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GIS based Approach for Planning the Evacuation Process During Flash Floods: Case Study for Gampaha Divisional Secretariat Division, Sri Lanka

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ABSTRACT

Gampaha district is one of the areas that suffer from frequent flash floods in Sri Lanka. Since flash floods occur unexpectedly, and with minimal warning, preparedness is essential to minimize losses during such a disaster. Planning the evacuation during a flood is a complex process; therefore, it needs focused consideration on several factors. The main objective of this paper is to propose a Geographical Information Systems (GIS) based approach to plan the evacuation process during a situation where there is a flash flood in the Gampaha Divisional Secretariat Division (DSD), with the intent to reduce negative consequences. The study has considered seven criteria: elevation, accessibility, land-use, availability of buildings, presence of water features, rainfall, and population density, in selecting locations for evacuation centers. These data were analyzed with the tools and models available in the GIS software package. As a first step, the flood inundation map was created using elevation and rainfall data. Evacuation centers were then identified outside of the inundated area. Finally, after field verification, 7 potential locations (Bandaranayake Vidyalaya, Bandarawatta Parakrama Vidyalaya, Sri Sumangalaramaya, Madegama Sri Sunandaaramaya, Sri Wajiraghanaramaya, St. Jude Church Idigolla, and Holy Cross College) were selected by considering the capacities such as elevation (above 15m from the Mean Sea Level), accessibility (within 200m from main roads), ownership (public only), and the number of people accommodated. The results of this study will be very helpful for the government, non-government organizations, and the victims to take immediate actions during a flash flood event in the study area.

1 Introduction

Floods can be considered as one of the most prominent disasters suffered by many people around the world, especially by Asians (Premasiri et al., 2017). It can be considered as an overflow of water that submerges land, which is not usually wet. Floods destroy human lives, their properties, and normal life styles. Floods can occur due to various reasons such as heavy rain, blocking of drainage systems, filling of wetlands for construction purposes, sand mining and dredging, unplanned construction projects, and the creation of massive impervious areas which reduces the infiltration of water to the ground (Islam et al., 2016). The time duration of a flood depends on certain factors such as landuse, soil type, natural and man-made structures and evaporation in relation to the topography, meteorology, and hydrology. This duration can vary from several minutes to several weeks.

A flood can be classified into two types: major and minor, according to the extent, depth or the duration of inundation (Hundecha et al., 2017). Further, according to the nature and the source of flooding, different types of floods are there (Turkington et al., 2016). Among them, riverine floods, in which a river overflows due to continuous heavy rain for several days, are the most common type of flood experienced by Sri Lankans (Rubinato et al., 2019; Turkington et al., 2016). Localized floods, generally known as urban floods, occur as a result of unplanned urbanization. The other type of flood which can be seen commonly in Sri Lanka is flash floods. They occur abruptly with a very short warning. Since understanding about the behavior of flash floods is very important to the general public, especially those living in urban areas (Rubinato et al., 2019), this study focuses only on flash floods.

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Though the time available is very short to prepare for, and respond to flash floods, their impact is sometimes very severe and violent (Modrick and Georgakakos, 2015). Flash floods generally occur due to several reasons such as heavy rain within a shorter time period, collapse of a man-made or a natural dam, or a block in a drainage system. Additionally, flash floods are highly related with the location, and the type and the amount of human activities. Therefore, identification of the potentiality for flood events, and vulnerable areas is very important in the process of managing such flash floods (Bapalu and Sinha, 2005).

Emergency evacuation process can be considered as a complex risk management strategy that is used to mitigate the impact of an emergency on a community. This type of process can be activated under various conditions such as fire, storm, flood or bad weather. Evacuation is the process of removing the crowd immediately from a disaster affecting area (Mustaffa et al., 2016). The effectiveness of any evacuation plan would be thoroughly depended on the planning and implementation. In order to enrich such a plan, it must use new and special technologies to uplift the trustworthiness of general public and victims.

