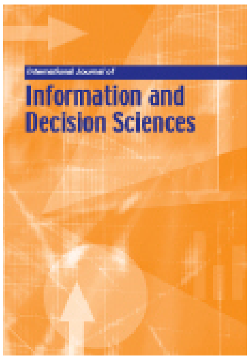

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A GIS-based framework for flood hazard vulnerability evaluation in Thudawa area, Sri Lanka

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Abstract: The objectives of our research were identifying and classifying flood risk areas into different classes in Thudawa area, Sri Lanka, and developing a geographical information system (GIS) model to identify flood vulnerability areas accurately in Thudawa area. It was expected to propose preventive guidelines of flood hazard vulnerability using geo-informatics. The methodological procedure is extremely important in this type of research thus, the spatial multi-criteria decision analysis (MCDA) procedure was used. For this research, analytical hierarchy process (AHP) was used for the criterion weighting. AHP calculations run upon the results of experts' judgment as proposed by the Satty incorporating pair-wise comparison method. The results of this study attempt to analyse the existing flash flood risk levels using the GIS-based multi-criteria analysis technique which allowed ranking of risk areas since it is important in the decision-making process to mitigate the flood risk in the study area.

Keywords: analytical hierarchy process; AHP; flood hazard; geographical information system; GIS; spatial multi-criteria decision analysis; MCDA; modelling; Sri Lanka.

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1 Introduction

With increasing urbanization natural disasters also have increased at a global, regional, and local scale. Natural hazards have been defined in several ways as catastrophic events that threaten humanity as a result of the interconnection between the natural and human ecosystems. Floods can be classified as one of the types of meteorological hazards. Among the natural disasters flood is one of the most destructive and frequent environmental disasters on the earth's surface in the world. Flood engineers, hydrologists, meteorologists, and geographers have come up with different definitions, so it is difficult to define them clearly. But generally, the natural behaviour of water is that it moves from higher ground to lower ground. This means if there is a higher ground adjacent to the lower ground, the lower ground is a lot more likely to experience floods. Additionally, anywhere that rains fall, floods can develop. This is so because more rains are bringing more water than it can be drained or absorbed by the soil, there is a flood potential. Among all the environmental hazards, flooding has produced the most devastating effects. Flooding is extremely dangerous and has the potential to wipe away, and the entire city, coastline or area, and cause extensive damage to life and property. Floods occur because of heavy rains or melting of snow or both when the flow in the river is so high that its natural cross-section is unable to contain it and most common floods happen around the world's largest/greatest rivers. Floods are a major threat to human endurance and historically have both caused the collapse of civilisations and forced the emergence of new cultures. The physical processes of flooding are complex. Increased population, climate variability, change in the catchment and channel management, modified land use and land cover, and natural change of floodplains and river channels all lead to changes in flood dynamics, and as a direct or indirect consequence, social welfare of humans (http://www.sciencedirect.com, 18.08.2019).

Floods can have harmful effects on the one hand but positive effects on the other and also. Floods can have destructive compensation and can have effects on the economy, environment, and people. During floods roads, bridges, farms, houses, and automobiles are destroyed. People become homeless. Then the environment also stands when floods happen. Chemicals and other hazardous materials end up in the water and ultimately seduce the water bodies and floods end up in and also flooding causes kill animals, and other insects, and causes defacing the natural balance of the ecosystem. Then many people and animals have died in river floods. Many more are injured, and others are made homeless. As a result water supply and electricity are disrupted, and people struggle and suffer. In addition to this flooding brings lots of diseases. On the other hand, there is also something good about floods, especially those that occur in flood plains and farm fields. Flood water carries lots of nutrients that are deposited in the plains. Sediments on the banks of rivers overflow into productive areas. Also, groundwater resources are fertilised by increasing the pool of water entering the groundwater reservoir due to overflowing water.

Many factors contribute to the occurrence and frequency of river floods. These factors are divided into two types as natural and human factors. Natural factors are heavy rains, long periods of rain, snowmelt and steep slope, impermeable rock, saturated soils, and compressed or dry soil. Urbanisation and deforestation are the main human factors that affected the flood. Precipitation is the dominant reason for river floods among the above factors.

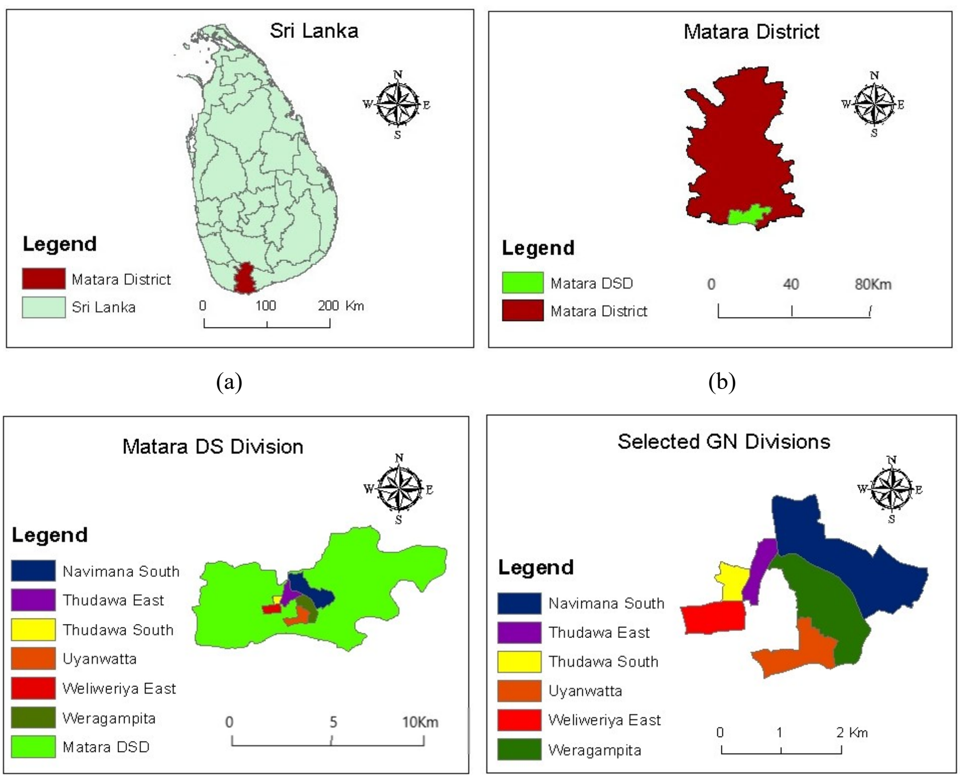
Although Sri Lanka is a small country, there is no shortage of hazards and disasters caused by environmental hazards. From time immemorial, catastrophic natural disasters have threatened the very existence of mankind. Floods, droughts, cyclones, and landslides are among these natural disasters, flooding has become a natural phenomenon that has always plagued mankind. In addition to droughts, floods have had a profound impact on human settlements, especially compared to other natural hazards. According to the field pattern of flooding in Sri Lanka, the wet zone and dry zone can be divided into two main zones. Southwest monsoon rains are a major contributing factor in flooding in the wet zone. Some years the tropical cyclones and depression caused by the southwest monsoon caused great flooding. Heavy rainfall and increased rainfall intensity are factors that directly affect flooding. In addition to these factors, the morphological features of river basins may have affected flooding. The downstream area of the river basins in the wet zone is constantly prone to flooding. In particular, Mahaweli, Kelani, Kalu, Walawe, Gin Ganga, Nilwala Rivers can be found. Lower basins of these basins are flooded due to overflow during monsoon rains. Annual floods in these areas cause pernicious floods under different comebacks. In Sri Lanka, over the last five years floods have caused huge damage and serious socio-economic risks.

