water

MDPI

Article

Integrated Flood Hazard Vulnerability Modeling of Neluwa (Sri Lanka) Using Analytical Hierarchy Process and Geospatial Techniques

W. M. D. C. Wijesinghe [1], Prabuddh Kumar Mishra [2,*], Sumita Tripathi [3], Kamal Abdelrahman [4], Anuj Tiwari [5] and Mohammed S. Fnais [4]

1 Department of Geography, University of Ruhuna, Matara 81000, Sri Lanka
2 Department of Geography, Shivaji College, University of Delhi, New Delhi 110027, India
3 Department of Environment Studies, Shri Lal Bahadur Shastri National Sanskrit University, New Delhi 110016, India
4 Department of Geology and Geophysics, College of Science, King Saud University, Riyadh 11451, Saudi Arabia
5 Discovery Partner Institute, The University of Illinois, Chicago, IL 60606, USA
* Correspondence: prabuddh@shivaji.du.ac.in

Abstract: This research aimed to apply the geospatial techniques and Analytical Hierarchy Process (AHP) approach to find vulnerable areas in terms of flooding in the Neluwa area, Sri Lanka. The study incorporated nine relevant criteria for the vulnerability classification under three sub-criteria; the built environment, physical environment, and socio-economic environment. Under the built environment, road networks and buildings were chosen as sub-criteria. The Normalized Difference Vegetation Index (NDVI), slope, elevation, water bodies, and stream density were taken as physical criteria. Land use and population density were considered as socio-economic criteria. All the criteria are set correctly in raster data, and their contents were well adduced. The study consisted of the use of different levels of criteria and combinations of different processes. The analytical results reveal that 14.24% and 30.24% of the total area are at a very-high risk and high risk for flooding, respectively. Only 5.17% of the land was classified as a risk-free area. Eastern, central, and western divisions of the study area are highly vulnerable to floods due to their low slopes. Based on the produced maps, the spatial extents and levels of risk were systematically identified. Data obtained through qualitative judgments related to the field were validated based on the approach used. The potential of this approach is effective in assessing the spatial vulnerability of these flood-affected areas. Using such criteria and a model-based approach will be constructive in identifying different flood scenarios and in providing a remunerative guideline for potential anticipatory measures and better land-based planning in the area.

Keywords: flood hazard; vulnerability; AHP; geospatial techniques; Sri Lanka

check for updates

Citation: Wijesinghe, W.M.D.C.; Mishra, P.K.; Tripathi, S.; Abdelrahman, K.; Tiwari, A.; Fnais, M.S. Integrated Flood Hazard Vulnerability Modeling of Neluwa (Sri Lanka) Using Analytical Hierarchy Process and Geospatial Techniques. *Water* **2023**, *15*, 1212. https://doi.org/10.3390/w15061212

Academic Editor: Martina Zeleňáková

Received: 3 January 2023
Revised: 11 February 2023
Accepted: 25 February 2023
Published: 20 March 2023

1. Introduction

The frequency of natural disasters has increased manifold in recent years, among other issues that have surfaced in both industrialized and developing nations. Global statistics show that 40% of socioeconomic losses are attributable to natural disasters [1]. This natural phenomenon is mainly due to global warming, which is responsible for changing patterns and intensities of rainfall, resulting in the overflow of rivers and streams. Due to factors such as the inability to cover waterways, the obstruction of drainage channels, climate change, urbanization and population increases, and the construction of physical structures for developmental activities, the frequency of flooding has increased around the world exponentially. A flood is a short-term and occasional rise in the water level of a river or body of water that is caused by heavy rainfall, ocean waves coming onto the shore, such

