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COMMUNITY-BASED EVACUATION ROUTES FOR HYDROMETEOROLOGICAL HAZARDS RESILIENCE: A CASE STUDY OF RATNAPURA DISTRICT IN SRI LANKA

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ABSTRACT

Sri Lanka has endured many hydrometeorological hazards due to torrential rains and monsoonal rains. These events disrupt communication networks, obstruct roadways, and can result in resource misallocation. Thus, setting in place mechanisms that could enhance situational awareness is essential and beneficial in building resilience in disaster management. This study aims to minimize the loss of lives and improve living conditions for the displaced by strategically allocating resources. Our approach involves the development of a decision management system. This system serves the dual purpose of guiding civilians to the nearest evacuation shelter and aiding stakeholders, including local authorities and Red Cross volunteers, in coordinating rescue operations and resource distribution. The research employs a multi-phase methodology, the research conducts susceptibility analysis to identify flood-prone areas based on terrain, land use, and soil data. Leveraging Synthetic Aperture Radar (SAR) satellite imagery, the inundation mapping phase assesses the flooding extent in Rathnapura, the selected study region. These maps are instrumental in optimizing evacuation routes and ensuring the secure movement of affected populations during flood events. The resulting flood risk map integrates with the system to generate the nearest evacuation route. This enables users to circumvent flooded areas inaccessible by land vehicles, ultimately saving crucial time in emergency situations. The data pertaining to the relocation of civilians to these evacuation shelters can be used by authorities to appropriately allocate food, water, medical supplies, and dry rations, and the route suggestion engine can be used in rescuing civilians stranded in their homes during floods. The Decision Management System in question was developed as a web application, which is currently being deployed on a local server with improvements underway to best serve the public and authorities.

Keywords: Disaster resilience, Evacuation, Flood susceptibility analysis, Route suggestion, Situational awareness

1. Introduction

Approximately 1.98 million Sri Lankans were afflicted by hydrometeorological hazards, primarily floods, between 2009 and 2018 according to the Disaster Management Center of Sri Lanka (Basnayake et al., 2019). The nation lacks a comprehensive emergency evacuation plan, especially in flood-prone areas. This study is dedicated to the establishment of community-based evacuation routes as a pivotal strategy to mitigate the impacts of such hazards. These evacuation routes serve a dual purpose: they reduce the risks associated with evacuations and ensure accessibility to shelter. The implementation of such routes necessitates coordinated efforts involving various stakeholders, including local government bodies, emergency services, and community organizations. Despite previous research in other countries, such as Bangladesh and Vietnam, focusing on flood evacuation planning using satellite imagery, machine learning models, and Geographic Information System (GIS) technology, Sri Lanka still lacks an equivalent investigation to address its specific challenges. The nation currently lacks comprehensive measures, such as land use planning controls, infrastructure investments, and improved traffic access, to preemptively mitigate these hazards. During natural disasters in Sri Lanka, numerous governmental, non-governmental, international, private, and volunteer organizations play active roles in emergency responses, including flood warnings, flood victim evacuations, and relief operations.

This research endeavors to address this knowledge gap by developing an enhanced community-based evacuation route suggestion engine specific to the Ratnapura District, focusing on the Kalu Ganga River basin. The system identifies flood-prone areas through the analysis of past flood occurrences using satellite imagery. The proposed Decision Management System is based on the Dijkstra algorithm and Shortest Path Distance approximation and will be made available as a web and mobile-based application, providing a comprehensive and optimal solution for community-based evacuation route planning. This approach can increase the resilience of the Rathnapura districts in Sri Lanka by ensuring that the communities are better prepared and enabled to respond to hydrometeorological challenges.

