

Mapping the Flood Risk Exposure Using Open-Source Geospatial Tools and Techniques: A Case of Gampaha Divisional Secretariat Division, Sri Lanka

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Abstract

The use of open-source data and tools in disaster exposure mapping is presented in this paper. Disaster exposure is a collection of the element at risk to potential loss. Gampaha divisional secretariat (DS) is a study area laid on the lower part of the Attanagalu Oya river basin. As the geospatial tools, OpenStreetMap (OSM), Java OpenStreetMap (JOSM), QGIS, GPS Essentials, and Open Map Kit (OMK) are used. The elements of disaster exposure, including the number of people or types of assets, are surveyed and inventoried using the OSM platforms. Local, national, and international agencies produce and evaluate the data. The study developed spatial data for building footprints of 165,000 households, street lengths of 2300 km, hospital units of 16, and utility units of 2300. This could overcome the main challenges of exposure mapping in the area. The procedure developed in the exposure mapping can be used in a data-sparse environment. Exposure mapping is generally used to estimate the impact of hazards or disasters, which are essential in effective disaster management. How are there still remaining challenges in disaster exposure mapping such as less awareness about the mapping procedure, lack of government support, internet access, hardware, and inability to understand the value of exposure mapping?

Keywords

Spatial Data, Disaster Management, Exposure Mapping, Open-Source Software

1. Introduction

A flood is a temporary submersion of land caused by water flow (Lin et al., 2016). Although the occurrence of flood cannot be prevented entirely, the risk of the flood can be reduced through proper planning and mitigation mechanism (Samu & Kentel, 2018). Spatial data collection related to flood exposure plays a significant role in flood planning, early warning systems, emergency response services, and the design of flood risk reduction (Esmail et al., 2022). Various studies have been developed several approaches to assess and map the elements in flood prone areas (Hagos et al., 2022; Lekamlage et al., 2022; Pushpakumara & Isuru, 2018; Schelhorn et al., 2014). The lack of sufficient spatial data is one of the main challenges in flood risk reduction. Recently, freely available spatial data, open-source software packages, and tools have been emerging in storing, analyzing, modeling, and visualizing spatial data (Schelhorn et al., 2014).

While the hazard defines the degree to which peril has its effect, exposure gives the estimate of the constructed elements, such as roads and buildings underlying the hazard footprint (Aggarwal, 2016). Vulnerability is the quality or state of being exposed to damage for a given peril. In general, risk due to any peril is a function of hazard, exposure, and vulnerability (Aggarwal, 2016; Fedeski & Gwilliam, 2007). Delineating exposure and hazard are a priority for all governments and policymakers in effective disaster management. The accurate and updated data is a primary component of identifying hazard, vulnerabilities, and exposure related to an efficient disaster management process (Aggarwal, 2016). Among the various types of data, remotely sensed data is dominant in disaster management initiatives. However, there are many challenges in applying remote sensing data for exposure mapping. They are; 1) Cost and availability of high resolution remotely sensed data; 2) Cost of image processing software, most of them are commercially based; 3) Lack of high skilled people to handle the remote sensing data and geospatial analysis. These challenges have significantly limited the spatial data availabilities in developing countries.

Open Cities is a project launched by the World Bank through its Global Facility for Disaster Reduction and Recovery (GFDRR) funds in November 2012 to enhance spatial data availability in South Asian cities (World Bank, 2013). The project brought together stakeholders from the government, donor agencies, the private sector, universities, and civil society groups to create usable information through community mapping techniques, to build applications and tools that inform decision-making and to develop the networks of trust and social capital necessary for these efforts to become sustainable (World Bank, 2013). This process has been evolutionary, with opportunities for experimentation, learning, failure, and adaptation incorporated into the project planning. The Spatial database to Gampaha city was developed under this project along with Batticaloa, Dhaka, and Kathmandu to facilitate innovative and data-driven urban and disaster management.

Open-Source tools and techniques are mainly employed in the spatial data

generation of the Open City project. In the present study, following the Open City project standards, open-source GIS tools, and techniques, including Java OpenStreetMap (JOSM), QGIS, GPS Essentials, and Open Map Kit (OMK), Open Data Kit (ODK), were used in flood exposure mapping in the study area. GPS Essentials is a mobile phone app that helps to navigate, manage waypoints, tracks, routes, and build the spatial dataset, while JOSM, OMK, and ODK help to collect, analyze, and share spatial data effectively. QGIS is a full-featured, user-friendly, free and open-source geographical information system (GIS) that governments have adopted, businesses, and NGOs worldwide in spatial data handling (Palino & Sparks, 2021).