as a storm surge, melting snow and ice, as well as ice jams, dams or levees breaking, and glacial lake outburst flow [2]. Floods are the most widespread natural extreme weather events and can vary greatly, ranging from a few inches to several feet. Floods are one of the disasters feared by people and increase the risk and vulnerability of a society. The aim of flood risk assessment is important in determining the probability and intensity of a long-term disaster. A river floods when the water level rises above its banks. All rivers and canals can be flooded. This includes everything from small streams to the largest rivers in the world. The term "vulnerability" indicates the measurement of potential risk, as well as the socio-economic ability to tackle the worst situation resulting from the disastrous event [3,4]. The concept of vulnerability includes the vulnerability of environmental and human systems to damage or injury, due to exposure to stressors and lack of adaptive capacity [5,6]. The areas that are vulnerable to flooding are more likely to experience socioeconomic and environmental effects. The premise that all vulnerability indicators are equally important is the foundation of several vulnerability indexes [7]. The use of composite proxy indicators is the most popular technique for measuring vulnerability in the context of global change. In more recent times, vulnerability analysis has used the multi-dimensionality notion [8].

Floods have been identified as one of the most devasting natural disasters, ranking highly worldwide [9], and Sri Lanka is not an exception. Although Sri Lanka is a small country, the impact of environmental hazards and disasters has not diminished. For a long time, natural disasters have greatly threatened the survival and functioning of the human environment. Floods, droughts, cyclones, and landslides are the major types of natural disasters. Floods in Sri Lanka have always been a natural phenomenon, affecting humanity and infrastructure. Based on the flood pattern in Sri Lanka, it can be divided into two main zones: wet and dry. With the onset of the southwest monsoon, there is a high tendency of flooding in the wet zone. In some years, the tropical cyclones and depressions, occurring due to the south-west monsoon, have resulted in significant flooding [10]. Thus, the monsoon season receives unusually heavy rainfall over a short period. Such heavy rains have occurred only in certain years. Soil that is saturated with rainwater is less absorbent. This can happen even if there is forest cover. The water then flows down the river valley. It could cause significant flooding in the lowlands of the river valley. To support risk reduction and long-term adaptation strategies, it is crucial to assess vulnerability to climate change and extreme events, such as floods [11]. Disaster management prioritizes crisis response, recovery, and disaster aid in nations such as Sri Lanka that are vulnerable to natural disasters. Numerous studies have demonstrated paradigm shifts, from disaster relief to the reduction of disaster risk and liability. A clear image of the situation on the ground and an indication of how much the danger is expected to affect the population, capital, assets, and location would be provided through vulnerability assessment and mapping [12,13].

According to the Irrigation Department of Sri Lanka, floods between 5 and 8 feet are minor. Conditions between 8 and 11 feet are considered major floods. Floods beyond 11 feet are catastrophic. Studies have revealed that although most of the flooding typically affects the wet zone, the inter-monsoon rains, which fall in the dry zone during the latter part of the year, can be so severe that the areas can become severely flooded. In the last three to four years, significant floods were reported in the country in May. In 2014, flooding has been reported from the Kalu, Kelani, and Gin river valleys. In 2016, floods were primarily observed in Kelani Valley, while in 2017, they were observed in the Kalu, Gin, and Nilwala Valley (www.vidusara.com, accessed on 21 December 2022). Such events reveal a likely increase in rainfall intensity that is in line with global climate change forecasts. However, the use of Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA), using the Analytic Hierarchy Process (AHP) method, for flood modeling has not been previously explored in the study area. Therefore, in the present study, these technological strategies have been analyzed, with the main difference being the use of the MCDA–AHP method for the Neluwa region along the Gin River for the first time.