The research attempted to study how geographical information system (GIS) integrated multi-criteria analysis help to identify flood hazard vulnerability in Matara, Thudawa area. Thudawa South, Thudawa East, Navimana South, Uyanwatta, Weliweriya East, Weragampita GN divisions selected as the study area situated in Matara District associated with Nilwala riverine area. On the 27th of May 2017 there was a huge flood situation that was most affected in Matara District. The reason for this flood was heavy rainfall and long periods of rain. As a result, 155,591 people belonging to 41,564 families have been displaced in 16 divisional secretariat divisions due to the flood situation in Matara District. 21 people were killed and 14 people were disappeared. One person was injured in that situation. 2088 damaged houses have been reported in that situation. Water supplies have been halted for 90% due to flooding of Kokmaduwa and Balakawala pumping stations (http://www.dinamina.lk, 06.06.2019).

In the multi-criteria decision-making process different analytical hierarchy process (AHP) methods are used by the decision-makers when various criteria to be considered in their decisions as fuzzy AHP, fuzzy multiple-attribute decision-making method (MADM), fuzzy TOPSIS, and Pythagorean fuzzy AHP, etc. In fuzzy AHP fuzzy sets combined with AHP and the method was introduced by Alavi et al. (2011). This method maintains the advantage of AHP and has to gain more popularity in multi-criteria decision-making. In fuzzy AHP there are four main steps as establishing the comparison matrix, aggregating multiple judgments, measuring the consistency, and defuzzifying the fuzzy weights (Yan et al., 2020). Fuzzy AHP provides a suitable condition for reasoning, deduction, control, and making a decision especially in vague conditions and it converts the quality judgment to quantitative numbers. Chang introduced a new approach for handling fuzzy AHP with the use of triangular fuzzy numbers for the pair-wise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons (Alavi et al., 2012). MADM refers to making decisions in a discrete decision space which is characterised by the explicit description of the set of alternatives and the attributes involved in the evaluation process. As one of the well-known ranking methods of multi-criteria decision making fuzzy TOPSIS was first introduced by Hwang and Yoon (Mokhtari et al., 2014).TOPSIS logic defines the ideal and anti-ideal solutions which are based on the concept of relative closeness in compliance with a shorter distance from a positive ideal solution and the farthest distance from a negative ideal solution (Alavi et al., 2012).In the Pythagorean fuzzy AHP method fuzzy sets are developed for provides more freedom to experts in expressing their opinions about the vagueness and impreciseness of the considered problem because in Pythagorean fuzzy experts do not have to assign membership and non-membership degrees whose sum is at most (Ilbahar et al., 2018). For the study authors used AHP spatial multi-criteria decision analysis (MCDA) for the flood hazard vulnerability assessment in the Thudawa area since this method was easy to use considering the mathematical background and complexity of other said AHP methods. Due to the unavailability of freely available software for AHP calculations manual calculations were performed for the study.

In their research on Laura et al. (2020), proposed a methodology for the analysis of social vulnerability to floods based on the integration and weighting of a range of exposure and resistance indicators in Ponferrada municipality in Spain. The majority of the data for the study came from open public data sources. In another research on assessing and mapping flood hazard vulnerability and risk in the upper Brahmaputra River valley using stakeholders' knowledge and multi-criteria evaluation. Through this study, Hazarika et al. (2018) tried to assess flood risk using an indicator-based methodology. Then they showed flood hotspots of vulnerability and risk of regional and sub-regional levels in the study area (Hazarika et al., 2018). In their research, Masood and Takeuchi (2012) tried to develop a flood hazard map using hydrodynamic simulation based on a digital elevation model. Data for the research came from shuttle radar topographic mission and hydrologic field observed data for 32 year period (Masood and Takeuchi, 2012). The research called flood hazard, vulnerability, and risk assessment for different land-use classes using a flow model Albaky et al. (2020) tried to introduce a new approach of assessing flood risk using vulnerability indices. Here 2D flood simulation was performed with a delft 3D model to compute floodplain inundation depths for hazard assessment at Baniacheng Upazila, Bangladesh (Albaky et al., 2020). In the research on flood risk map based on GIS and multi-criteria techniques (case study Terengganu Malaysia), Ranya et al. (2015) tries to determine flood potential areas using spatial multi-criteria evaluation technique because the heavy floods in the Terengganu have shown an increasing trend in recent years. In this research, the spatial multi-criteria analysis was used to rank and display potential locations, while the AHP method was used to compute the priority weights of each criterion (Ranya et al., 2015). In the research titled 'GIS-based multi-criteria analysis for flood risk assessment: case of Manouba Essijoumi Basin', NE Tunisia Saidi attempted to study the potential of GIS-based multi-criteria analysis for flood hazard identification in Manouba Essijoumi basin, NE Tunisia. It analysed the relationship between the spatial distribution of vulnerability, exposure, and hazard to investigate the risk to communities. This research undertakes quantitative methods including vulnerability assessment, hazard assessment, risk evaluation, etc. slope, drainage density, permeability, land use, spontaneous habitats, and rainfall intensity were used as multi-criteria of this research (Saidi et al., 2019). Daniela and Usman have been undertaken another research in 2018 as 'Flood risk mapping using GIS and multi-criteria analysis' as a case study in the Greater Toronto area. The objective of the research was to take action on reducing the number of people affected by social vulnerability and economic losses. But they mainly aim to develop updated and accurate flood risk maps in the Don River watershed within the Greater Toronto area (Rincon et al., 2018). In Rincon et al. (2018), was created flood risk maps in their study at Abidajan District, Ghana with integrating GIS and MCDA. Slope, drainage density, soil type, population density, isohyets were used as the main criteria of the study used in the Arc interface (Rincon et al., 2018). In the research of GIS-based mapping of flood in Eravurpattu DSD in Sri Lanka, Aashifa et al. (2017) tried to develop a GIS-based flood model using variables such as the number of flood occurrences, population density, elevation and the distance between the water bodies and the flood occurred area. In his research of flood hazard mapping in the lower reach of the Kelani River, Gunasekara (2008) has tried to prepare flood depth and extend maps for different return periods using a hydrodynamic model in Arc view.