Gampaha is located in the Colombo metropolitan area as a second-order city in the urban hierarchy of Sri Lanka. The urban form of the city is where the administrative, commercial, educational, recreational, health, and judicial functions agglomerated (Lekamlage et al., 2022; Pushpakumara & Isuru, 2018). Meanwhile, the city is expanding rapidly as a growth node in the proposed central expressway. However, the area is considered a flood-prone area due to its location in the Attanagalu Oya river basin (Pushpakumara & Isuru, 2018). This basin is situated in the wet zone of the country, with annual rainfall ranging from 1400 to 2500 mm (Lekamlage et al., 2022; Perera & Wijesekera, 2012; Pushpakumara & Isuru, 2018). The intensive rainfall occurs from October to November with the second inter-monsoon and from May to June with the southwest monsoon. The basin is located in the primary economic hub, which houses three leading industrial estates: Ekala, Ja-Ela, Minuwangoda, and Katunayake. Approximately 5% of Sri Lanka's total population lives in the area bordering the Kelaniya and Maha Oya River basin (Lekamlage et al., 2022).

In this study, we intended to develop a methodology to capture the spatial data in the GDS area where the frequent flooding occurs due to its location in Attanagalu Oya lower river basin. Specifically, JOSM, OMK, ODK, and QGIS tools apply, and flood risk exposure maps are presented. Further, the created spatial data is shared through OpenStreetMap (OSM). This study provides valuable information for effective urban and disaster management planning. The methodology developed in this study could be used to capture the spatial data in developing countries cost-effectively.

2. Methodology

2.1. Study Area

The Gampaha DSD situated in the western part of Sri Lanka (Figure 1). Gampaha is one of the significant growth nodes in the Colombo metropolitan area (Subasinghe & Murayama, 2017). At the same time, the city is the second largest city in the Gampaha district, after Negambo. The name “Gampaha” derived from the Sinhala name, which means “Five Villages” (Lakpura, n.d.). These five villages were Ihalagama, Pahalagama, Medagama, Pattiyagama and Aluthgama. Until 1945, Gampaha was under the category of the village council (Lakpura, n.d.).

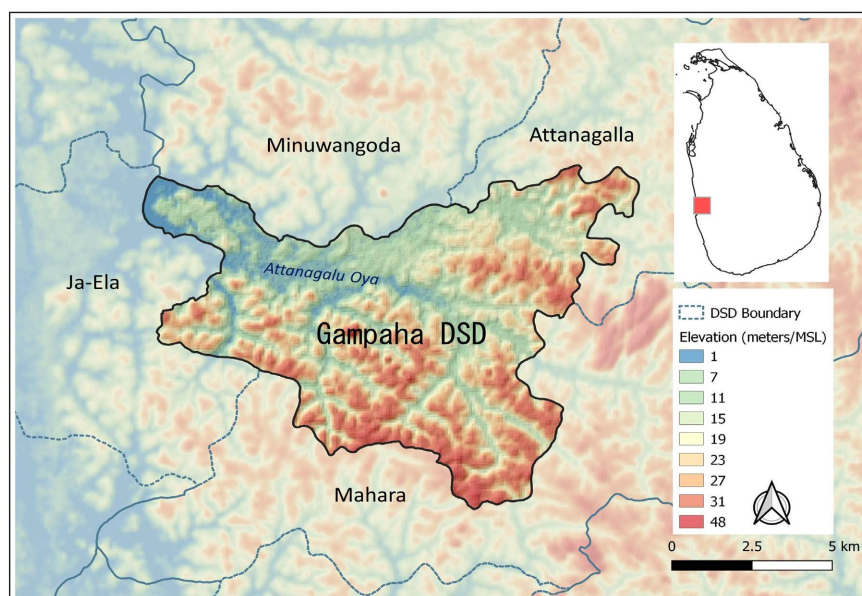


Figure 1. Location of study area: Gampaha DSD.

In 1978, the government declared Gampaha as a separate district formally recognized as a village council of Colombo district (Mallawarachchi et al., 2018). With these administrative changes, government established the Gampaha urban council. In 2002, the Gampaha urban council was upgraded to a municipal council. According to the present statistical data, Gampaha DSD houses around 62797 people (SoSLC, 2018).

