Development Suitability Analysis of Frequently Flood Affected Areas in Sri Lanka – a Case Study in Rathnapura Municipal Council Area

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***Abstract*—Flood is a natural phenomenon which is difficult to avoid but can control. Flood hazard tends to escalate into disaster, especially in urban areas, due to the high concentration of population. Therefore, flood mitigation measures have become one of the main discussing point in the society. Nowadays there has been a significant move from flood protection to flood risk management. Spatial planning has been identified as one of the fundamental flood management measures, since it can influence the incidence of flooding and its consequential damage, by regulating the locations of activities, types of land use, and scales of development and designs of physical structures. In order to develop such a successful spatial plan, it is important to identify the suitability of the land for the development. However, adequate attention is not still paid to develop a proper mechanism for evaluating this development suitability. The main objective of this research is to analyze the development suitability of the lands, considering both Emergency Evacuation Easiness and the flood risk level of the land. This analysis will be useful to develop a set of guidelines for the future development activities. The research has used the Geographical Information System based approach to model the development suitability of the lands. Two main aspects were assessed in this regard: flood risk level and emergency evacuation easiness. It was assessed by taking the Rathnapura MC as the case study area and the uncertain event as the flood disaster. The research resulted a development suitability map displaying the development suitability levels of each land plots of the study area. This map is very useful for urban planners to decide which type of development is suitable for different areas considering the natural disaster. The same method can be applied to other natural disasters to get an idea about the development suitability of the areas which frequently affect with natural disasters.**

***Index Terms*—development suitability, emergency evacuation easiness, flood risk management, spatial planning, vulnerability & risk assessment**

I. Introduction

Flood hazard is one of the most devastating natural hazards which have caused a large number of fatalities and economic losses [1]. Due to the unplanned urban expansion and lack of urban management, risk of disasters & potential of economic and human losses from natural hazards is increasing in the developing world. Flood is such a main natural disaster. Nowadays, it has become a more critical issue as developments are spreading into flood prone areas. So, flood related issues such as displacements, evacuation delays, and structural damages are also increasing day by day.

Asia is highly vulnerable to flooding than other continents. Exclusively, the deaths caused by flooding in Asia accounted for 96% of the total disaster related deaths between 1950 and 2011, followed by the America at 2.6%, Africa at 0.9%, and Europe at 0.4% and Oceania at 0.02% [2].

As a result of these flood related issues, flood risk management has become a major discussing point in the present society. Already, different risk management mechanisms have been introduced to the world. Evacuation planning is one of the main flood risk management methods, among them [3].

When evaluating the flood risk, recent disaster experiences also prove the need of considering the existing evacuation easiness. Specially, for large scale developments, it is necessary to check the availability of evacuation routes and evacuation shelters, since these developments can attract a huge population to the area. If that crowd is unable to evacuate immediately during a flood disaster, the number of fatalities can increase [4].

However, adequate attention is not still paid towards evaluating the existing evacuation easiness, when proposing developments in disaster prone areas. Additionally, a very little investigation was carried out regarding the evaluation of suitability of the land for the development, considering both flood risk & evacuation easiness, when performing spatial planning.

The purpose of this study was developing a proper mechanism, to evaluate the suitability of the land for the

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development considering both flood risk level of the land and evacuation easiness of the people in the area.

With the help of that mechanism, safety level of the area was supposed to be evaluated. It will be useful for,

- Providing enough evacuation facilities for existing developments
- Selecting the suitable locations for future developments

Improving the safety level of the area by improving the evacuation easiness or reducing the flood risk level.

II. Objectives

The objective of this research is to analyze the development suitability concerning frequent flooding events in the case study area and introduce a set of guidelines for the future development activities with the help of identified development suitability levels.

III. Study Area

Flood disaster in Rathnapura Municipal Council (RMC) area was taken as the case study for this research. As mentioned in the Sri Lanka's Climate Change Vulnerability Data Book (2011), most of the emerging town areas in the Sabaragamuwa Province are highly vulnerable to flooding & landslide disasters. Specially, RMC has been identified as, highly vulnerable area.

To measure the development suitability, two main aspects were assessed: flood risk and emergency evacuation easiness. These two aspects were analyzed based on two frameworks.

Flood Risk - Vulnerability and Risk Assessment (Framework, derived from vulnerability analysis, which was introduced by the European Commission on "Assessing Vulnerability to natural hazards in Europe.) [5].

Emergency Evacuation Easiness - Emergency Evacuation Easiness Assessment (Framework, derived based on Chinese National Standard on evacuation shelter planning) [6].