Figure 1 Location of (a) Sri Lanka, (b) Matara District, (c) Matara DSD and (d) selected GN divisions for flood hazard vulnerability assessment within Matara DSD (see online version for colours)



(a) (b)

(c) (d)

The research analysed the spatial distribution of vulnerability levels of flood hazards in the study area. At present structural measures are not suitable for that task. Most of the non-structural measures like flood forecasting, proper early warnings, and conducting awareness programs among the flood-affected community can be very effective. The application of GIS and remote sensing technology to map flood areas will make it easy to plan non-structural measures that reduce the flood damages and risks involved. It will be a great benefit to the people to implement a flood management program that consists of flood forecasting and flood hazard and vulnerability mapping. Therefore, the benefits of this research are very much for the people living in Nilwala riverine area. The main objective was to develop a GIS-based model for flood hazard vulnerability in Matara, Thudawa area. And also, identifying and classifying flood hazard risk areas into different vulnerability classes and proposing preventive guidelines of flood hazard vulnerability based upon the GIS model which developing through the study. Poorly conducted hazard and risk assessments can lead to poor risk management decisions, from insufficient protection to the wasting of scarce finances on unneeded protection. Well-conducted flood hazard and risk assessments, on the other hand, can provide valuable support for a range of decisions such as land-use master planning, design of infrastructure, and emergency response preparation. GIS is one of the most powerful analytical tools in many research areas. It offers several different technologies, processes, and methods. And also MCDA gives a logical well-structured process to follow so different factors can be identified. Multi-criteria analysis has been widely applied to solve decision-making problems related to water resources and also AHP was used as the weighting method. So, the result of the study attempts to analyse GIS-based multi-criteria risk analysis as produced maps that allow ranking of risk areas.

2 Materials and methods

2.1 Study area

Matara district which is situated near Nilwala River close to the sea is in between Galle and Hambantota districts in southern Sri Lanka. It possesses an attractive land containing an extent of 1282.5 Sq. km. or 128,250 hectares. Matara District falls in between 5.8–6.4 north latitude and 80.4–80.7 east longitude. The district has a wet climate with having a mean rainfall of 2564.9 mm, and a temperature of 29.1°C. 1.96% of the total land extent of Sri Lanka belongs to the district. Matara district covered 650 GN divisions. Six GN divisions namely, Thudawa South, Thudawa East, Navimana South, Uyanwatta, Weliweriya East, Weragampita selected as study area as in Figure1.

2.2 Nature of data

Due to time and financial and technical constraints, all spatial data for the study was taken from the Sri Lanka survey department digital data layers which were prepared in 2015 through their airborne survey. All the layers including administrative boundaries, land use, transport network, water bodies, residential buildings of Thudawa area was on the 1:10000 scale. Slope and elevation maps were prepared using the survey department contour point shapefile on the same scale. The population density map was prepared using the available demographic data in Matara divisional secretariat office at the GND level.

2.3 GIS-based multi-criteria decision making process

Multi-criteria analysis has been widely applied to solve decision-making problems related to water resources. This approach is used for flood risk assessment and requires the GIS to evaluate the vulnerability in the study area. This research used the multi-criteria analysis to classify the villages falling in vulnerability into various flood risk zone called very high risk, high risk, moderate risk, less risk, and risk-free by using hazard vulnerability map following five major steps as structuring, standardising, criteria weighting and vulnerability assessment of the flood hazard.

Table 1 Major and minor criteria of the study

Major criteria	*Minor criteria*	*Scale*
Physical environment	Slope	1:10,000
	Elevation	
	Streams	
Socio-economic environment	Population density	1:10,000
	Land use	
Built environment	Residential buildings	1:10,000
	Transport network	

2.3.1 Criteria selection

Structuring considers the identification of the goals of the flood hazard. The main goal of this research is the flood hazard vulnerability assessment using multi-criteria analysis in risk areas. Seven criteria were identified as in Table 1 is relevant to the evaluation of flood hazard vulnerability as road network, residential buildings, streams, population density; land use, slope, and elevation significantly determine the level of flood hazard severity in the study area. Slope, elevation, and streams were taken as sub-criterion under the physical environment. Under the socio-economic environment population density and land use were considered. And also residential buildings and transport networks were considered as sub-criterion under the built environment. Main criteria of this research selected based on the previous research and theoretical conceptual planning aspects on GIS-based flood vulnerability assessment.

2.3.2 Criteria scoring

The values of the various criterion maps (factors) are expressed in different levels of measurements. To compare criteria with each other in the multi-criteria process, all values need to be standardising, which is transformed into the same unit of measurement (from 0 to 1). Standardising is a measure of appreciation of the experts through their judgments for the risk concerning each criterion. The pair-wise method will be used for standardising class maps utilising the results of a semi-structured questionnaire survey. To perform AHP calculations to weight assignment for criterion basically, a semi-structured questionnaire survey was utilised. It used 12 questionnaires in the purposive sampling basics from expertise in the disaster management field, civil engineering, academic, surveying, and GIS field. During the questionnaire survey, 12 questionnaires were distributed among said experts.

2.3.3 Weight assignment and ranking

Different criteria usually have different importance levels. One of the most promising techniques for the development of weights is the pair-wise comparison which was developed by Saaty (1990) in the context of a multi-criteria decision-making process known as the AHP. The pair-wise comparison method converts these comparisons of all pairs of criteria to quantitative weights for all criteria. The final step is to obtain the composite vulnerability assessment map for flood hazards through a weighted overlay technique by combining all criterion maps. This combination is carried out by weighted linear combination (WLC) method. Consequently, the result will be a vulnerability map with having approximately five classes as very high-risk areas (WHR), high-risk areas (HR), moderate risk areas (MR), fewer risk areas (LR), and risk-free areas (RF).