Attanagalu Oya River is the main river basing of Gampaha DSD. The Attanagalu Oya originates from the lower pen plains of Kegalle District (Lekamlage et al., 2022). The geographical location of the basin is in the wet zone of Sri Lanka between the latitudes $7^{\circ}00'$ and $7^{\circ}17'N$, longitudes $79^{\circ}50'$ and $80^{\circ}15'E$ (Perera & Wijesekera, 2012). The basin area is vulnerable to frequent flooding. At Gilapitamada, the river's upper basin has a maximum elevation of 300 MSL and a catchment area of around 250 km^2 that is mainly composed of rubber and coconut estates (Pushpakumara & Isuru, 2018). The lower catchment is used primarily for paddy cultivation. The Attanagalu Oya irrigation project, the biggest irrigation project in the basin, irrigates more than 4000 acres of paddy farming (Lekamlage et al., 2022). The average inundation area of Attanagalu Oya is about 35 square kilometers in severe flooding (Pushpakumara & Isuru, 2018).

2.2. Data

This study used the field survey, observation, GPS tracking, and open-source web-based mapping software, mobile apps, and tools including ODK Collect 1.4.5, JOSM 9979, field papers, GPS Essential 4.4.20, and QGIS 2.8 to collect the primary data. The survey covered 162 Grama Niladhari divisions (GND). We used the Open-source maps to extract surface information such as building types, number of floors, roof type, roads, water bodies, vegetation, and other

points of interest. JOSM, Field papers, GPS essential, and QGIS were used as open-source software, and mobile apps such as ODK collect were used to collect the buildings' characteristics and spatial analysis.

The existing governmental documents in the GND office, local disaster management center, and reports of development officers (DO) were used as secondary data sources. As a main spatial data, 1:50,000 topographical maps of the survey department were integrated with open-source GIS tools.

2.3. Data Collection Procedure

The study area (162 GNDs) was divided into eight subdivisions. Spatial data of each subdivision was collected separately with the DOs and GND officers. Methodological flow is shown in **Figure 2**.

Task Manager: “Task Manager (TM)” tool was used to manage the spatial data collection procedures. The spatial database of each subdivision was developed. The Humanitarian OpenStreetMap team has developed this tool to coordinate volunteers and organize groups to map on OpenStreetMap. The progress of data completion can be seen when the data collector collaborates through TM. **Figure 3** shows the working space of TM.

JOSM: JOSM enables the editing of the collected data stored on OSM. JOSM is

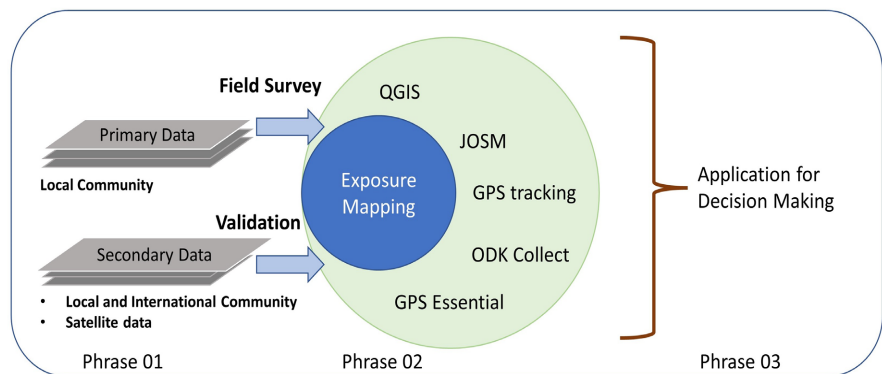


Figure 2. Methodological flow.

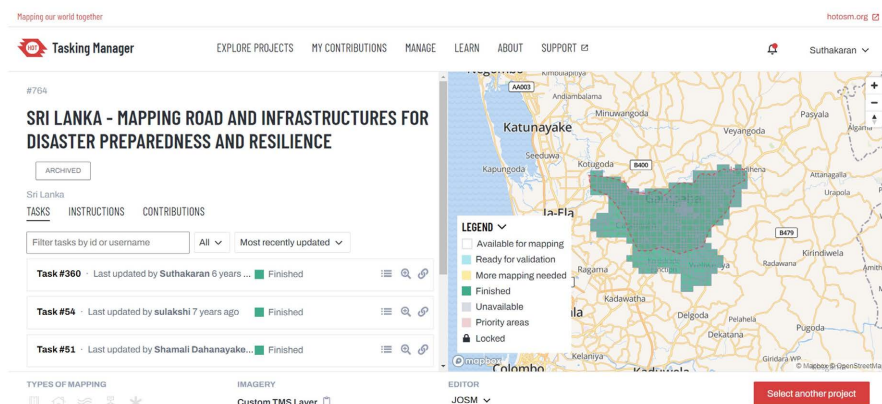


Figure 3. Working-space of Task Manager.

an open-source, extensible flat form that supports GPX tracks, OSM data, and satellite imagery. Building footprint and street tracing is quite a challenging task since many building footprints and streets need to be tracked in a short time. JOSM was used to edit and validate the data collected through the TM. **Figure 4** shows the interface of JOSM and traced building footprint.