The evacuation time, which is generally known as the benchmark, can vary with different factors such as the scenario of the disaster and flow of public activities (Haynes et al., 2009). It also needs to consider about the personal conditions of the victims that are highly affected, and the individuals' ability to escape. The most important condition which should be included in any evacuation plan is, giving right information to the right person at the right time, without putting them in danger, which leads to a better evacuation.

An evacuation center can be defined as "a center which provides affected people with basic human needs, including accommodation, food and water" (Australian Emergency Management Glossary, 1998). These centers can be used for the people who are directly affected by the emergency, and those who do not have a shelter at the moment because they can't reach their homes due to the emergency situation. The locations should be selected and established by the responsible authorities according to a proper plan. Under this scenario, priority needs to be given for some basic needs of the victims, as well as their physical and mental well-being. Usually, government buildings and religious centers in the area are selected as evacuation centers.

The evacuation process includes several steps such as detection, warning, preparation to evacuate, movement through a network, arrival to the shelter and verification by relevant authorities for further management (Stepanov and Smith, 2009). There are several factors that affect to conduct an evacuation process effectively. They are: warning time, response time, evacuation routes, traffic flow conditions, information and instructions dissemination procedure, and dynamic traffic control measures (Lim Jr et al., 2013). Also, the evacuation process should be arranged and implemented through safe paths in order to avoid dangerous zones.

By considering all these matters associated with flash floods, the problem needs to be analyzed under a scientific background. Therefore, the main objective of this study is to propose an evacuation plan during a flash flood event for the affected population in Gampaha DSD according to the magnitude of the disaster. Establishing a proper mitigation processes has become essential to a country like Sri Lanka, because the country is facing severe urban flood hazards. However, this evacuation plan can be useful for any other area that is prone to urban flash floods. Due to the nature of human activities, urban areas are easily affected by flash floods than rural areas. According to the past experiences, Gampaha urban area is one of the worst affected areas in the country (De Silva and Jayathilaka, 2014). Past experiences emphasized that the floods occurred in the years of 2010, 2016, 2017, 2018 and 2020 have impacted on 8% - 12% of the total population, and 23% - 40% of the total land area of the Gampaha DSD (De Silva and Jayathilaka, 2014; DMC, 2020; Igshana et al., 2017; Wijesekera and Rajapakse, 2013).

2 Literature Review

Studying about flash flood management and evacuation planning has become an intense topic around the globe due to its importance. Lim Jr et al. (2013) studied about the evacuation planning by giving attention to transportation modeling, behavioral science, and risk analysis. Mioc et al. (2008) created an online street network analysis for flood evacuation using a web GIS system which consisted of several attributes such as a street network, an application to analyze the flooding of road network in real-time conditions, a flooding spatial data model, and a flood monitoring and prediction system. By using this Web GIS application, users can get an idea about the routes that can be used as evacuation paths by considering the nature of the current situation of the flood, water depth, and the vehicle type. This system can cater to the needs of both the public and authorities in a flash flood situation.

Kongsomsaksakul et al. (2005) proposed a model to find the optimal locations for shelters in planning the evacuation procedure during a flood. In this approach, it was assumed that authorities have the power for traffic control at the moment of evacuating using a bi-level programming and genetic algorithms. Further, Premasiri et al. (2017) attempted to introduce a warning system for urban flood hazard mitigation using GIS, Global Positioning Systems (GPS), Hypertext Preprocessor, Remote Sensing, Google Application Programming Interfaces, Java Script, Arc Server, and Google My Maps. This was an innovative and real time approach with more scientific and technological advancements. However, factors such as soil infiltration, wind speed, soil type, and land use have not been used to create the warning system in this study.