Based on data availability and relevance to the study area, three main criteria were used, physical environment, socio-economic environment, and the built environment. Slope, elevation, and streams were taken as sub-criterion under the physical environment. Under the socio-economic environment, population density, and land use were considered. And also, residential buildings and transport networks were considered as sub-criterion under the built environment. All the sub-criterion maps were created using digital shapefiles in the 1:10,000 scale collected through the survey department as in Figure 2.

Table 2 Main criteria weight matrix prepared using the opinion of one expert

Criteria	*A*	*B*	*C*
A	1	7	1/7
B	1/7	1	1/6
C	7	6	1

Table 3 Weights calculated by AHP using the experts' opinions

Main criteria	*Weight*	*Sub criteria*	*Weight*
Physical environment	0.4043	Slope	0.2804
		Elevation	0.2818
		Streams	0.4374
Socio economic environment	0.1099	Population density	0.3123
		Land use	0.6875
Built environment	0.4885	Residential buildings	0.7984
		Transport network	0.2014

Source: AHP weights calculation based on experts' opinion-questionnaire survey (2020)

Figure 2 Sub criterion maps used for the study (a) slope, (b) elevation, (c) water bodies, (d) population density, (e) roads, (f) land use and (g) houses (see online version for colours)

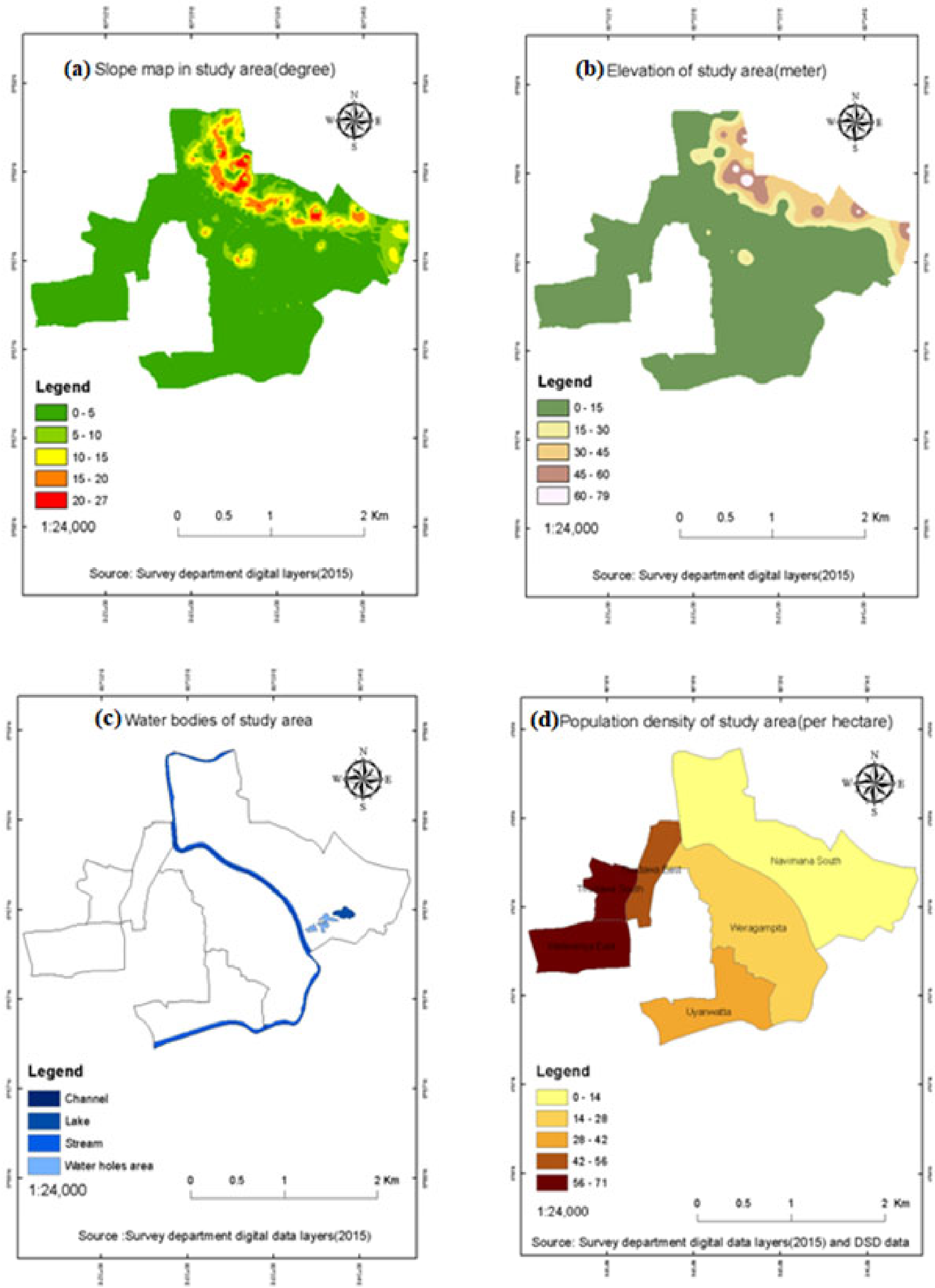


Figure 2 Sub criterion maps used for the study (a) slope, (b) elevation, (c) water bodies, (d) population density, (e) roads, (f) land use and (g) houses (continued) (see online version for colours)