Field Papers: The Field paper is an open-source mapping tool. It can enable the user to generate new field papers and upload maps that can be downloaded anywhere in the world. It comprises the details of OSM in a printed sheet. It is a web-based tool for easily creating a printable map atlas to print and add notes to. It allows the mappers to update the buildings and roads on a published map; later, during the updating process, users easily update the information using QR code.

Further, Field Papers easily formats the page layout for a multi-page paper atlas with OSM. Field Papers gives the privilege to the user to decide how many splits can be made to prepare separate maps. During the preparation of survey materials, each GNDs has been divided into reasonable squares to ensure Mappers can access the detail of each data on the map ([LearnOSM, n.d.](#)). Thus, field

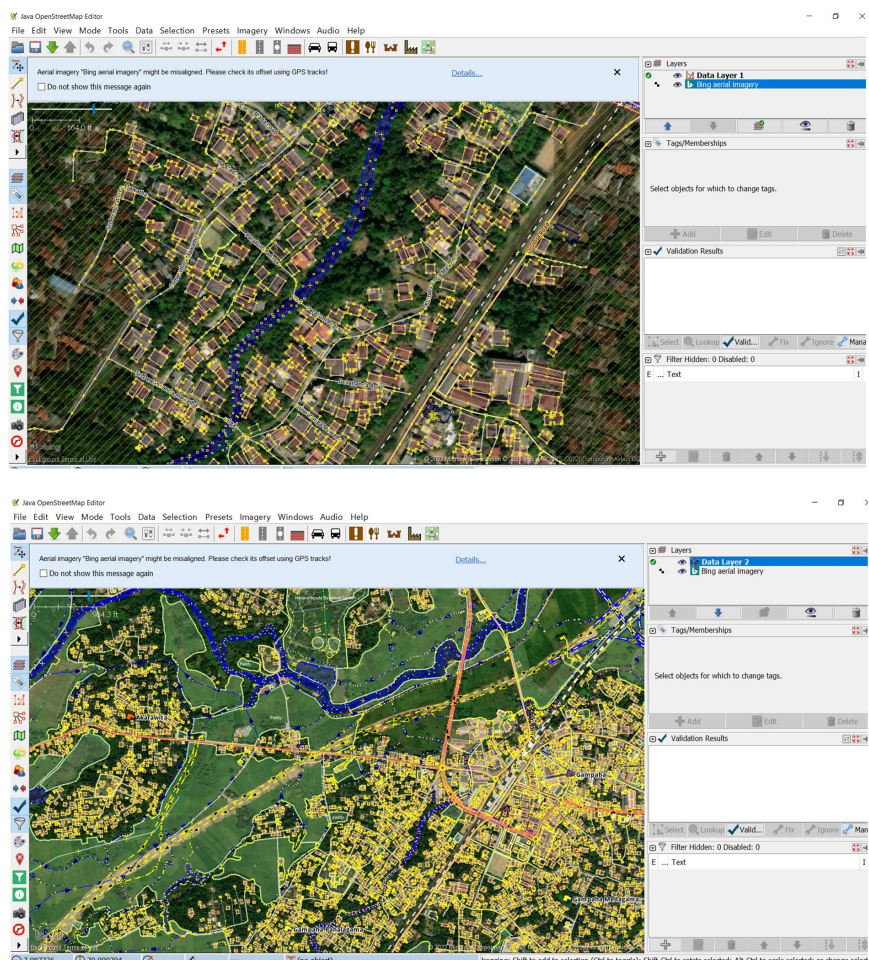


Figure 4. JOSM interface (Tracing building footprint).

papers are the most convenient and efficient way of collecting exposure data and information. Once the paper is recorded as a user's request, it can be used as a printed map to record notes and observations about the completion of the survey. Also, it provides access to the newly updated maps.