IV. Method

To achieve the objective two main sections were undertaken through method: vulnerability and risk assessment and measure of emergency evacuation easiness. The flow chart of the methodology is given in Fig. 1.

A. Vulnerability Analysis

This is the first component of measure of development suitability of the land. It consists of 3 sections: hazard assessment, vulnerability analysis and risk analysis. Each section has explained in the following paragraphs.

B. Hazard Assessment

For this study, 5-year flood scenario was used to prepare the flood hazard map shown in Fig. 2. Considering the hazard rank formula "(1)", flood inundated area was weighted using these three factors (d, v, DF)

$$HR=d\,(v+n)+DF \quad (1)$$

- HR = Hazard Rating
- d = depth of flooding (m)
- v = velocity of flood waters (m/s)
- DF = Debris Factor
- n = 0.5 (constant)

C. Vulnerability Assessment

To assess the vulnerability, vulnerability dimensions were identified through literature. For each dimension an indicator and the percentage of influence was defined. Table I displays the identified dimensions, their indicators and the percentage influence given to each indicator.

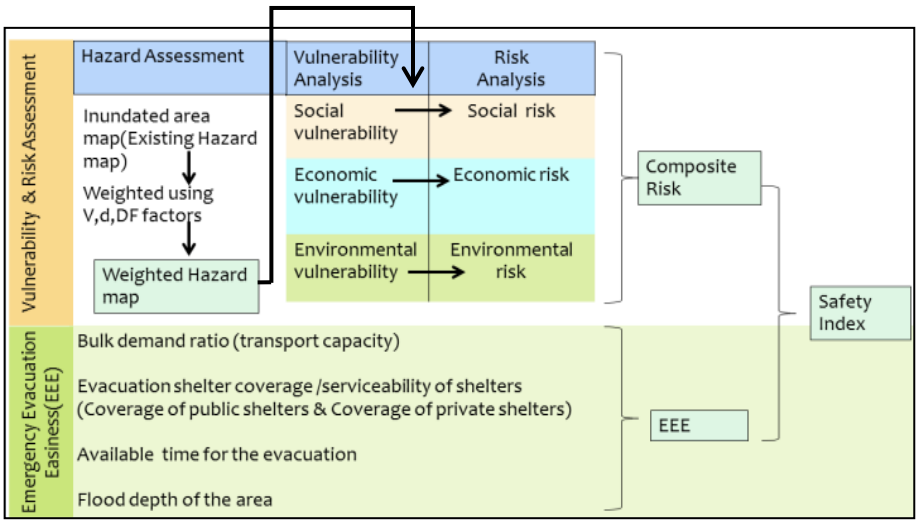

Figure 1. Flow chart of method.

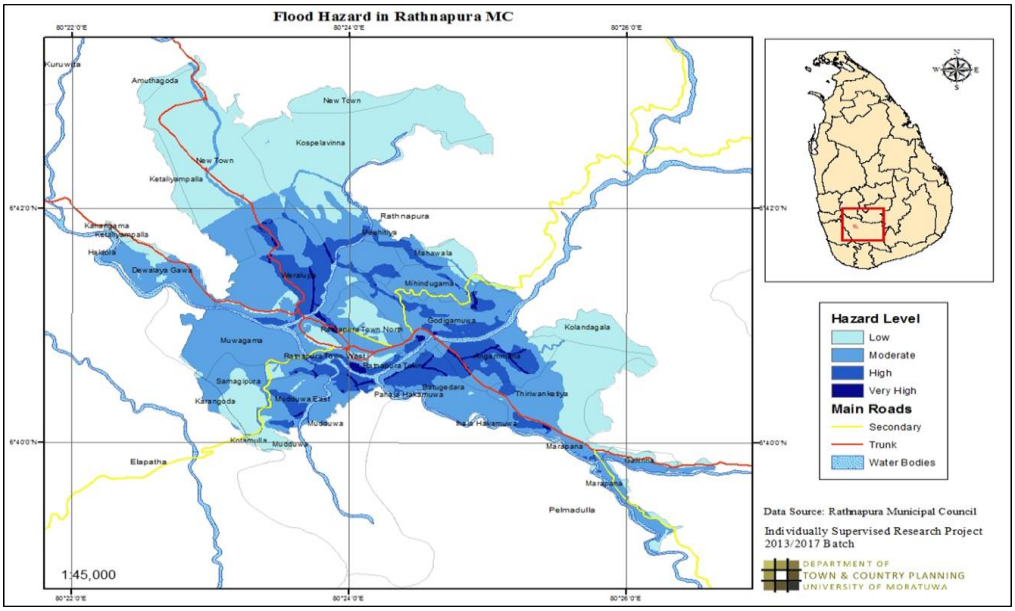

Figure 2. Hazard map of Rathnapura MC.