2. Literature Review

Remote sensing has been recognized as a crucial tool in disaster management and flood mapping (Helderop & Grubesic, 2019). Satellite and aerial photography have proven to be effective tools for evaluating and monitoring the extent of inundation. Remote sensing has emerged as a valuable tool for identifying vulnerable areas and optimizing relief efforts. This technique facilitates quick and accurate decision-making by offering a comprehensive understanding of the spatial extent of flooding and its associated impacts. This information is crucial for facilitating the efficient distribution of resources and the implementation of targeted interventions. Using a combination of geographic information systems and remote sensing, (Lee et al., 2017) Lee seeks to evaluate the vulnerability of

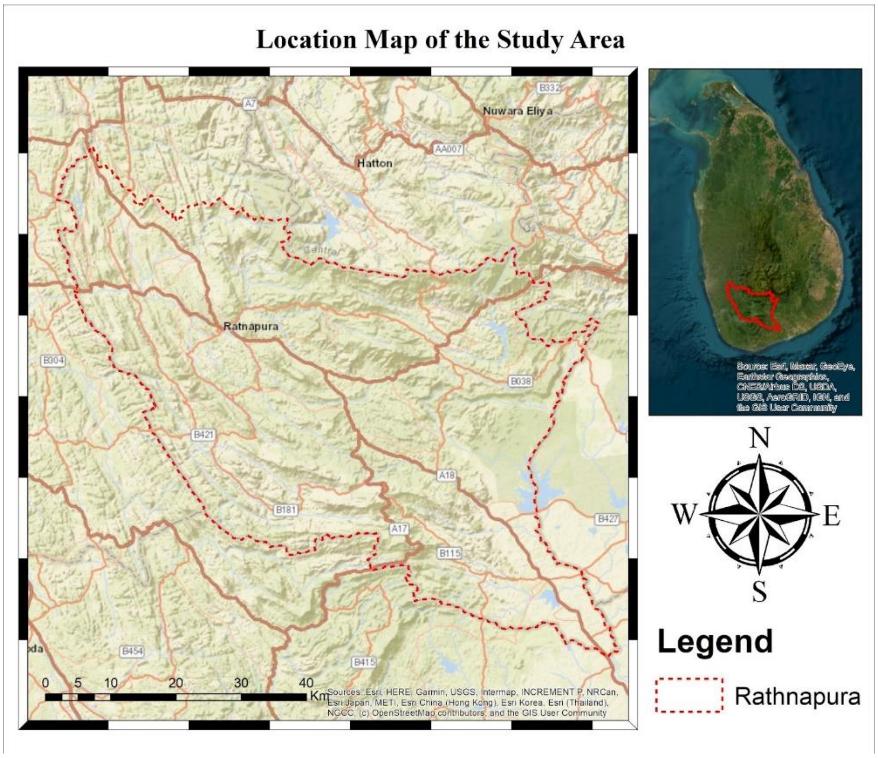

Figure 1. Location map of the study area.

individuals to floods. Using spatial analysis and remote sensing data, this method calculates the likelihood of inundation in different regions based on factors such as land cover, elevation, and proximity to bodies of water. The evaluation's findings are then depicted on a map. Recent technological advancements, such as remote sensing and deep learning algorithms, have fundamentally transformed the methodology for determining the extent of urban flooding.

In order to provide real-time route suggestions, the implementation necessitates sophisticated algorithms and a robust computing infrastructure capable of handling extensive data. In time-sensitive situations, the provision of precise and efficient evacuation routes necessitates meeting specific computational requirements. The affordability of producing and implementing devices remains a challenge for low-income nations due to high production costs. The existence of this discrepancy poses a challenge in developing efficient evacuation pathways, especially in regions prone to flooding. In order to overcome this obstacle, it is imperative to devise cost-effective approaches that can be applied in highly restricted settings with scarce resources (Tariq et al., 2021) (Munawar et al., 2021). To mitigate the negative consequences of flash floods in the Gampaha Divisional Secretariat Division (DSD), a proposed approach involves utilizing Geographical Information Systems (GIS) to plan the evacuation process that explores the initial steps that can be taken to implement such a GIS-based approach. In the selection of evacuation centers, the study has taken into account seven key criteria: elevation, accessibility, land use, availability of buildings, presence of water features, rainfall, and population density (Edirisinghe, 2021).

3. Methodology

Figure 2 illustrates the overall study of our research. This study can support informing the authorities' decision-making process for flood risk assessment and contribute to the development of effective evacuation planning.