Matsuo et al. (2011) considered time-space distributions for safety evacuation, and examined the flood risk of different community levels using an integrated flood evacuation simulator. They further, suggested using this type of simulator for disaster education, disaster prevention planning, and evacuation training and planning at both individual and community levels. Two approaches: specific force per unit width and the moment and friction instability, were introduced in this study to assess the safe evacuation path during a flash flood event

Goerigk et al. (2014) proposed an integrated model to solve the issue of evacuation in urban areas using multi-criteria optimizations by developing a genetic algorithm. Evacuation time and the risk were considered in order to deal with the bus routing, shelter location selection, and individual traffic routings simultaneously. The effectiveness of the study was determined by using real world data computations. Different levels of data aggregation were also compared. The model is a part of Decision Support System where the planner of evacuation procedure is able to use several scenarios and to compare various solutions. The model can be used in the preparedness phase in disaster management.

Mustaffa et al. (2016) studied about the suitability of evacuation centers through Remote Sensing and GIS techniques. In this study, GIS was used to extract the road access, percentage of the affected area, and to calculate the elevation of area, while flood inundation maps were used to check the suitability. The study proved that a good evacuation center that is located near residential areas at a higher elevation can hold enough victims, while still having proper road access to offer help for needy people. Jamrussri and Toda (2018) attempted to evaluate the flood vulnerability maps by fuzzy logic and Analytic Hierarchy Process (AHP). The main objective of this study was to identify suitable places for evacuation centers in order to reduce the risk and loss of life, and to explore the available time for evacuation in an emergency situation. Safe evacuation conditions, flood shelter, the physical status of evacuees, shortest evacuation path, and road capacity were the factors used to calculate the time for evacuation. However, due to the dynamic nature of the evacuation process, the study emphasized the necessity of developing contingency plans to manage, and reduce messy and fraught processes in flood evacuation.

Ng and Waller (2009) suggested an evacuation route planning model by considering the demand (number of evacuees) and capacity (road capacities), and provided a framework to determine the amount of demand inflation/supply deflation necessary to ensure a user-specified reliability level. Ng and Waller (2009) stated that since excessive rainfall become more prevalent everywhere, it is less obvious that the design of transportation networks for congestion reduction and evacuation planning is mutually exclusive. Pillac et al. (2016) proposed a conflict based path generation approach for evacuation planning using an algorithm.

Yang et al. (2007) attempted to plan a flood evacuation process, taking inundation as the input. In this approach, a dynamic flood model and a prediction at various levels were incorporated into evacuation planning. As the final output, it identified assembly points, shortest paths, and optimum safer areas. Simonovic and Ahmad (2005) developed a computer based model for flood evacuation planning using the behavior of humans during a flood emergency evacuation. This model simulates three facts: number of families in the evacuation process, acceptance of the orders of evacuation by the residents of the risk area, and the number of victims required to bring all the evacuees to the level of safety.

3 Study Area

Gampaha DSD territory, in which the co-ordinates of the centroid are 7.0940° N, 79.9970° E, is 91.704km^2 in extent and situated in the Western Province of Gampaha District, Sri Lanka, was selected as the study area for this study (Fig. 1). Gampaha district is having a significant rainfall at an average of 1,744mm mm throughout the year, with the minimum average rainfall at 29 mm in January and maximum at 231 mm in June. Attanagalu River is the main contributing factor for the flash flood in Gampaha urban area (De Silva and Jayathilaka, 2014).

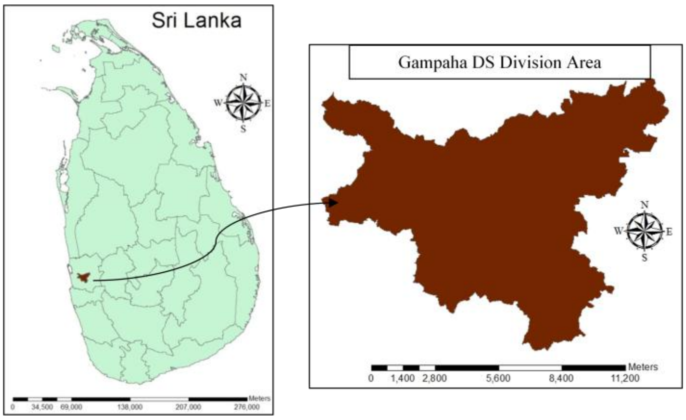

Fig. 1: Gampaha DS Division Area (*Source*: Survey Department of Sri Lanka)