This methodology under the proposed new approach allows for a comparison between parameters; as flood conditions are more prevalent in the studied region, flood risk has been identified in different zones through the proposed approach and methodology. Geo-informatics is considered an obligatory tool for spatial analysis and the identification of interrelationships between multiple criteria, and is widely used for natural hazard risk assessment and management. The use of GIS and remote-sensing techniques is one of the most applicable methods to measure and explore flood vulnerability areas [14]. The use of MCDA techniques with AHP comprises one of the most commonly utilized and accepted methods, and has for several decades in the field of research. Saaty has proposed the AHP methodology to better understand the selected variables and criteria in the study in a hierarchical manner [15]. The variables used are comparatively investigated and after ranking them, appropriate values are assigned to the parameters by following befitting procedures [16]. MCDA and AHP methods have been used successfully in many studies in recent years and have been identified as appreciable technical tools in complex decision-making, criterion selection, and problem analysis. MCDA will enhance the effectiveness of studies by incorporating a wide range of technical, environmental, and socio-economic criteria into successful holistic decision-making through this method. The MCDA method was used to map flood vulnerability areas with geospatial techniques. Admittedly, the Remote Sensing (RS)- and Geographic Information System (GIS)-based spatial data is instrumental [17–19] in facilitating a more accurate representation and visualization of results in the study using MCDA [20]. The sustainability and development of the country or region's physical and socioeconomic climate depend heavily on flood hazard management and mitigation techniques. Risk assessment is very helpful in mitigating the impact of flooding on the community, property, and environment.

Several studies have been conducted using geospatial techniques in order to map flood risk through a variety of approaches, in a national and international context. Nuwanka and Withanage [10] have conducted a GIS-integrated MCDA analysis for the identification and analysis of zoning flood hazard vulnerability in the Nilwala river mouth, in Sri Lanka. Here, they also used three main criteria, including the physical, socio-economic, and built environment. Weights for the major and minor criteria were assigned through the expert judgment method, using AHP. The results highlight that out of the total study area (523 ha), 98.9 ha (18.9%) was at the high-risk level and only 38.9 ha (7.4%) was in a risk-free category. In their research, Ouma et al. [21] have described flood risk vulnerability in an urban area using AHP and GIS techniques. Through the AHP method, the research attempted to create a hierarchical structure that would present the best possibilities for flood risk assessments. The results of the study confirmed that the GIS-based AHP method could be used, in this study, as an effective tool in creating flood hazard maps. The study indicated that these integrated methods can be used efficiently and coherently, with spatial data, to reach definitive outcomes. In their work, Vignesh et al. [22] employed an AHP model based on Multi-Criteria Decision-Making Analysis, in order to identify flood risk zones in the geospatial environment's southernmost district of Tamil Nadu, Kanyakumari. They discovered that the district's risk zones are dispersed throughout a vast area. The study highlighted that unplanned urbanization, in addition to rapid population increases, is an important element that needs to be taken into account in the future management of floods in the studied region. A study conducted at a local scale in Bangladesh aimed to develop the spatial multi-criteria-integrated approach, and to apply this to flood vulnerability mapping, by utilizing geospatial techniques and incorporating sixteen criteria selected under three main vulnerability components, which included physical vulnerability, social vulnerability, and coping capacity. Results showed that including the coping capability has a significant impact on vulnerability [3].

In the Attica region of Bihar, India, Feloni et al. [23] have widely utilized an improved methodology to determine flood susceptibility. The creation and use of a GIS-based multi-criteria analysis approach for identifying locations vulnerable to flooding occurrences are originally reported in this context. Additionally, there have been several significant

flood incidents in the area in recent years. According to the transformation procedure, the generated maps show values between the criterion values of zero and one or one and five. The combination of AHP and GIS in the experiment proves to be powerful in its applications for flood vulnerability assessment, in any region. Twenty-one sub-criteria under five main criteria have been applied through Google Earth Engine software, along with the AHP process, in order to create flood risk maps. All criteria required weighting and were present in the form of raster datasets. Thus, based on the opinions of officials involved in soil management and experts in fields such as disaster management, weights for the major and minor criteria were assigned by using AHP. The flood sensitivity map was produced using a range of values for each of the five classes' unique criteria. Using sub-criteria grouped under each of the five criteria, an integrated flood hazard zoning map was created. Flood hazard maps based on basic criteria were used more extensively, in order to develop the final flood zone map. Swain's study will be useful in terms of mapping flood-prone areas, in order to minimize floods and allow designers, stakeholders, and decision-makers to properly monitor areas at risk of flooding, as well as to avouch proper, effective, and sustainable socio-economic development [24].