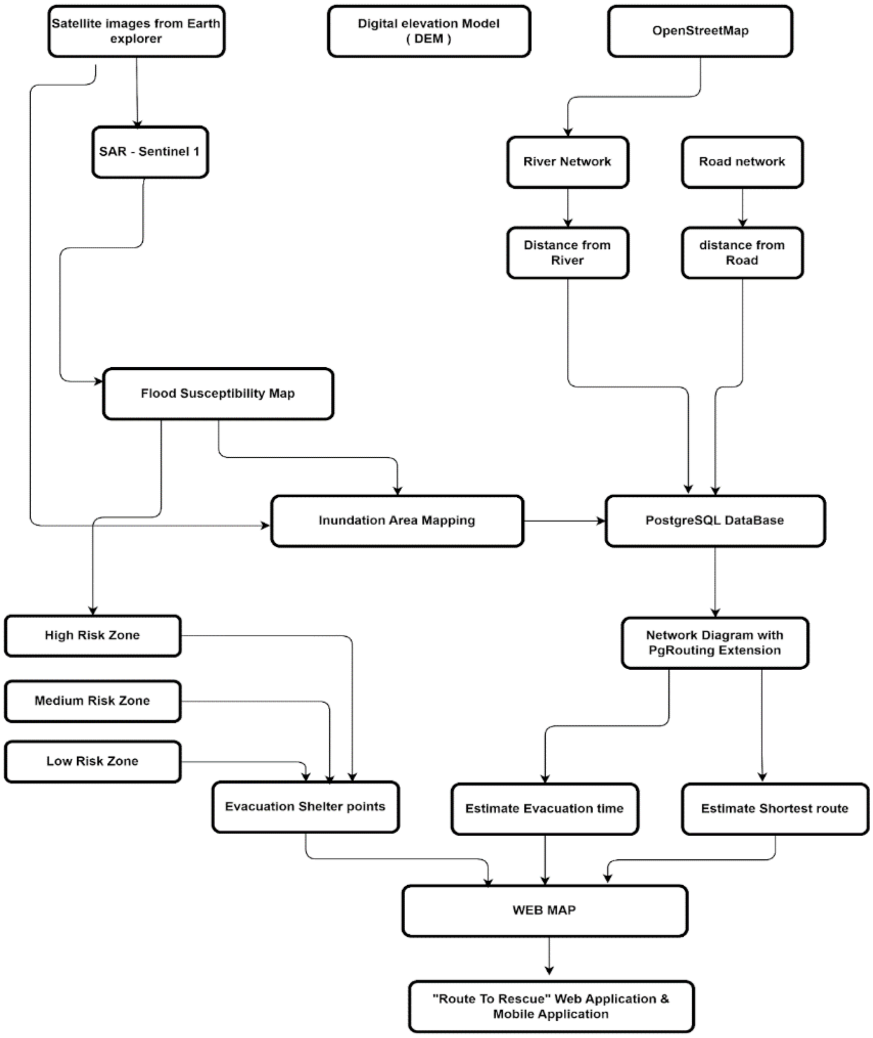

Figure 2. The workflow of this study.

3.1. Data sources

The datasets furnish the necessary elevation data for conducting hydraulic analyses. The present study utilized regular updates to flood occurrence records from the Disaster Management Centre (DMC) in Sri Lanka. The data was analyzed based on the severity of the floods, their frequency of occurrence, the number of individuals affected over the years, and the count of fatalities and injuries resulting from these floods enabling us to stay abreast of recent events, ensuring that our analyses reflect the latest data. Employs graphical analysis to examine the data obtained from desinventar.net, based on that Rathnapura was observed to have experienced a significant impact, with a high incidence of flash floods being identified in the vicinity of the Kalu gang river basin. The present study aims to obtain topographic data, including Digital Elevation Models (DEMs) or LiDAR data, for the designated study area. The data will be sourced from Earth Explorer and will be utilized for mapping purposes in subsequent stages of the research. The present study is focused on collecting comprehensive water body data, specifically pertaining to the Kalu Ganga and its sub-river network. This includes the acquisition of river shapefiles to ensure the accurate representation of the river systems in both Google Earth Engine and QGIS. This study utilized SAR-enabled satellite images obtained from Google Earth Engine to investigate the Rathnapura district and Kalu Ganga river basin from 2010 to 2022. The images were collected from the Sentinel satellite, which is known for its high-resolution and multi-spectral capabilities.