Printed maps and Questionnaire: Before the field survey, printed base maps were developed for all GNDs. Questionnaires and XML, ODK file, GPS Essential and Open Map Kit were installed in tabs, and Questionnaires were ready with the mappers, which could be more beneficial in identifying the exact paths and points. Also, a clear picture and understanding of the surveying area are mediated.

2.4. OpenStreetMap (OSM)

The final phase of the primary data collection procedure involves the use of OSM. It serves as a platform to build a database of survey data for the disaster exposure mapping. Compared to other GIS software, OSM is free and simple to use. Contributors to OSM have the ability to generate, edit, and share their own spatial data.

OSM data consists of nodes, ways, relations, and tags (Mapbox, n.d.). A node is a single point with a latitude and longitude. A single node can be a point of interest such as a tree, a mailbox, or a place such as a city or a village. A way is a line. Lines are made by connecting many nodes together. A way can be a road, rail track or a trail. An area is a way where the starting and ending point are the same. But not all the closed ways are always areas. For example, a circular road would be a closed way but not an area. A lake, on the other hand, would be an area. Otherwise, an area can be a shape or a polygon. An area includes a building, a sports field, or a forest. Relations are used to group geographically-related objects together. Relations could be used to group such roads of a bus route. Easily can be developed a bus route instead of drawing a new set of ways, describing the roads which are needed to be a part of the bus route using a relation. A tag in OSM is a key or value pair that is used to describe an object. The key explains what kind of object it is, for example an amenity or a highway.

Users can then use the value to specify the nature of the object, such as a bank or pharmacy for an amenity and a main road or residential street for a highway. There are many tags already used in OSM, but there is flexibility to create new tags in case the user would like to map that nobody else has mapped before. This versatility indicates that it can freely add whatever keys and values users think are necessary. Many users or editors, however have presets for common key (value pairs), which makes it easier and faster to edit maps. Change sets are sets of edits within OSM. Once the edit starts, the changes made during editing are saved in a change set. This change set can be seen in the history tab of the map and are associated with the user account. The final outcome of the process can be found as a completed spatial open-source database that can extend to produce the maps per the user's requirements.

3. Results and Discussion

3.1. Flood Exposure Mapping

According to the UN definition, exposure is “the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas” (UNISDR, 2017). As explained in the UNDRR glossary, “measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest” UNISDR (2017). As described by the Pelling (2012), Cardona (2005) and Dilley et al. (2005), exposure is a term used to describe the elements at risk. **Figure 5** depicts the interaction of risk, exposure, and vulnerability in the context of a flood risk.

Flood exposure is defined as valued societal elements (e.g., people, buildings) located in flood plains (Hagos et al., 2022). Mainly, flood exposure analysis's main components are the extent of flood hazard and aggregating the intersecting population and/or built environment assets (Aggarwal, 2016). Flood exposure is not only ambiguously defined, it is also examined using various approaches, methods and techniques. Detailed exposure analysis is only possible if accurate spatial data is available. So, flood risk analysis is strongly dependent on the accuracy of spatial data.

Further, risk exposure mapping plays a fundamental role in the disaster risk reduction (DRR). Specifically, GIS-based exposure mapping estimates the impact of hazards or disasters, such as the number of people or infrastructure affected (Westen, 2010). This understanding is an integral part of DRR. General practice of exposure mapping is conducted through remote sensing image analysis. In order to develop more accurate exposure maps, high-resolution satellites such as QuickBird, GeoEye, and LiDAR are used. However, they are expensive to acquire and not often readily available, covering a large area. In contrast, the identification of spatial features through the conventional multispectral does not

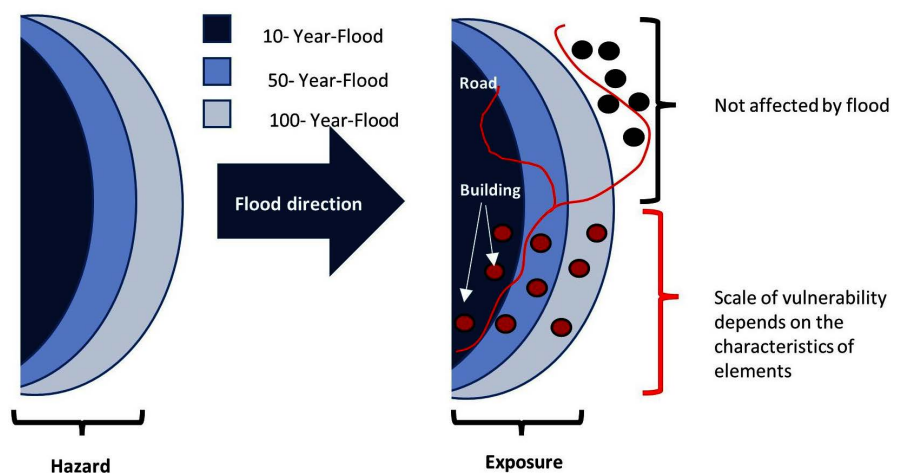


Figure 5. Interaction of risk, exposure, and vulnerability in the context of a flood-risk.

fulfill the main objectives of exposure mapping due to their less accuracy. Therefore, the integration of several data sources is important in exposure mapping.