TABLE I. VULNERABILITY DIMENSIONS

Vulnerability Dimension	Elements at Risk	Indicator	Influence
Social	Residential population	Population Density	20%
	Children	14>Age group(Density)	20%
	Elderly population	60<age group(Density)	20%
	Women	Density of Women	20%
	Disable people	Density of disable people	20%
Economic	Land uses	Economic impact on land uses	25%
	Job security	Job security per area	25%
	Buildings	Building density	25%
	Unemployment	Unemployed population density	25%
Environmental	Land uses	Environmental impact on land uses	100%

Primary source: Compiled by the author
Secondary source: Vulnerability & Disaster Risk Assessment for Rathnapura MC Area,2011

To evaluate the vulnerability level, total MC area was divided into 10m* 10m cells. Those cells were weighted considering the element at risk in the cell, using a scale of 1-10 based on the quintile interval and prepared raster layers. Next, those raster layers with weighted risk elements were overlaid to prepare final social, economic and environmental vulnerability maps. Weights for the environmental elements were decided using report of Vulnerability & Disaster Risk Assessment for Rathnapura MC.

Final vulnerable maps were classified into four groups as low, moderate, high and very high based on the quintile interval.

D. Risk Assessment

Risk is the probability that negative consequences may arise. When hazards interact with vulnerable areas, people, property and the environment are at the risk. Equation 2 explains the disaster risk formula.

$$\text{Risk} = (\text{Hazard}^* \text{ Vulnerability})/\text{Capacity} \quad (2)$$

To evaluate the social, economic and environmental risk in the RMC, vulnerability maps were separately overlaid with the prepared hazard map.

E. Evacuation Easiness

Using primary and secondary data, evacuation easiness was evaluated based on four factors. To evaluate the influence of each factor, separate GIS layers were prepared and overlaid them to identify the evacuation easiness in the area.

Bulk-lane demand ratio in the area (transport capacity). Equation 3 explains the bulk lane demand measurement.

$$\text{Bulk lane Demand} = P/C \quad (3)$$

where,

P= Number of people within the specific region or cluster/Total vehicle demand leaving a neighborhood
C= Number of lanes of roadway leaving a neighborhood [7].

- Evacuation shelter coverage in the area (Coverage of public shelters & Coverage of private shelters

All the shelters within the area were categorized into two groups according to the ownership;

- Private shelters: Schools, temples, mosques and other public buildings

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- Private buildings: Houses, resorts and other private structures

According to the Chinese National Standard, effective coverage area of a public shelter is 500m. Therefore, 500m was used as the buffer interval to prepare the map of coverage area of the public shelter. Shelter coverage of a private evacuation shelter is usually lesser than a public shelter. According to the field observations, the effective coverage area of a private shelter is limited to 100m buffer. So, considering 100m buffer intervals, the coverage area of a private shelter was identified., Thus, coverage areas of each evacuation shelter was identified using 'Euclidean distance' tool in Arc GIS.

Available time for the evacuation

In this study, 1 -year, 2- year and 5-year scenario maps were used to identify the immediately inundated areas in the MC boundary.

Assumption:

- Inundated areas even during 1 year floods, are immediately inundated areas. (Available evacuation time is low)
- Additional inundated areas during 2 year floods are moderate inundated areas (Available evacuation time is moderate)
- Additional inundated areas during 5 year floods are low inundated areas (Available evacuation time is high)

F. Flood Depth of the Area

The maximum flood depth which can be considered as safe for evacuation is 0.3m above ground level. Therefore, flood levels above this value were considered as critical situations for evacuation. Thus 03m was considered as the threshold flood level. Using the inundated depth of the area, flood depth layer was prepared using the 'Raster classification method'