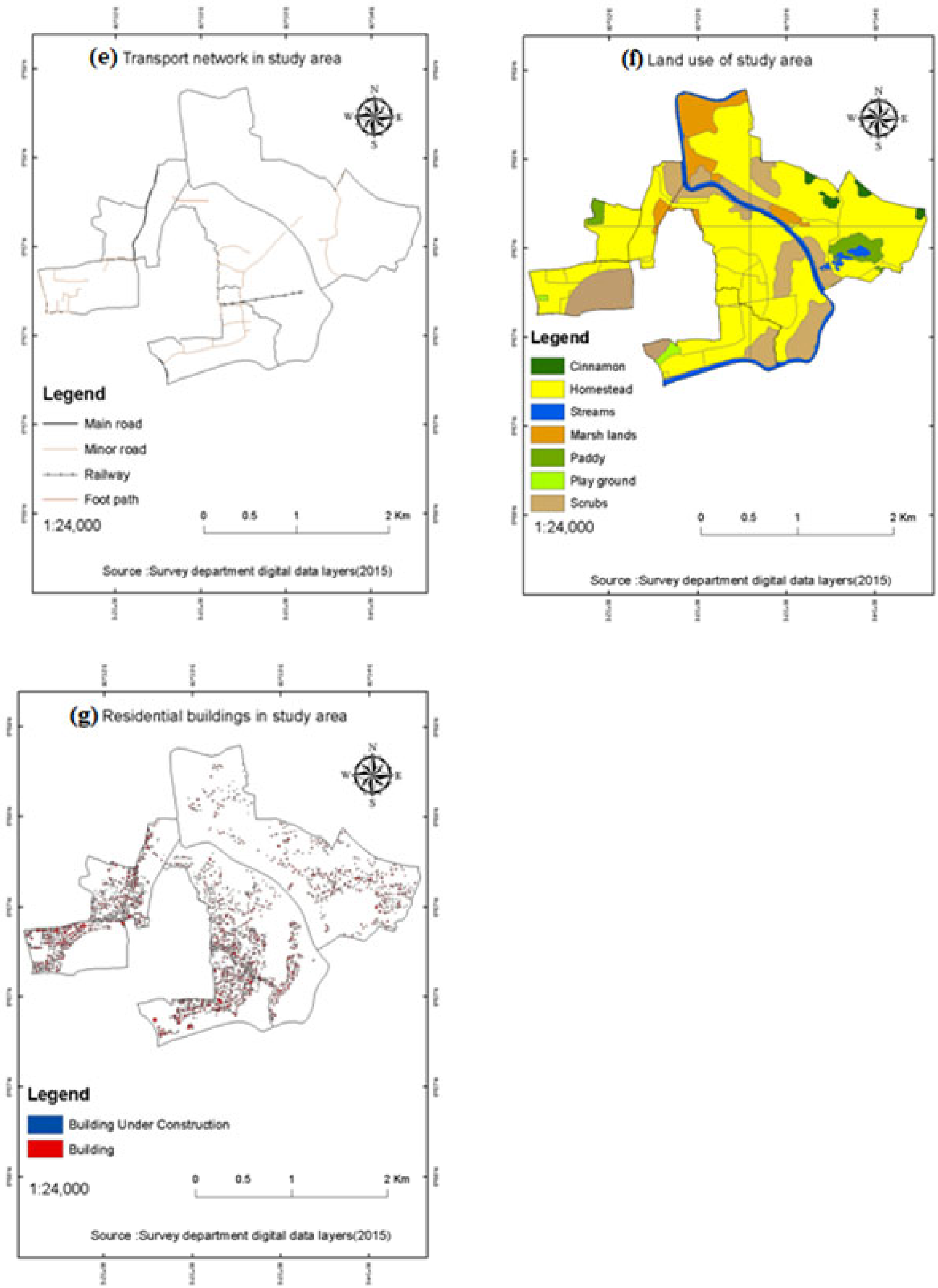
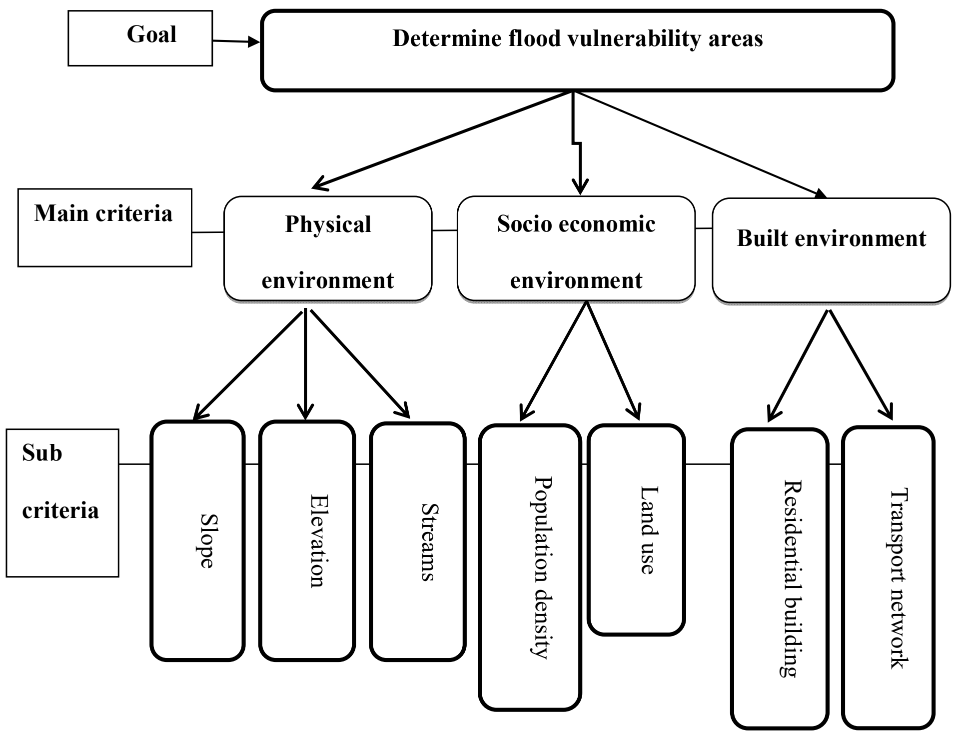


Figure 3 The hierarchical model used to determine flood vulnerability areas comprising goal, main criteria, and sub-criteria used for the study

