.org/10.1016/j.ijdrr.2023.104096

Comfort, L. K., & Dunn, M. W. (2023). Building Community Resilience to Disaster Risk: A Sociotechnical Approach. *Hazardous Seas: A Sociotechnical Framework for Early Tsunami Detection and Warning*, 1.

Dushyantha, C., & Ptuhina, I. (2020). Flood risk assessment of river "Kelani Ganga" exceeding its threshold water level. *E3S Web of Conferences*, *157*. https://doi.org/10.1051/e3sconf/202015702006

Franco, Z., González, J. J., Canós, J. H., Nguyen, Q. N., Frisiello, A., & Rossi, C. (2019). *Mobile App for Crowdsourcing in DRR The Design of a Mobile Application for Crowdsourcing in Disaster Risk Reduction*.

Geekiyanage, D., Fernando, T., & Keraminiyage, K. (2021). Mapping participatory methods in the urban development process: A systematic review and case-based evidence analysis. In *Sustainability (Switzerland)* (Vol. 13, Issue 16). MDPI. https://doi.org/10.3390/su13168992

Gunathilaka, M. D. K. L., & Harshana, W. T. S. (2023). *Climate Change Effect on the Urbanization: Intensified Rainfall and Flood Susceptibility in Sri Lanka* (pp. 49–151). https://doi.org/10.1007/978-3-031-19059-9_3

Habib, E. H., Miles, B., Skilton, L., ElSaadani, M., Osland, A. C., Willis, E., Miller, R., Do, T., & Barnes, S. R. (2023). Anchoring tools to communities: insights into perceptions of flood informational tools from a flood-prone community in Louisiana, USA. *Frontiers in Water*, *5*. https://doi.org/10.3389/frwa.2023.1087076

Jayasinghe, S. N., Madurasinghe, M. A. V. N., Weerahannedige, D. C., Weerakoon, D. R. Y. Y. B., Dassanayake, S. M., Gunawardana, A., Dissanayake, D. M. P. V., & Prasanna, R. (2023). Flood risk assessment in the vulnerable economic zones: a case study in the Kelani river basin. *6th International Conference on Business Research (ICBR 2023)*, 1–16. https://doi.org/10.31705/ICBR.2023.9

Junhua, L., Spatolisano, M., Wilmoth, J., Hanif, N., Schweinfest, S., Zhu, J., Pierra, N., Mukherjee, S., Koudenoukpo, J., & Spiegel, S. (2023). *Towards Sustainable Development For All Department of Economic and Social Affairs*. https://www.un.org/en/desa/highlights-report-2022-2023.

Kankanamge, N., Yigitcanlar, T., Goonetilleke, A., & Kamruzzaman, M. (2019). Can volunteer crowdsourcing reduce disaster risk? A systematic review of the literature. In *International Journal of Disaster Risk Reduction* (Vol. 35). Elsevier Ltd. https://doi.org/10.1016/j.ijdrr.2019.101097

Kaur, K. (2024). *Role of Community in Management of Disaster*. www.ijfmr.com

Khosravi, K., Pham, B. T., Chapi, K., Shirzadi, A., Shahabi, H., Revhaug, I., Prakash, I., & Tien Bui, D. (2018). A comparative assessment of decision trees algorithms for flash flood susceptibility modeling at Haraz watershed, northern Iran. *Science of the Total Environment*, *627*, 744–755. https://doi.org/10.1016/j.scitotenv.2018.01.266

Krishna, A. V., Ramasubbareddy, S., & Govinda, K. (2020). *A Unified Platform for Crisis Mapping Using Web Enabled Crowdsourcing Powered by Knowledge Management* (pp. 195–205). https://doi.org/10.1007/978-981-15-0633-8_19

Krommyda M, Tsiakos V, Rigos A, Tsertou A, Amditis A, Georgiou H, Jonoski A, Popescu I, & Assumpcao T. (2019). *Innovative sensors for crowdsourced river measurements collection*.

Leventhal, E. L., Chiu, D. T., Nathanson, L. A., & Horng, S. (2024). Mobile Disaster Applications. In *Ciottone's Disaster Medicine* (pp. 307–309). Elsevier. https://doi.org/10.1016/B978-0-323-80932-0.00046-X

Madhavaram, S., Matos, V., Blake, B. A., & Appan, R. (2017). ICTs in the context of disaster management, stakeholders, and implications. *Journal of Information, Communication and Ethics in Society*, *15*(01), 32–52. https://doi.org/10.1108/JICES-11-2015-0038

Manandhar, B., Krishna Balla, M., Awal, R., Man Pradhan, B., & Manandhar Sc, B. M. (2010). *11 th ESRI India User Conference*. https://doi.org/10.13140/2.1.4416.6402

Mayer, B. (2019). A Review of the Literature on Community Resilience and Disaster Recovery. In *Current environmental health reports* (Vol. 6, Issue 3, pp. 167–173). Springer. https://doi.org/10.1007/s40572-019-00239-3

Mohammad, S., & Huq, S. (2016). COMMUNITY BASED DISASTER MANAGEMENT STRATEGY IN BANGLADESH: PRESENT STATUS, FUTURE PROSPECTS AND CHALLENGES. *European Journal of Research in Social Sciences*, *4*(2). www.ifrc.org/.../disasters/what-i