4 Data Requirement and Methodology

In order to achieve the main objective, preparing an evacuation plan during a flash flood event for Gampaha DSD, the study used seven parameters in order to identify the safe places and paths from the residencies of the victims. Those parameters were the elevation, transportation (access), land-use, buildings, water features, rainfall and population density. These data were collected mainly from the Survey Department of Sri Lanka, and the Department of Census and Statistics of Sri Lanka. The data obtained from the Survey Department were at the scale of 1:10,000, while the statistical data were the results of the last census conducted in 2011.

The rain gauge data of Gampaha GN division were obtained from the Irrigation Department of Sri Lanka, in order to identify different flood/water levels and the respective rainfalls associated with the risk levels. There were three main gauge levels defined by the Irrigation Department of Sri Lanka for Gampaha area namely; normal level, minor level and major flood level (Table 1).

Table 1: Risk level data (*Source*: Irrigation Department of Sri Lanka, 2016)

Risk level	Water level (m)	Rainfall (mm)
Normal level	< 4.4	<100
Minor level	4.4-5.5	100-120
Major level	> 5.5	120<

GIS datasets were first converted into the same projected coordinate system of Sri Lanka Datum 1999 (SLD99). The flood inundation map was then created using the elevation data and rain gauge data. Elevation data were used to create a Digital Elevation Model (DEM) of the study area. The prepared DEM and Hydrological tools in the GIS package were used together to prepare inundation maps for different flood scenarios such as normal, minor and major risk levels according to the different water levels shown in the Table 1. The Raster Calculator tool in GIS was used to delineate the area which was affected according to various gauge levels. By overlaying land-use classes, population and buildings on these inundation maps, the affected areas and buildings were extracted.

Possible evacuation centers were selected using transportation, buildings and DEM data layers with different criteria using a model prepared in the ArcGIS environment (Fig. 2). In the study, the locations above 15m elevation were selected as 'safe' areas with prior knowledge and experiences of the victims and experts in the disaster management field. In order to consider about the access to these safe locations which are to be used as evacuation centers, 200m buffer zones were created around the main and minor roads in the transportation network. Suitable buildings in the safe locations for establishing evacuation centers were selected from the building layer. Three layers were intersected in order to identify locations satisfying all of these criteria to be utilized as evacuation centers. After that, the selected buildings were ranked according to their capacity.

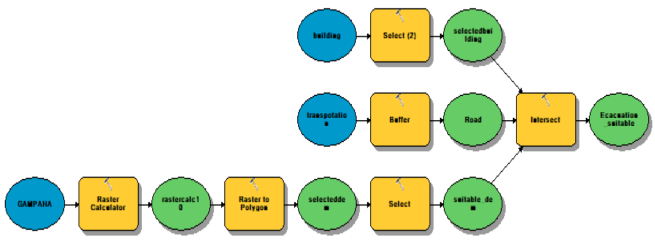

Fig. 2: Model of GIS Based Analysis

5 Results and Discussion

As the first step of this study, flood inundation maps under normal flood, minor flood and major flood events were prepared as shown in Fig. 3 for the study area. According to the figure, the extent of the inundation area for each flood type was as 8.64km^2 for normal, 10.79km^2 for minor, and 15.69km^2 for major floods. They represent 9.42%, 11.77% and 17.11% from the whole study area, respectively.