Eight conditioning factors were utilized to construct redeeming thematic maps by Souissi et al. [25] in their study of GIS-based MCDM–AHP modeling, for flood susceptibility mapping of dry regions, in southeastern Tunisia. The included parameters were elevation, groundwater depth, slope, lithology, land use/cover, rainfall intensity, distance from the drainage network, and drainage density. By assigning different values when creating reclassification maps, and also by considering the flood status of the area and giving an appropriate weight to each theme, the average weight of the factors and the importance of each class were calculated using the Pair-Wise Comparison Matrix (PCM) methodology. As such, the results that were realized after linking the MCDM–AHP–GIS methods in the study area will be a valuable tool for authorities, designers, engineers, hydrologists, and decision-makers, in order to identify flood risk zones and to assess the flood risk index. Decisions are easy to make to reduce the risk of flooding. At present, it is possible to detect an increase in the impact of flood hazards on peoples' lives and property. These floods occur regularly in the Southern Province, Western Province, and Sabaragamuwa Province of Sri Lanka.

Therefore, flood hazard management is an essential factor. The present study has been conducted based on the awareness of how the flood conditions have varied in the study area, that is, around the Gin River, and how to recognize and act on pre-flood hazard conditions. This type of research is not taken into account in the study area. As a result, the current endeavor is topical and novel, in order to implement the quick assessment of flood susceptibility, utilizing the MCDM and GIS. This study tried to prepare flood risk maps in the Neluwa area along the Gin River, since floods are one of the major natural disasters in the Gin River basin, and act as the most devastating natural hazard in the area, resulting in a loss of property and human lives. Henceforth, based on the results, the study will provide a potential flood mapping and assessment methodology for the region, integrated with GIS and AHP. For weighing the major and sub-criteria, AHP was used through a questionnaire method, in order to obtain ideas from experts in the field. Attempts have also been made to rank the flood risk areas through a structured process and extensive use of multiple criteria decision analysis. It was an effective way to analyze the physical, socioeconomic, and built environment as the main criteria, in order to analyze the expected results and outcomes.

2. Materials and Methods

2.1. Study Area

Neluwa Divisional Secretariat (DS) is located in the Northeastern boundary of the Galle District, between 120–140 km in the North and 145–170 km in the East (Figure 1). The total land extent of this division is 15,348 ha, and consists of 34 Grama Niladhari Divisions (*GNDs*). The area is located between the Northern latitudes 80–19/89–29.5 and Eastern longitudes 6–17/6–25.5. Neluwa DS comprises 9% of the total land area of Galle District,

and is in fourth place among the Divisional Secretariat Divisions in the district, in terms of size. The average elevation of this division is more than 300 feet. According to the distribution of rainfall in this division, two main zones can be identified: areas receiving 2500–3000 mm and areas receiving between 3000–4000 mm. Overall, this division can be termed as a lowland wet zone that receives more than 3000 mm/year of rainfall, and does not have high temperatures and wind speeds [26]. Neluwa Divisional Secretariat is made up of rocks belonging to the Pre-Cambrian period. The area is especially rich in chanokites and meta sedimentary rocks of the Vijayan complex.