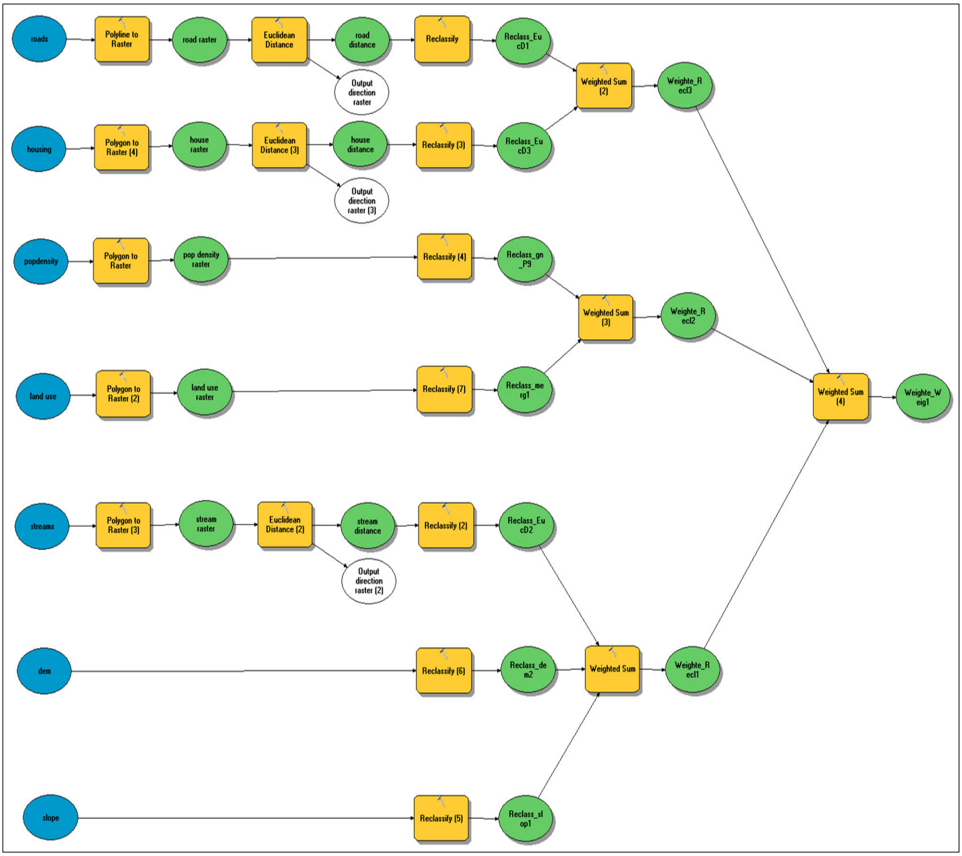


The AHP process is a structured technique for organising and analysing complex decisions. In the study, the AHP structure was constructed with the goal, major criteria, and sub-criteria shows as in Figure 3. Major and minor criteria weighting done using the results of a questionnaire survey done with 12 experts including two geography lecturers who expertise in the geo-informatics field. And also, five Disaster Management Centre (DMC) officials including two assistant directors and three disaster mitigation officers were rank each criterion as their expertise and experiences in disaster mitigation. Four engineers and one land surveyor who having experience in the built environment were also given their opinions on criteria weighting and ranking. Main criteria matrices were filled as mentioned in Table 2. A comparison matrix was used to assigns weights to the main criteria and sub-criteria. All the results of the AHP calculation are shown in Table 3. Score values are standardised to 0 (risk free), 1 (less risk), 3 (moderately risk), 5 (high risk), 7 (very high risk). Then criteria vulnerability levels are calculated. To developing priorities for alternatives AHP was used based on the said 12 experts. It followed several steps as developing AHP, developed paired matrix, assign values, and weight calculations.

2.3.4 Developing a GIS model

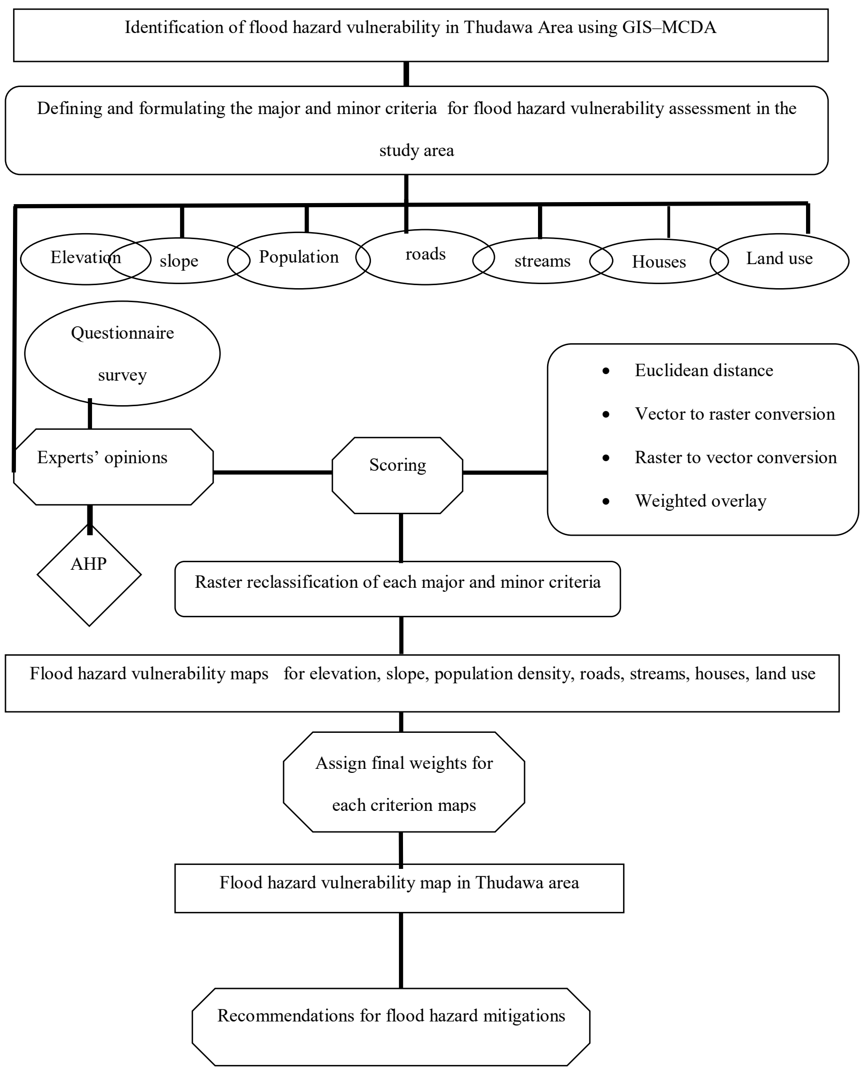
A model is representing the reality of observations adequately. As software, Arc GIS 10.3 version developed by the Environmental System Research Institute (ESRI), USA was utilised. The model builder in Arc GIS 10.3 is a visual programming language for building geoprocessing workflows that use to create, edit, and manage models. It is very significant for constructing and executing workflows.

Figure 4 Arc Map 10.3 model builder procedure of flood hazard vulnerability assessment in Thudawa Area, Sri Lanka (see online version for colours)



In the research model builder (Figure 4) was used and also it used to perform GIS-based spatial analysis with aided the Arc GIS 10.3 software. Each shapefiles were converted into raster format and then Euclidean distances were calculated using a criterion score table based on experts' opinions. After that raster reclassification and weighted overly tools used in model builder to getting final risk zoning maps for sub and major criteria. The spatial analysis procedure depicted as in Figure 5 performed using Arc model builder. As spatial techniques calculation of Euclidean distance (buffering), clipping, vector to raster conversion, Raster to vector conversion, raster reclassification, and weighted overlay using the Arc map interface. Here hierarchical structures were used to represent the main goal and then priorities developed for alternatives on experts' judgment based on paired comparisons. Criteria evaluation and weight assignment determined upon importance. Generally, the AHP model process consisted of main steps as breaking the main problem, developing AHP hierarchy, pair-wise comparison, assign score values and weights upon experts' judgments, determine priority variables, and identify flood risk levels. In the study preparing a flood risk map was the main goal in level 0 and criteria analysis was done in level 1 and weights assignment was done for each criteria's characteristics in level 2. Elements under each criterion (physical, socio-economic, and built environment) were set based on the existing literature on GIS-based flood risk assessment. The binary combination was based on the scale between 1 (equally) and 9 (absolutely better). Judgments from the twelve experts in the field of disaster management were used to assign weights importance of one indicator again another. And final AHP based flood risk map shows all areas susceptible to be flooded. The spatial extent of the risk map was determined using the settlement patterns of the area. The final flood risk map defined five levels of risk areas from risk-free to very high risk.