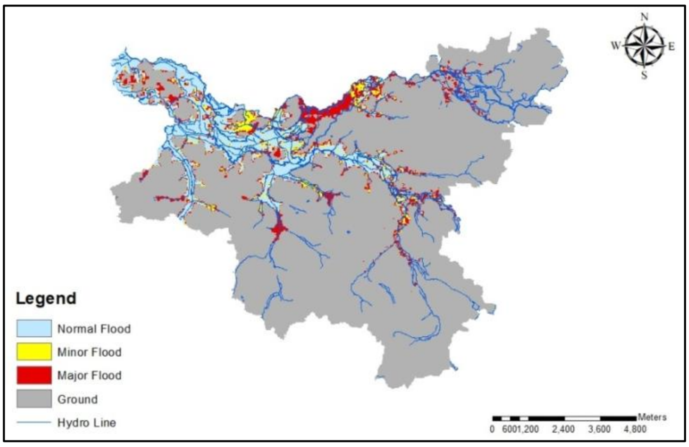

Fig. 3: Flood Inundation Map of Study Area

Further, it can be noticed that these three categories of inundation levels have been covered under different land-use types. The extents and percentages of these, according to the risk levels, are shown in Table 2.

Table 2: The Extents of Risk Levels at Land-use Types

Land-use Type	Normal Flood		Minor Flood		Major Flood	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Barren land	0.01	0.12	0.01	0.09	0.02	0.13
Coconut	0.06	0.69	0.08	0.74	0.13	0.83
Home land	0.42	4.86	0.75	6.95	2.10	13.38
Marsh	0.10	1.16	0.11	1.02	0.14	0.89
Oil palm	0.01	0.12	0.01	0.09	0.01	0.06
Paddy	7.59	87.85	9.32	86.38	12.58	80.18
Rubber	0.04	0.46	0.05	0.46	0.07	0.45
Scrub	0.31	3.58	0.33	3.06	0.40	2.55
Other	0.10	1.16	0.13	1.21	0.24	1.53
TOTAL	**8.64**		**10.79**		**15.69**	

When considering about the impacts of flood on different land-use classes in the study area, the areas with 'Paddy' have been observed to be highly affected under all three stages of flood events.