V. Analysis and Results

A. Preparing Development Suitability Map

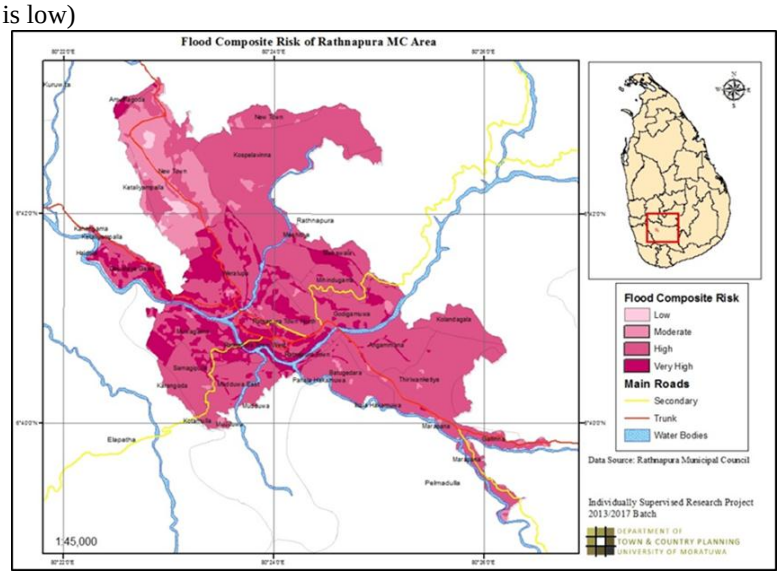

Figure 3. Composite flood risk map.

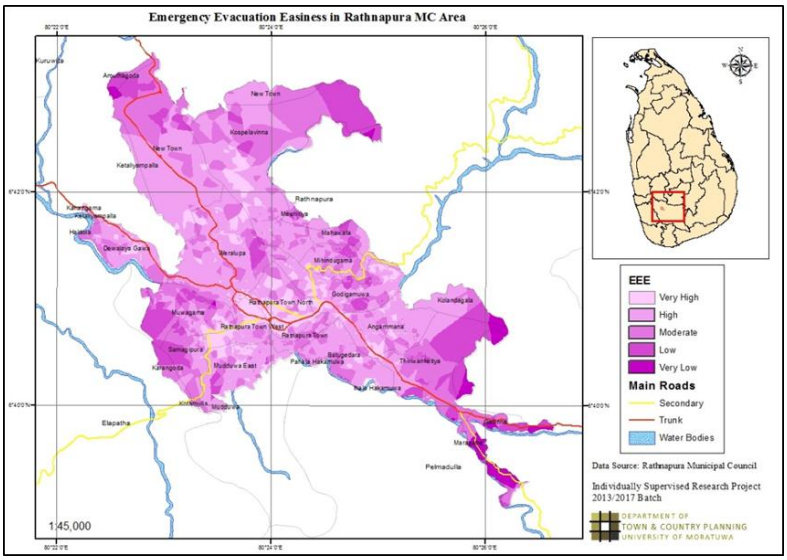

Figure 4. Emergency evacuation easiness of the study area.

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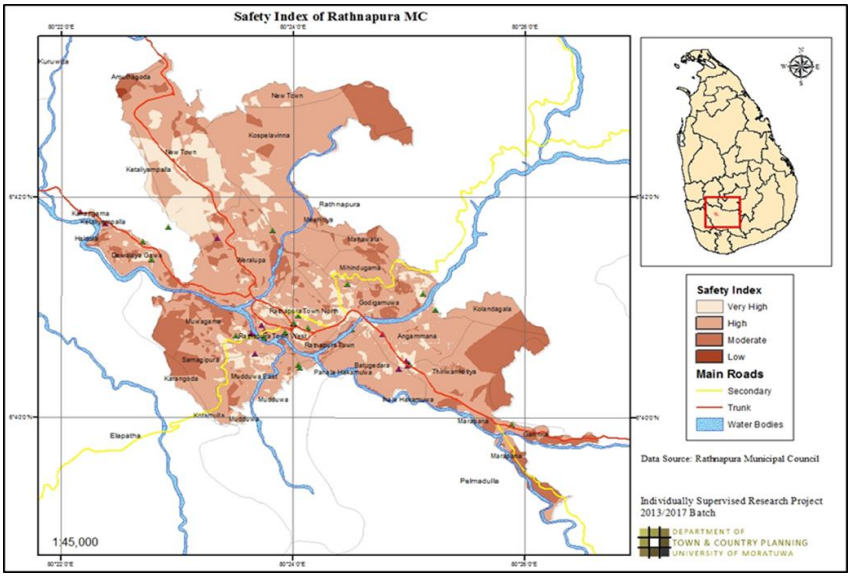

Figure 5. Development suitability map for the study area.

The composite flood risk map indicates the flood risk level in RMC, relevance to economic, social and environmental dimensions. Fig. 3 displays the prepared composite flood risk map. According to this map, total MC area has divided into four categories considering the flood risk level.

High flood risk patches has spread in whole MC area, especially in Dewalaya Gawa, Weralupe, Rathnapura town, Mudduwa, Godigamuwa, Angammana, Muwagama. Predominantly, these areas have residential and commercial uses.