3.2. Flood susceptibility analysis

The present research employed GIS-based methodologies to assess the vulnerability of regions susceptible to flooding in the Rathnapura district, with a particular focus on the Kalu Ganga river basin. Through this methodology, it was possible to discern regions of varying susceptibility, including those with high, low, and medium levels of susceptibility. The present study utilized various methodologies to assess the probability of inundation in a specified geographical region. The findings obtained from the analysis were subsequently utilized to formulate effective measures aimed at reducing the potential impact of flooding within the area. To perform a susceptibility analysis, it was imperative to obtain data pertaining to independent variables such as soil profile, land use/land cover, slope, and rainfall. The data was sourced from the Disaster Management Center of Sri Lanka. The identification of susceptibility areas was predicated on the evaluation of flood susceptibility and risk severity. This research employed overlay analysis as a fundamental operation in conducting flood susceptibility analysis using Geographic Information Systems. The present methodology entails the amalgamation of numerous strata of information to generate a solitary resultant stratum that embodies the spatial interconnection amid the input strata. Overlay analysis has been a commonly employed technique in prior research endeavors aimed at identifying regions that are vulnerable to flooding.

3.3. Inundation area mapping

The cartographic delineation of inundation areas has been identified as a crucial component of flood risk evaluation and mitigation. The initial step in our study involved the utilization of the Google Earth Engine platform, which offers access to a diverse range of satellite imagery and remote sensing data. These datasets were analyzed and processed to generate flood inundation maps. The present study utilized secondary data derived from high-resolution satellite imagery and RBI map scale 1:25,000 as a point of reference for the creation of a village map. The subsequent task involved procuring high-resolution satellite imagery and topographic data for Rathnapura through the utilization of Google Earth Engine. Furthermore, in this step, elevation data from Rathnapura district was utilized to comprehend the potential impact of flooding. The elevation of the Kalu Ganga river basin, which encompasses the Rathnapura district, was also mapped. The flood susceptibility analysis outcomes were integrated with the topographic data to generate an inundation model. The validation of the generated inundation maps entails a comparative analysis of past water bodies and historical flood events that have occurred within the vicinity of the Kalu Gang River Basin. Subsequently, a comparative analysis was conducted to juxtapose the current flood extent with historical watersheds. This methodological approach facilitated the acquisition of significant insights pertaining to the behavior and patterns of flooding in the region. A watershed is defined by its topographic boundary and the presence of a receiving body of water. The present analysis facilitated comprehension of the evolution of floodplains over time, identification of regions that are more vulnerable to inundation, and evaluation of the efficacy of flood management interventions. Furthermore, conducting a comparative analysis between the flood extent and historical water bodies can facilitate the evaluation of the precision of the produced inundation maps.

3.4. Route suggestion engine and shelter mapping

3.4.1. Road network analysis

A comprehensive examination of the road network in the district of Rathnapura is carried out to create a route suggestion engine. The nearest evacuation route can be analyzed using ArcGIS. For planning evacuations, the Rathnapura district's extremely vulnerable villages are divided into various zones. Several road networks, including national highways, state highways, and village roads, are digitized using ArcGIS software. This analysis involves looking at the current road network and locating potential detours. Road conditions, elevation, and the possibility of road closures during flooding are taken into consideration. Elevation analysis identifies high-elevation areas that can be used as detours when low-lying areas are submerged during floods. Data on traffic patterns and flow can be used to identify problems or areas of congestion that could affect emergency response or evacuation routes.

3.4.2. Evacuation route planning

The following step is to identify the shortest and safest evacuation routes from flood-prone areas to designated shelters using graph algorithms, particularly Dijkstra's algorithm. Routes that avoid low-lying areas at risk of flooding can be found with the aid of elevation data. The viability of the suggested routes is ensured by taking accessibility factors such as bridges or elevated roads into consideration, along with the layer of flood susceptibility map.