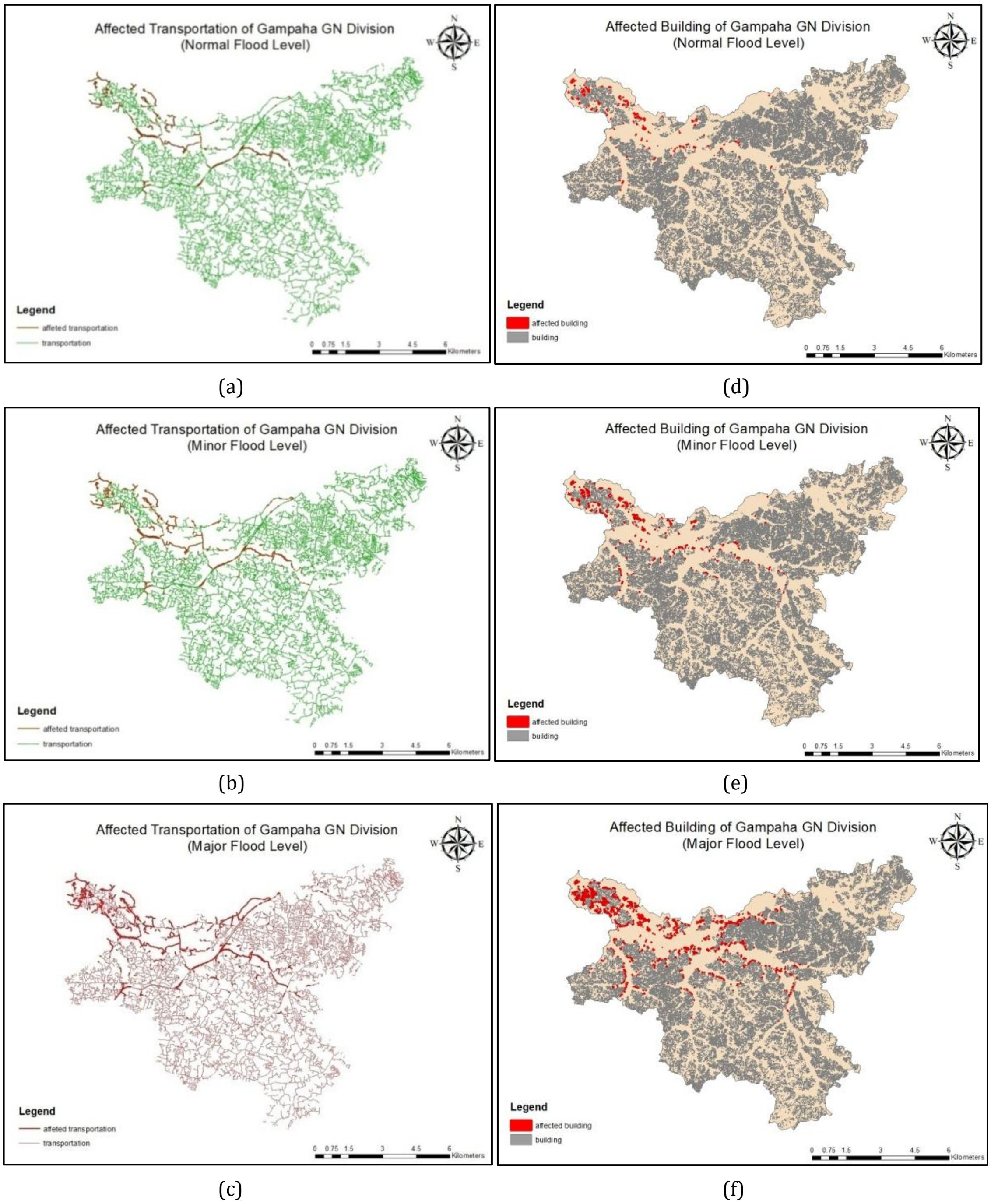

Fig. 4: (a) Affected roads under normal flood level, (b) affected roads under minor flood level, (c) affected roads under major flood level, (d) affected buildings under normal flood level, (e) affected buildings under minor flood level, (f) affected buildings under major flood level.

This is a very critical observation, since the economical loss is great. Another considerable portion of flood impacts the 'Home lands' on which most of the victims are found.

Since transportation can be considered as a major factor for selecting evacuation centers, the study attempted to identify affected routes under different flood scenarios. According to the results of this analysis, it can be observed that 3.74% of the major roads and 2.08% of the minor roads in the study area are affected during a normal flood situation (Fig. 4-a). Furthermore, 5.46% of the major roads and 3.01% of the minor roads in the study area would be inundated during a minor flood level, while 11.49% and 5.99% of the major roads and minor roads, respectively, in the study area would be flooded from a major flood (Fig. 4-b and Fig. 4-c).

The building type and the capacity of buildings are also major factors in selecting evacuation centres, especially during a flood event. Therefore, in this study, affected buildings were identified under different flood levels. The results of the study reveal that 483 (0.71%) buildings have been affected under a normal flood situation (Fig. 4-d). From these buildings, 90.48% are public buildings and 7.24% are commercial buildings (Fig. 4-e and Fig. 4-f). It can be identified that 896 (1.32%) buildings are situated in the minor flood level zone, where 92.63% of buildings are public buildings and 5.47% are commercial buildings. The results show that 2534 (3.73%) buildings have been affected due to a major flood event. Of these, 92.98% and 6.04% are public and commercial buildings respectively.

The main objective of this study was to identify suitable locations to be used as evacuation centers. For this, four (04) factors were taken into consideration. Firstly, any evacuation center should be situated in an elevated area, and therefore, only buildings which are situated above 15m above MSL were selected. Only public buildings were selected as evacuation centers. The accessibility is also another important factor to be considered, and hence, buildings situated within 200m from the main roads were selected. Finally, the capacities of the selected buildings were considered. When considering all of the above factors, seven locations were found to fulfil the requirements, and they are shown in Fig. 5.