3.2. Use of Open-Source Software

The methodology of this study combines several data sources and tools to detect the spatial features more accurately. The field-based data collection is the most critical data collection method used in this study. Further, features of the area were traced using JOSM, TM, QGIS, and other tools. The field-based data collection method allowed us to map the building footprint and other features in precise locations. Recent advent of online open-source software and open-mapped platforms enhanced the capabilities of data gathering, analysis, and accessibilities. These accurate spatial data facilitate several stages of flood risk management as every aspect of it is referenced by location.

OSM played an important role in flood exposure mapping of this study. OSM is an open-source and open-access spatial data management system which contains web-platform contains four main parts. The mapping interface allows users to find information in any geographic location. Users also can extract the spatial data for further use or processing. Anyone can edit the geographic information by digitizing, uploading GPX, or correcting errors in their local areas. The OSM community wiki gives guideline for spatial data editing. This study used the JOSM in flood exposure mapping of Gampaha and uploaded them into OSM.

3.3. Advantages of Used Approach and Its Limitations

This study's approach contributes to overcoming challenges in acquiring elements at risk by providing cost-effective solutions (Figure 6).

We could develop a comprehensive spatial database for the Gampaha DSD with the description of elements at risk.

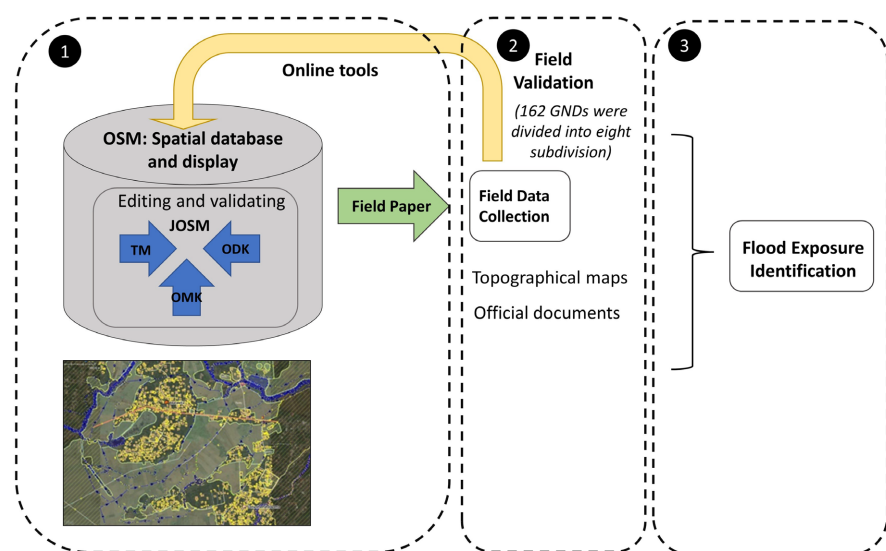


Figure 6. Approach developed by the study.

As an output, this study was able to identify the magnitude of the flood prone areas of the Gampaha DSD and the 165,000 actual households affected by the flood exposure. The 165,000 numbers of households and the assets at risk with all typologies were inventoried in a spatial database. In addition to the households, roads, hospital and amenities were traced (**Table 1**). The elements can be seen in the OSM analytics web (<https://osm-analytics.org/#/>). **Figure 7** shows how they are stored in the OSM analytics web.

High-resolution images are not available on the open geospatial platform, especially in the OSM application. This was the major challenge we had to face when mapping flood risk. This study used Bing and Maxar Premium imagery to map the building's layout, route, point of interest, and land use. These two images are, therefore, not updated during the field study; we faced many challenges in validating the exposure data, which resulted in spending more time on site modifying the spatial data compared to apps, maps, and existing ground-based

Table 1. Spatial dataset produced.