Rathnapura New Town area categorized as a low risk area. According to the land use map, most of these lands are vacant lands. But, main commercial activities are still concentrated in high risk areas in Rathnapura old town.

Next the Emergency Evacuation Easiness (EEE) map was prepared. Fig. 4 displays the prepared EEE map. According to the map, total RMC has been categorized into five groups. Most of the areas which have high EEE are located near Rathnapura town area. Besides, small patches with high EEE, could be seen all over the Rathnapura MC.

Using the derived composite flood risk map and the EEE map, a development suitability map for the study area was derived for the five-year flood affected area. Fig. 5 displays the development suitability map. According to it, Old town area has high development suitability though its flood risk is high because, it has high EEE. However, Muwagama, Godigamuwa areas has low development suitability as these areas have both high flood risk and low EEE.

As a conclusion, this development suitability map indicates that some high safe locations are located adjacent to low safe locations. These zones can be developed as observation points. Safety index is not proportional to the contour elevation. Therefore, high elevated areas always are not safe locations for the development. Validation of Flood composite map was done based on UNDRO Risk Calculation, (1982). Validation of EEE was done base on the locations of existing evacuation shelters.

B. Development Guidelines for the Study Area

After analyzing the development suitability of the study area, a set of development guidelines were proposed to the area referring literature. Table II displays the summary of development guidelines extracted from literature [8].

This guideline with land use classification was prepared based on few factors such as flood impact, comparative susceptibility, resilience to flooding, and community impacts caused by their damage or loss.

TABLE II. PROPOSED DEVELOPMENT GUIDELINES

Safety index Level	Land use type	Examples
Very high	Civil infrastructure and most vulnerable in the SPP 2014 glossary.	• Police stations • Ambulance stations • Fire stations • Hospitals • Essential transport infrastructure (including mass evacuation routes) that has to cross the area at risk • Essential utility infrastructure (electricity generating power stations and grid and primary sub-stations) • Residential institutions such as residential care homes/ prisons, nurseries, children's homes and educational establishments • Installations requiring hazardous substance consent

High	Highly Vulnerable Uses	• Buildings used for dwelling houses • Hostels and hotels • Non-residential uses for health service • Social services homes (ambulant /adult) • Student halls of residence • Landfill and sites used for waste management facilities for hazardous waste
Moderate	Least Vulnerable Uses	• Shops • Financial, professional, and other services • Restaurants and cafes • Land and buildings used for agriculture and forestry • Hot-food takeaways • Drinking establishments • Nightclubs • Offices • General industry • Storage and distribution
Low	Water Compatible Uses	• Flood control infrastructure • Water transmission infrastructure • Water-based recreation • Amenity open space • Outdoor sports and recreation • Sand and gravel workings • Docks, marinas and wharves • Navigation facilities • Dockside fish processing and refrigeration

VI. Conclusions

The main objective of the research was to develop a map displaying the development suitability considering the natural disasters occur in Sri Lanka. For this task the flood disaster was considered as an example. Considering the flood events frequently occur in Rathnapura area a development suitability map was developed. The results were pleasing and the same technique can be applied for other disasters such as landslides, droughts, cyclones, etc. Planners can use this development suitability map as a guideline for the development. As it indicates the existing safety level of the area, they can decide whether the existing safety level is enough or not for the specific development. If that safety level is enough, they can implement the development. Whether the safety level is not sufficient, they can select another suitable area for the development or improve the safety level of the land through providing evacuation facilities or reducing flood risk.

Besides that, this visual interpretation can be used to proposed evacuation routes, evacuation shelters to the residence also since, it indicates the critical locations for the evacuation. Those areas need to be given high priority when establishing shelters or evacuation routes. The development guidelines prepared based on the development suitability can be used to identify the suitable land uses for the area based on its safety level.

VII. Limitations of the Study

These findings are more applicable to the disaster events that can occur in the night time, due to the unavailability of day time building wise population. Besides that, the number of evacuees in a certain area can be changed with the time.

VIII. Suggestions and Recommendations for Future Research

This research can be further focused to analysis about other disasters such as landslides and prepare the development suitability maps [6]. It will improve the decision making regarding development of lands. Besides that, through findings of the building wise day time population, EEE map can be developed for day time disaster evacuation. It will also improve the accuracy of the development suitability map.

If this development suitability map can be developed for the flash flooding events, it will be useful to identify the safety lands according to the rainfall intensity. Further this development suitability map will be useful to develop an impact range index.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Ms Jayasekara assisted in data gathering. Dr Ranasinghe and Dr Mrs. Gunasekara analyzed data, wrote the paper and conducted research. All approved final paper.

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