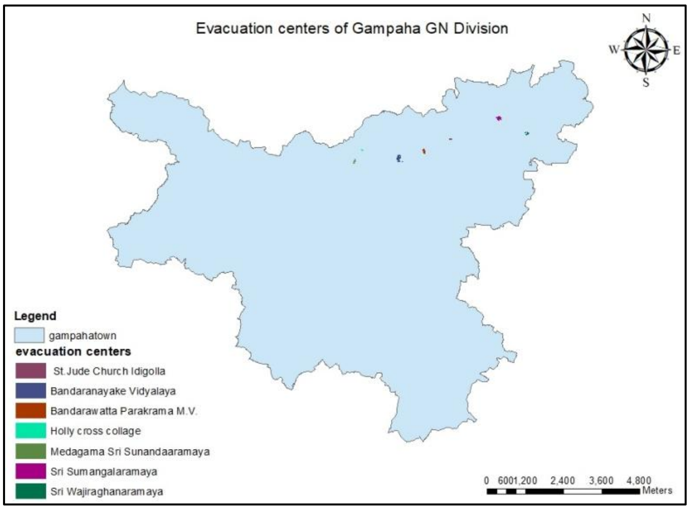

Fig. 5: Selected evacuation centers of Gampaha DSD.

The capacities of the identified shelters, extents, type of building, and the number of people that can be accommodated are shown in Table 3. After selecting possible evacuation centers, the Grama Niladhari divisions under which the jurisdiction of the building falls were given responsibility to plan the evacuation process of general public in a disaster situation effectively and efficiently.

Table 3: Selected evacuation centers capacities of Gampaha DSD

Name of Center	Type	Extent (m^2)	No. of People
Bandaranayake Vidyalaya	School	7999.83	2000
Bandarawatta Parakrama Vidyalaya	School	3937.50	1000
Sri Sumangalaramaya	Temple	3480.84	900
Madegama Sri Sunandaaramaya	Temple	3296.16	800
Sri Wajiraghanaramaya	Temple	1820.84	450
St. Jude Church Idigolla	Temple	1126.50	300
Holy Cross Collage	School	471.08	100

6 Conclusions and Recommendations

The current study introduces a GIS based approach to manage the evacuation process during a flash flood event in Gampaha DSD area, Sri Lanka. The necessity of this type of process has been emphasized by the general public and organizations such as Disaster Management Center of Sri Lanka through their past experiences. Furthermore, the study stresses the importance of the planning process in this type of situation since most victims get panicked easily due to the limited time for preparing for the disaster. In a disaster situation, it is very important to identify a proper evacuation road plan in order to be at the evacuation center as soon as possible.

Identification of the flood inundation areas is essential as these areas need to be given more attention to reduce the impact of flooding. Here, both high and low inundation areas should be considered, and therefore, the cost can be reduced when it is applied at the initial stage. By considering the outputs of this study, the inundation areas can be correctly identified, and suitable locations for evacuation centers can be identified. The flood controlling measures can be applied for such areas in order to maintain the water level and the capacity of the water features.

The final result of the study was identifying and proposing a set of buildings for evacuation centers. Since the capacity was one of the most important factors, the resulting buildings were ranked according to their capacity. Finally, the top seven locations that had the highest capacities were selected and listed. Affected land use, transportation and buildings were identified for the different flood levels such as major, minor and normal. By using this result, an evacuation planning system can be developed and a proper donation procedure can be conducted since the capacities and locations of the evacuation centers are known.

The final results of this research can be extended to create a network analysis related to the paths heading to each evacuation center. Then the victims can use them through their mobile phones to access the evacuation centers without any delay. Another future research path is that a location allocation related to these evacuation centers can be conducted. Then it will be easier to allocate victims to different centers and pre-identify their paths.

Since flood causes many other consequences such as pollution and landslides, the results of the current study can be used to further investigate such issues. This evacuation plan has been designed for a limited area. It can be further extended for the whole country, and can be combined with the administrators to create an emergency information system. Another thing that can enhance the research is adding real time traffic data into the network routine since traffic is dynamic.

Author Contributions

Conceptualization, methodology, analysis, writing—original draft preparation, E.A.K.R.E. and W.D.M.V., and writing—review and editing, P.G.R.N.I.P. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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