Element	Coverage
Building	165,000 (Households)
Roads	2300 (km)
Hospital	16 (unites)
Amenities	2300 (unites)

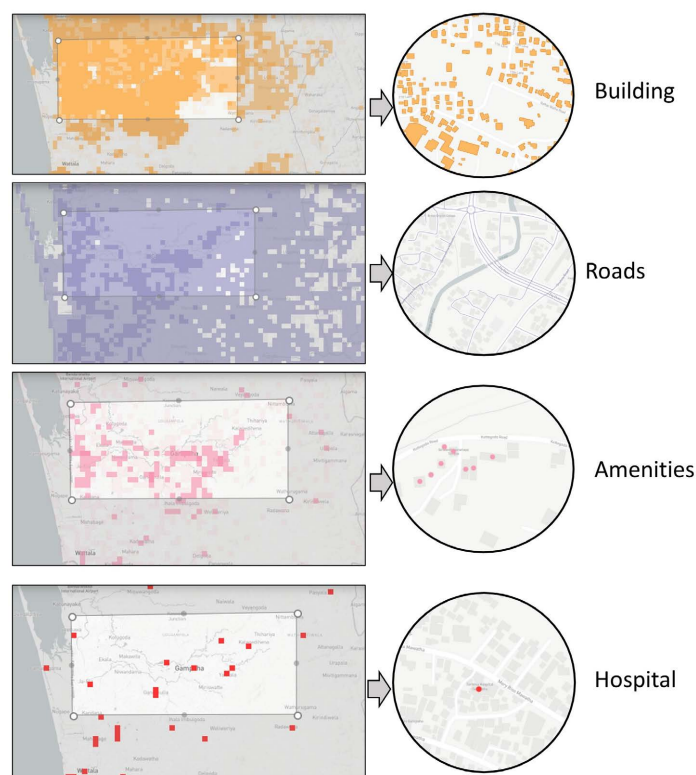


Figure 7. Elements available at <https://osm-analytics.org/#/>.

data. Less awareness of media attention was also a big challenge. Although OSM applications are a very user-friendly method, these applications are not used everywhere in the country due to lower media attention.

3.4. Uses of Output and Way Forward

The spatial data produced in this study is very useful to identify the elements at the flood risk in Gampaha DSD, located in the lower part of the Attanaglu Oya river basin (Figure 8). Socioeconomically, area is susceptible due to its location in Colombo metropolitan area, which is Sri Lanka’s only metropolitan area and the country’s “heartbeat” (Subasinghe et al., 2016). Gampaha has a high concentration of industrial activities in Sri Lanka with the recent shift of industrial establishments from Colombo in the last several years. It results location of Export Processing Zones in Katunayaka and Biyagama and the industrial estates in Ekala (Lekamlage et al., 2022).

However, policy makers and implementing agencies are not giving much attention to flood risk reduction in Gampaha. Therefore, the results of this exposure mapping will propose a set of recommendations to attract the attention of different organizations working on DRR activities. Through this mapping