Figure 5 Research flow and spatial analysis procedure of flood hazard vulnerability assessment in Thudawa area, Sri Lanka



3 Results and discussion

3.1 Flood hazard vulnerability on sub criteria

According to the reclassified risk vulnerability map for slope, is classified into five classes as risk-free, less risk, moderate risk, high risk, and very high risk. According to slope criteria, low slope areas having high flood risk in the areas. Low flood risk can be identified in areas with a high slope. The elevation is a very significant criterion for flood situations. But the elevation of the study area is between 5m–80m. Because of the elevation of this study area, it does not appear to be very high. According to the reclassified vulnerability map, it performed high elevation areas can be identified as low flood risk areas. And also low elevation areas can be identified as high flood risk areas. The study area closest to the Nilwala River is the most affected area by floods. High flood risk is indicated in areas close to the river according to the reclassified vulnerability map. There were 14,134 populations in the study area, according to Divisional Secretariat, Matara in 2019. A high population can be identified in this area. According to the reclassified vulnerability map, high flood risk occurred in high population areas. Land use is a major criterion that causes a flood situation. In this study, homestead areas are at high risk for flood situations regarding reclassified vulnerability maps. The study area is flood-prone. Nilwala River is throughout the middle of this area. So, it affected residential buildings in this area. According to the reclassified vulnerability map, high-risk areas can be identified in residential building areas in Thudawa area. It can be identified as high-risk areas as in Figure 6.

3.2 Flood hazard vulnerability on major criteria

The results of final weights indicated 18.91% (98.99 ha) is a very high-risk area for flood hazard and 46.38% (242.79 ha) are high risk out of the total area based on physical criteria. Not only that approximately 21.66% (112.32 ha) is risk-free/less risk area in Thudawa area as shown Table 4 and Figure 7.

After assigning weights for each sub-criterion as population density and land use under socio-economic criteria indicated 56.03% (293.57 ha) are very high risk and high-risk category for flood hazard vulnerability assessment in Thudawa area. And it was indicated 15.68% (82.23 ha) only risk-free/ less risk area out of total area shown in Table 5 and Figure 7.

Table 4 Flood hazard vulnerability levels for physical criteria

Risk category	*Area (ha)*	*Percentage (%)*
Risk free	38.97	7.44
Less risk	74.35	14.22
Moderately risk	68.31	13.05
High risk	242.79	46.38
Very high risk	98.99	18.91
Total	*523.41*	*100*

After assigning weights for all sub-criterion for the built environment results indicated that 62.11% (325.6 ha) only very high risk and high risk for flood hazard in Thudawa area. And it revealed that 18.51% (97.06 ha) only risk-free out of the total area for flood hazard as shown in Table 6 and Figure 7.

Figure 7 Flood risk vulnerability maps for (a) physical, (b) socio-economic and (c) built environment criteria in Thudawa area, Sri Lanka (see online version for colours)

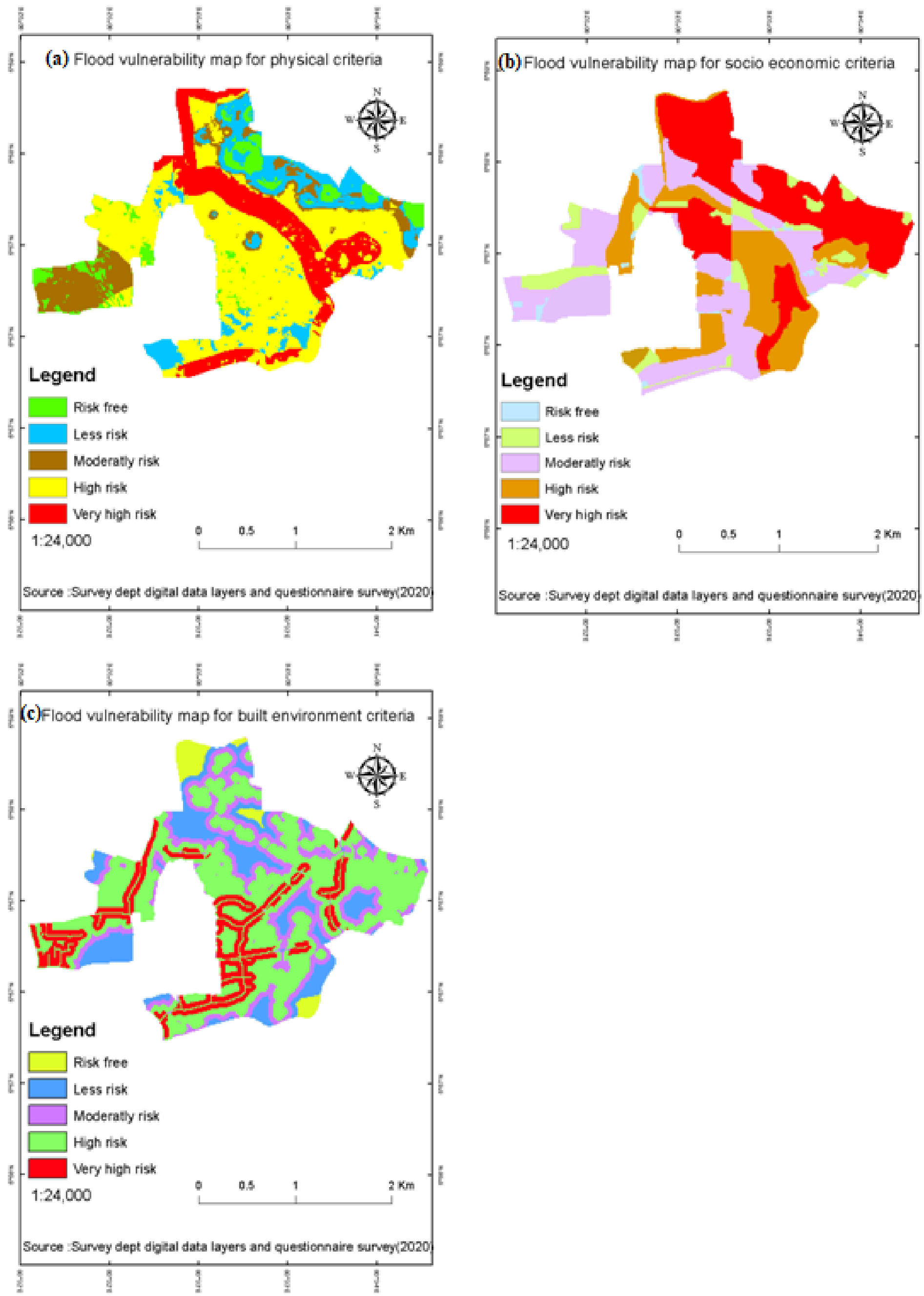


Figure 8 (a) Flood hazard vulnerability zones (b) Residential buildings which laying on different vulnerability zones in Thudawa area, Sri Lanka (see online version for colours)