3.5. Model evaluation

The model was developed as a web application which was deployed locally awaiting further improvements for it to be made available publicly. This model was tested using a hypothetical scenario where an individual seeks to find the shortest route to the nearest evacuation shelter. The model being built on OpenStreetMap, a free-to-use platform allows limitless usage but with the downside of not having access to real-time traffic data which would be available on a platform like Google Maps API. Overall, through the evaluation, the model was capable of performing the functionality of suggesting a user-best route circumventing hazard areas. There is room for improvement as more functionalities can be introduced to also help authorities coordinate rescue operations like locating displaced individuals in areas of the country unfamiliar to them, and circumventing roads that are inaccessible by land vehicles.

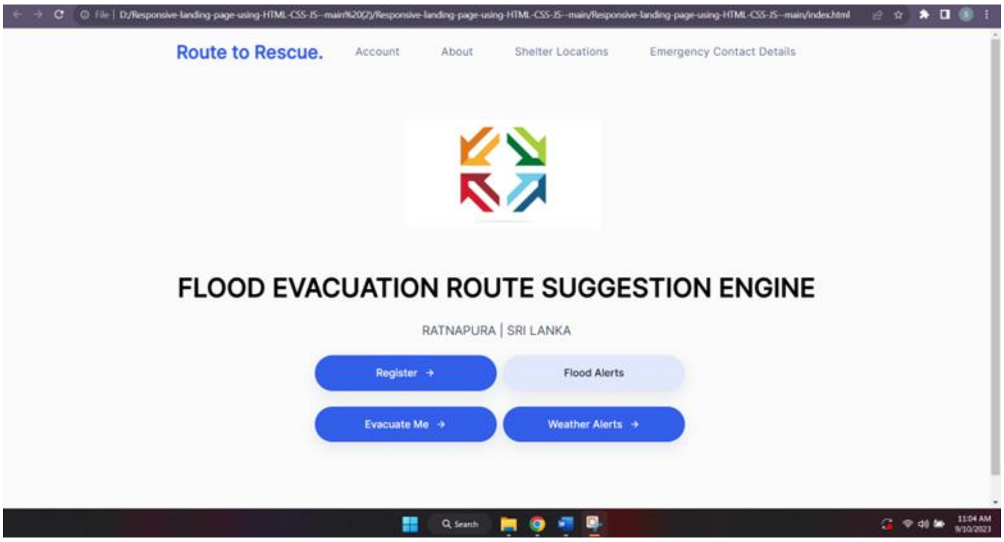

Figure 3. Homepage of the web application.

4. Results and Discussion

In the first phase susceptibility analysis was completed with topography mapping. The second phase concluded inundation mapping compared with past water bodies and the third phase completed mapping road layer network identification for emergency evacuation centers (EEC) in specific divisions in the Kalu Gang River basin in Rathnapura.

4.1. Flood susceptibility analysis

By integrating various factors such as terrain characteristics, land use patterns, and soil permeability, the analysis aimed to provide a comprehensive understanding of flood vulnerability in the study area. The results of the flood susceptibility analysis revealed significant insights into the flood risk across different regions of the Rathnapura district.

The findings of the flood susceptibility analysis highlighted the importance of considering multiple factors in assessing flood vulnerability. This map depicted zones with higher probabilities of flooding, indicating areas where the impact of hydrometeorological hazards is likely to be more severe.