Ni, P., Kamiya, M., Shen, L., Gong, W., & Xu, H. (2019). Reviews of Global Urban Competitiveness 2017–2018 Driving Force, Agglomeration, Connectivity and the New Global City. In P. Ni, M. Kamiya, & H. Wang (Eds.), *House Prices: Changing the City World: The Global Urban Competitiveness Report (2017–2018)* (pp. 49–131). Springer Singapore. https://doi.org/10.1007/978-981-32-9111-9_2

Paton, D. (2019). Disaster risk reduction: Psychological perspectives on preparedness. *Australian Journal of Psychology*, *71*(4), 327–341. https://doi.org/10.1111/ajpy.12237

Pérez-Gañán, R., Dema Moreno, S., González Arias, R., & Cocina Díaz, V. (2023). How do women face the emergency following a disaster? A PRISMA 2020 systematic review. *Natural Hazards*, *116*(1), 51–77. https://doi.org/10.1007/s11069-022-05663-7

Pradhan, B., & Youssef, A. M. (2010). Manifestation of remote sensing data and GIS on landslide hazard analysis using spatial-based statistical models. *Arabian Journal of Geosciences*, *3*(3), 319–326. https://doi.org/10.1007/s12517-009-0089-2

Rahmati, O., Pourghasemi, H. R., & Zeinivand, H. (2016). Flood susceptibility mapping using frequency ratio and weights-of-evidence models in the Golastan Province, Iran. *Geocarto International*, *31*(1), 42–70. https://doi.org/10.1080/10106049.2015.1041559

Raja, G., & Thomas, A. (2019). SAFER: Crowdsourcing Based Disaster Monitoring System Using Software Defined Fog Computing. *Mobile Networks and Applications*, *24*(5), 1414–1424. https://doi.org/10.1007/s11036-019-01267-x

Ranaweera, D. K. D. A., & Ratnayake, R. M. K. (2017). Urban Landuse Changes in Sri Lanka with Special Reference to Kaduwela Town from 1975 to 2016. *International Journal of Innovative Research and Development*, *6*(6). https://doi.org/10.24940/ijird/2017/v6/i6/jun17014

Roy, T., Nasreen, M., Hasan, Md. K., & Sony, M. M. A. A. M. (2023). Community Priorities in Disaster Risk Reduction Interventions. In *Coastal Disaster Risk Management in Bangladesh* (pp. 335–355). Routledge. https://doi.org/10.4324/9781003253495-21

Saja, A. M. A., Teo, M., Goonetilleke, A., & Ziyath, A. M. (2021). Assessing social resilience in disaster management. *International Journal of Disaster Risk Reduction*, *52*, 101957. https://doi.org/https://doi.org/10.1016/j.ijdrr.2020.101957

SerasinghePathiranage, I. S., Kantakumar, L. N., & Sundaramoorthy, S. (2018). Remote Sensing Data and SLEUTH Urban Growth Model: As Decision Support Tools for Urban Planning. *Chinese Geographical Science*, *28*(2), 274–286. https://doi.org/10.1007/s11769-018-0946-6

Singh, R., Manoharan, G., & Singh, S. (2024). *Strategic Deployment of AI and Drones Enhancing Disaster Management in Natural Disasters* (pp. 172–203). https://doi.org/10.4018/979-8-3693-3896-4.ch009

Tehrany, M. S., Pradhan, B., & Jebur, M. N. (2014). Flood susceptibility mapping using a novel ensemble weights-of-evidence and support vector machine models in GIS. *Journal of Hydrology*, *512*, 332–343. https://doi.org/10.1016/j.jhydrol.2014.03.008

Teo, M., Goonetilleke, A., Deilami, K., Ahankoob, A., & Lawie, M. (2019). Engaging residents from different ethnic and language backgrounds in disaster preparedness. *International Journal of Disaster Risk Reduction*, *39*, 101245. https://doi.org/https://doi.org/10.1016/j.ijdrr.2019.101245

UNDRR. (2021). *Human Cost of Disasters: An overview of the last 20 years*.

Varsha, R. V., Naganandini, S., & Hariharan, C. (2024). *Utilizing AI and Machine Learning for Natural Disaster Management* (pp. 279–304). https://doi.org/10.4018/979-8-3693-4284-8.ch013

Walsh, B., & Hallegatte, S. (2019). *Socioeconomic Resilience in Sri Lanka Natural Disaster Poverty and Wellbeing Impact Assessment*. http://www.worldbank.org/prwp.

Xu, P., Wang, D., Wang, Y., Wu, J., Heng, Y., Singh, V. P., Liu, C., Wang, L., Shang, X., & Fang, H. (2024). Quantifying the urbanization and climate change-induced impact on changing patterns of rainfall Intensity-Duration-Frequency via nonstationary models. *Urban Climate*, *55*, 101990. https://doi.org/10.1016/j.uclim.2024.101990

Zangana, H. M. (2022). Creating a Community-Based Disaster Management System. *Academic Journal of Nawroz University*, *11*(4), 234–244. https://doi.org/10.25007/ajnu.v11n4a1485