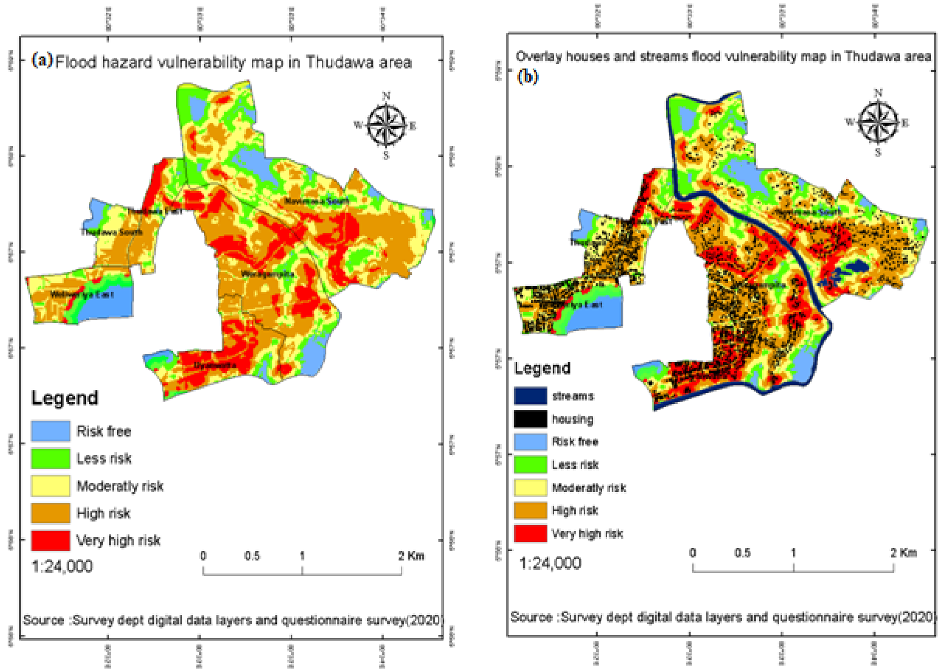


Table 5 Flood hazard vulnerability levels for socio-economic criteria

Risk category	*Area (ha)*	*Percentage (%)*
Risk- free	28.23	5.38
Less risk	54.00	10.33
Moderately risk	148.06	28.26
High risk	119.41	22.79
Very high risk	174.16	33.24
Total	*523.86*	*100*

Table 6 Flood hazard vulnerability level for built environment criteria

Risk category	*Area (ha)*	*Percentage (%)*
Risk-free	18.12	3.45
Less risk	78.94	15.06
Moderately risk	101.48	19.36
High risk	248.54	47.41
Very high risk	77.06	14.72
Total	*523.14*	*100*

Source: ARC GIS 10.3 software-based flood risk area calculation (2020)

Table 7 Flood hazard vulnerability levels in Thudawa area

Risk category	*Area (ha)*	*Percentage (%)*
Risk- free	28.49	5.53
Less risk	75.12	14.44
Moderately risk	129.17	24.65
High risk	214.12	40.84
Very high risk	76.07	14.54
Total	*523.97*	*100*

Source: ARC GIS 10.3 software based flood risk area calculation (2020)

3.3 Flood hazard risk in Thudawa area

When assigning final weights for each major criterion map through weighted overlay it was indicated 55.38% (290.39 ha) of the area is under high risk for flood hazard vulnerability in Thudawa area. Out of 524.27 ha, 5.52% (28.99 ha) is risk-free for flood hazards in this area. And result performed the out of area 14.44% (75.72 ha) is less risk category in Thudawa area as Figure 7 and Table 7. The map reveals that integrated flood vulnerability is higher in the Thudawa area as it laying along the lower plain near to river mouth of the Nilwala River. Despite the eastern part (Thudawa East and Thudawa South GND) central and south western parts of the study area (Weragampitiya and Nawimana south GND) are in high-risk areas. According to the flood risk map overlaid with residential areas most of the people will suffer from the flood during flood events and this means that during floods in these zone people are more prone to damage than other areas of the risk zones. On the contrary, about 10 % of residential buildings are established in less and risk-free areas.

4 Conclusions

The main objective of the research was the delimitation of the flood vulnerability levels concerning physical and socio-economic parameters. The results show that spatial variation of composite parameters of flood vulnerability is a powerful tool for directing future investigations and management in risk areas. Final results revealed that 55.38% of areas are at high risk for flood hazard vulnerability indicating a high potential of the area for flooding. Out of the total land area, 24.65% are moderate risk, 14.44% are less risk area and out of the total area, 5.53% are risk-free for flood hazards in Thudawa area. The study can be considered as a first attempt to cover the physical, socio-economic as well as built environment dimension of flood risk. So, decision-making based on risk/vulnerability to be another important task. Generally level of flood hazard vulnerability is a function of physical, socio-economic, and built environment criteria. Thus, densely populated areas have more economic assets and livelihood options as well as a high risk of the flash flood. It will affect residential buildings in this area since most of the houses were laying in high-risk zones according to the results of this study. The study was selected seven criteria as slope, elevation, distance from roads, distance from houses, distance from rivers, land use, and population density under three major criteria as physical, socio-economic, and built environment criteria for identification of vulnerable locations. But some useful criteria could not be considered as flood frequency, rainfall due to lack of data. So, it is very fruitful and accurate to add more criteria for future GIS-based flood vulnerability identification in the same area. In the Sri Lankan context, DMC plays a major role in identifying and mitigating flood risk. Thus, this model will be helpful as a practical guide to identifying flood risk areas in the study area. And also, DMC and other decision-makers and /researchers can be carried out the same flood risk models using more criteria as rainfall, water level, flood frequency in any flood risk areas.

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