Higher Risk Zone Villages		Medium Risk Zone Villages			Lower Risk Zone Villages		
Column1	Column2	Column3	Column4	Column5	Column9	Column10	Column11
Galathura	Ellagawa	Ayagama	Meddekanda	Panahaduwa	Gawaragiriya	Kendagamuwa Ihalagama	Masimbula
Madabaddara	Idangoda	Dethabadakanda	Mulgama	Sankhapala	Nikagoda	Paleegala	Meddegama
Divurumpitiya	Kiriella	Dumbara	Neluyaya	Alpitiya	Pallekada	Sirisamanpura	Niyangama
Ganegoda	Matuwagala	Dumbara Manana	Polwathugoda	Balavinna East	Paragala	Vilegoda	Panawala
Getahetta	Yatipawwa	Ellahena	Thotupalathenna	Balavinna North	Pimbura	Digana	Rakwana North
Huladduwa	Depane	Gangodakanda	Uggalkalthota Left Bank	Bambaragasthenna	Pitakanda	Niriella	Rakwana South
Iddamalgoda	Kandangoda South	Ketepola	Vikiliya	Buluwana	Udugala	Weragama	Rakwana Town
Kalatuwawa East	Kosgoda	Kolambewa	Welekumbura	Dambavinna	Aldora	Diyapota	Warayaya
Kendagamuwa Pahalagma	Theppanawa	Pahala Galathura	Welipathayaya	Ematiyagoda	Ampitiyawatta	Embilipitiya New Town	Yahalawela
Meennana	Theppanawa Pahalagama	Sinhalagoda	Wijanathkumbura	Galahitiya	Balangoda	Embilipitiya Pallegama	Belihuloya
Napawala	Wathupitiya	Udugala North	Asgangula North	Godakawela	Balangoda Town	Embilipitiya Udagama	Bellankanda
Uduwaka	Ihala Hakamuwa	Vithanagama	Asgangula South	Hapurudeniya	Bowatta	Hagala	Bolthumbe
Walavita	Maudella	Batugammana	Bopetta Didda	Hiramadagama	Dehigasthalawa	Halmillaketiya	Halpe
Yakudagoda	Pahala Bopitiya	Bulathgama	Hewainna	Horamula	Diyavinna	Hingura	Ihalagalagama
Amuwala	Pahala Hakamuwa	Damahana	Kalatuwawa West	Kapuhenthenna	Ellepola	Hingura Ara	Kanathiriyanwala
Dellabada	pelmadulla Town	Durakanda	Karandana West	Kompitiya	Gawaranhena	Julangete	Karadiyamulla
Gangulvitiya	Pelmadullagama	Egoda Waleboda	Kiriporuwa	Madampe North	Godakumbura	Kumbugoda Ara	Karagasthalawa
Haldola	Udathula	Ellewatta	Mahara	Madampe South	Jahinkanda	Kuttigala	Kinchigune
Karangoda	Batugedara	Horaketiya	Mahingoda	Maragala	Kalthota	Maduwanwela	Kumbalgama
Kotamulla	Dewalegawa	Imbulamura	Mapota	Mawathalanda	Kalupedigama	Modarawana	Maddegama
Pallegedara	Kahangama	Kirimetithenna	Mitipola	Ridivita	Kongahamankada	Moraketiya	Morahela
Raddella	Rathnapura Town	Kirindigala	Miyanakolathenna	Thambagamuwa East	Kumara Gama	Mulendiyawala	Muttettuwegama
	Thiriwanketiya	Kuragala	Moragala	Thambagamuwa West	Mahawalathenna	Padalangala	Nittamaluwa

Figure 4. Flood susceptibility based on villages.

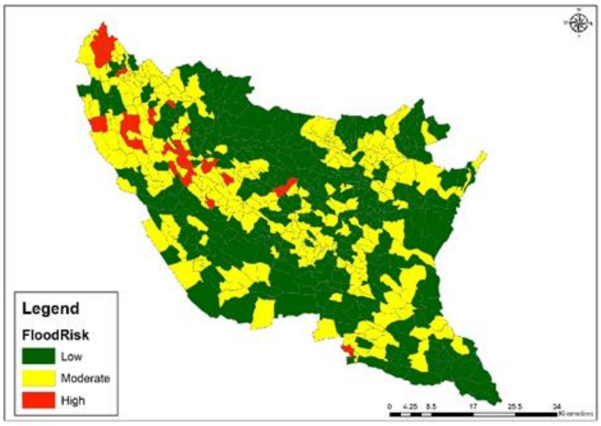

Figure 5. Flood risk map of Rathnapura.