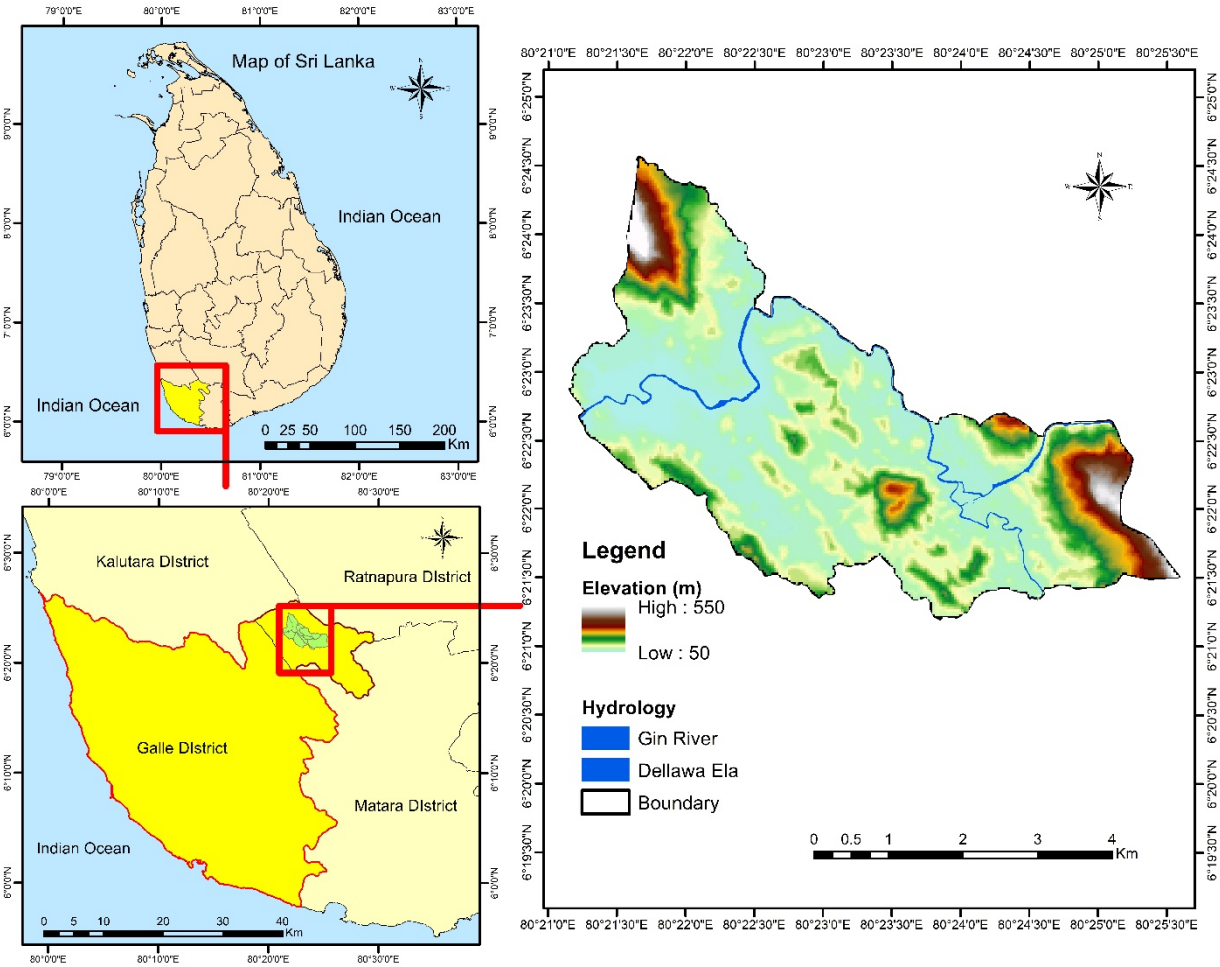

Figure 1. Study area.

2.2. Data Sources

The research has been carried out according to the framework of the AHP, MCDM, and GIS, in the geospatial environment, and using ArcGIS 10.8 software, developed by Environment System Research Institute (ESRI), USA. Based on a comprehensive literature survey and expert opinions, three major criteria have been chosen and those were divided into nine sub-criteria for flood vulnerability mapping. The study was based on different types of data, according to the main criteria obtained from the Survey Department of Sri Lanka, with a scale of 1:10,000. Population census data were gathered from the resource profile of Neluwa D.S.D., as mentioned in Table 1. It was important to collect relevant datasets when mapping flood-prone areas through a geotechnical approach.

Table 1. Vulnerability criteria used in the study.