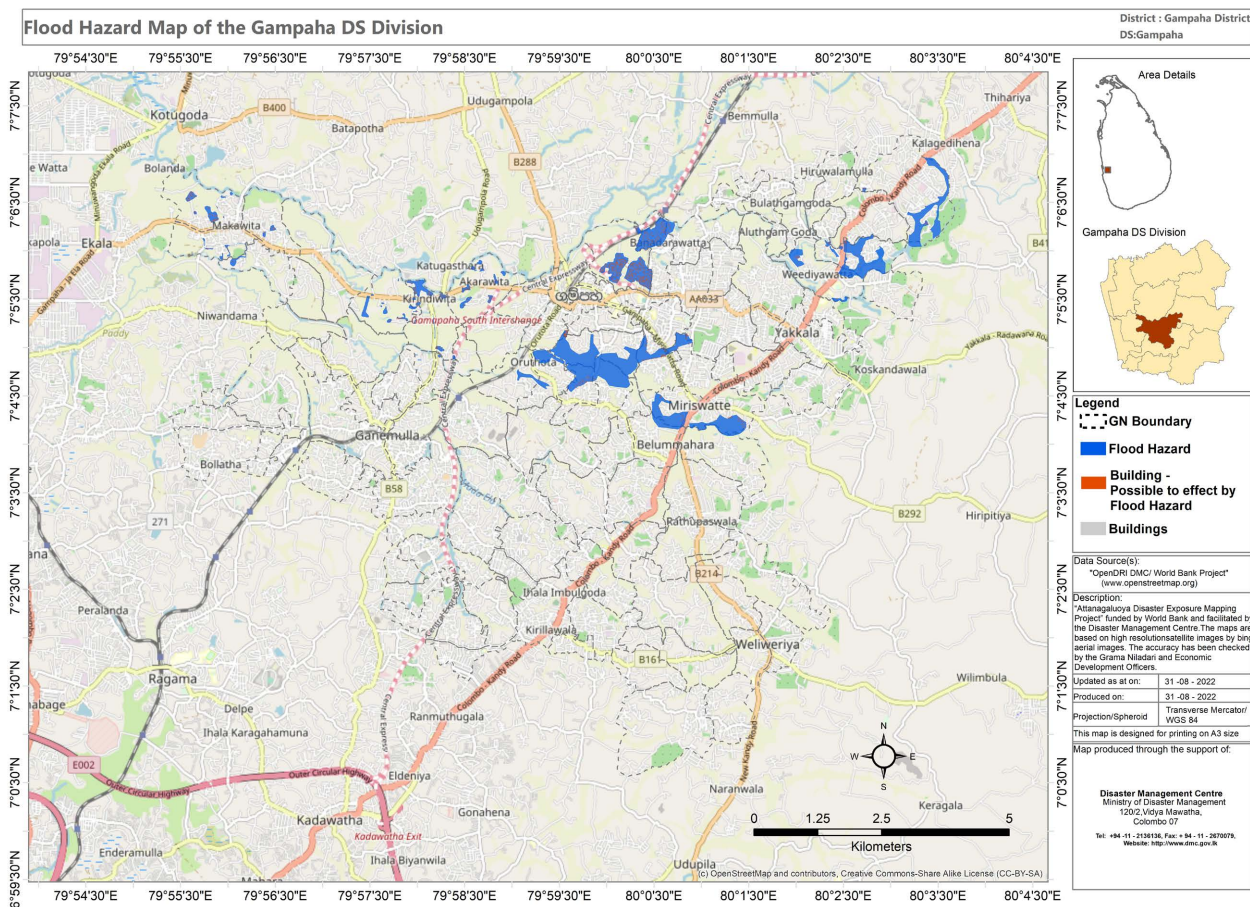


Figure 8. Flood hazard map of the study area.

exercise, the identification of flood zone and flood risk was addressed in comprehensively. The spatial dataset of road networks containing details of road name and surface conditions can be used to prepare the escape route for flood risk reduction.

The study further mapped the public buildings in Gampaha and its neighborhood that can be used as evacuation sites. The online geospatial database which produced this study is accessible to everyone and interested OSM users can update it. In the future, the government offices of the district secretariat and the disaster management center can use this online database to prepare a DSD development plan and design a disaster management monitoring mechanism in Gampaha DSD.

The demarcation of flood-prone areas is essential in different administrative levels for DRR mechanisms. Several environmentally important areas were identified in this study. We recommend that these ecologically sensitive areas should be protected areas which are located in the Attanagalua Oya river basin. Ordinary buildings, such as the Power companies, fire stations, hospitals, schools, and community buildings, should not be built in flood-prone areas.

The findings are essential to Gampaha district Disaster Management Center when they prepare of the emergency management plan, evacuation route, evacuation center and evacuation centre management plan which can help reduce the impact of floods. Meanwhile, community awareness is essential for these areas. The produced spatial data can be used for community awareness programmes. District Secretary and Gampaha Disaster Management Center should work closely with the Meteorological Department and the Irrigation Department to prepare an appropriate rain forecasting system for the upper catchment area. Present information management system is not well implemented in the area. So, the developed approach in this study and OSM can be used to extract the information and generate an emergency management plan and mitigation plan.

4. Conclusion

This study has developed a flood exposure map to Gampaha DSD, one of the main cities in the urban hierarchy of Sri Lanka and the country's main socio-economic "powerhouses", using open-source mapping tools. The final result of the study included building footprints of 165,000 households, street lengths of 2,300 km, hospital units of 16, and utility units of 2300. The study framework can be used to assess the exposure of assets to potentially hazardous events. The rapid extraction of vulnerable items, updated by the different participants, can be used to improve action planning for risk mitigation and response measures. The benefit of involving individuals in the process is that it reduces the cost of acquiring and maintaining the database of potentially hazardous substances and improves awareness of potential risks. Although many advantages could be identified in the approach used, real-world applications have many challenges such as less awareness about the mapping procedure, lack of government sup-

port, internet access, hardware, and inability to understand the value of exposure mapping.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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