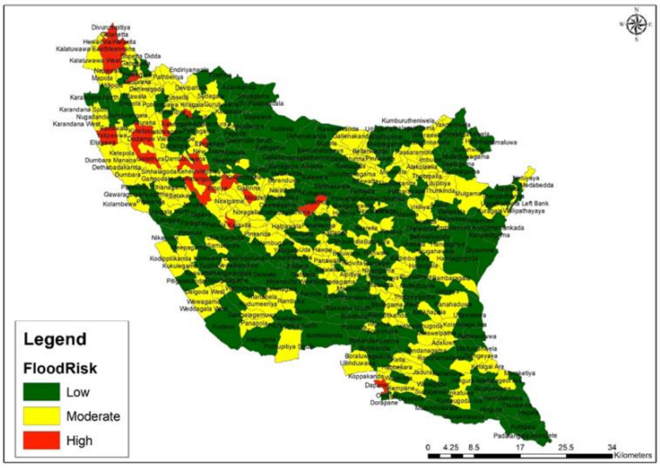

Figure 6. Flood risk map (Division-wise).

4.2. Inundation area mapping

The inundation area mapping utilized SAR (Synthetic Aperture Radar) satellite images from Google Earth Engine to assess and map the extent of flooding in the Rathnapura and Ampara districts. The results of the inundation area mapping provided valuable insights into the spatial distribution and extent of flooding in the study areas. By incorporating the inundation area maps into the route suggestion engine, the study aimed to optimize evacuation routes to ensure the safe and efficient movement of affected populations during flood events.

4.3. Route network identification

To identify specific evacuation routes for the divisional base disaster evacuation by utilizing a route network identification approach in conjunction with pre-existing emergency evacuation centers data. The present study identifies the Emergency Evacuation Centers and route network in the Elapatha division due to the high severity of flooding in the region, as depicted in Figure 7.

5. Conclusion and Implications

Given the lack of availability of capital for investments in preventive measures for hydrometeorological hazards and in mitigating the effects in developing countries like Sri Lanka, it is imperative that more research should be encouraged regarding utilizing pre-existing resources to strengthen disaster resilience. In investigating the past flood event data, the frequency of flood occurrences in Rathnapura district alone is alarming, juxtaposed by the rarity of initiatives to prevent such hazards. While conducting the study, the concept of developing a decision management system to aid in creating situational awareness seems timely, practical, viable and necessary in a developing

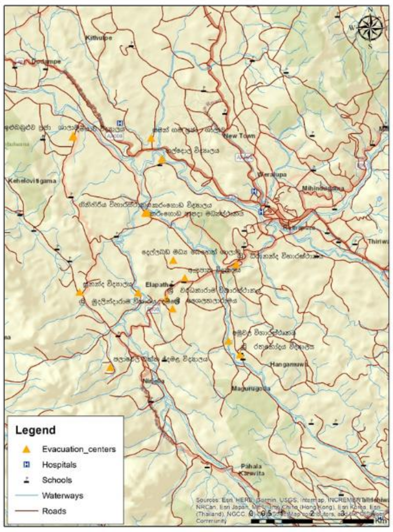

Figure 7. Route networks and EEC planning.

country like Sri Lanka. The study is in line with the thinking of research conducted in countries like Bangladesh, Vietnam, etc. in recommending the use of GIS tools, and SAR satellite imagery in flood susceptibility analysis and mapping. While other research advocates the use of statistical analysis and neural networks in predicting rainfall levels and inundation levels, it requires an input of data across a multitude of variables. This data is not readily available in countries like Sri Lanka, nor is it updated regularly. In practical implementation of the decision support system, the web application and mobile application are viable financially as the operating cost is limited to maintenance of the system and usage fees if it was decided to opt for Google Maps API instead of OpenStreetMap later in deployment. Given the ease of access through mobile platforms, high usage of the platform can be expected and essentially strengthen disaster resilience. In conclusion, a decision support system of this nature is a very viable and affordable option for developing countries in strengthening disaster resilience, and it is recommended that further research should be conducted to further improve the reliability of the model, accounting for real-time events such as unexpected road closures due to falling debris, fallen trees, traffic collisions, etc.

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