Main Criteria	Sub Criteria	Data Sources
Built Environment	Buildings	Survey Department Digital data Layers, 2022
	Road network	Survey Department Digital data Layers, 2022
Socio-Economic	Population	Resource profile of Neluwa DSD, 2020
	Land use	Survey Department Digital data Layers, 2022
Physical Environment	NDVI	USGS, Landsat 8, 2022
	Water Bodies	Survey Department Digital data Layers, 2022
	Stream Density	Survey Department Digital data Layers, 2022
Shapefile	Slope	Using Survey Department Contour line, 2022
Shapefile	Elevation	Using Survey Department Contour line, 2022

Note(s): **Source:** Compiled by Author, 2022.

Based on the literature, the available data, and their applicability and impact on flood risk in the current study, the criteria and alternatives were chosen. By mapping the choices for each criterion, the spatial thematic layers of each chosen criterion were created. In this study, we created nine thematic layers, under three vulnerability components. For each raster layer, the spatial resolution was set at a cell size of 30 m × 30 m using ArcGIS 10.8 software. For its use in predicting flood situations and representing vegetation cover, the Normalized Difference Vegetation Index (NDVI) was computed. Here, the NDVI was calculated using the following formula [27]:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

NIR and R stand for near-infrared band and red band, respectively. The following equation has been used in relation to the LANDSAT 8 data:

$$\mathrm{NDVI} = \frac{\mathrm{Band\ 5} - \mathrm{Band\ 4}}{\mathrm{Band\ 5} + \mathrm{Band\ 4}}$$

With the help of ArcGIS, DEM was also used to create the area's elevation map. The line density analysis Tool in ArcGIS was used to generate the drainage density network. Elevation and slope are key factors in determining a terrain's stability when considering the topography of the Neluwa area. The amount and direction of surface runoff or groundwater that reaches a location are influenced by the slope. The main factor affecting how much rainfall contributes to stream flow is the slope. It regulates the duration of subsurface, infiltration, and overland flow. Since its concentrations indicate the type of soil and its geotechnical characteristics, the drainage network is an essential ecosystem for reducing risks. A weight value, corresponding to its relative relevance, was assigned to each element in order to undertake a thorough assessment of the impact of each criteria on flood generation in the research area. Pairwise comparison analysis, a method Saaty introduced in 1980, was used to determine the weight [21].

2.3. GIS Approach

There are some methods that we experimented with, in order to decide on the best alternative. Among them, AHP is one of the most popular methods. The AHP method is used to weigh criteria and sub-criteria by evaluating Disaster Management (DMCs), stakeholders, regional planners, or experts affiliated with the decision-making process. Given that AHP is the easiest decision-making approach to prototype, it has emerged as one of the most popular techniques for combining decision-making processes and geospatial analysis [28]. This indicates that the approach is simple to use and yields effective and precise findings for spatial analysis. AHP has gained popularity as a consequence of its

simple deployment and successful outcomes. This method is as widely used as the MCDM method, for considering the flood risk in various regions/countries [29]. Major criteria maps are created based on values at different levels. A comparison is then made of the relationship between each criterion in the standardization process, and potential flood risk is identified and assessed through criteria weights using relevant field experts and their judgments. The comparison between the criteria was most aptly identified using the MCDA method, through GIS technology that applied Satty's [30] AHP scales as pair-wise comparisons, as mentioned in Table 2. However, to reclassify the criterion maps, standardization was done by the pair-wise comparison method. The next step was to establish weights for each criterion. According to the weight calculation, different criteria had different importance levels. In the current research, we report the judgments of experts from the field of hydrology, GIS, and disaster management. Additionally, sub-criteria maps were reclassified and weighted based on the experts' opinions. To calculate AHP weights for the criteria, ten semi-structured questionnaires were collected from experts, including civil engineers, disaster managers, university lecturers, AHP-based researchers, GIS experts, and other researchers in the field. Accordingly, experts' opinions were used to construct a pair-wise comparison matrix and to allot weights as per the importance of each criterion. The experts were selected based on their basic knowledge and research experiences.

Table 2. The AHP scales for paired comparisons.

Numerical Scale	Scale
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important
2, 4, 6, 8	The importance lies in between two degrees

Note(s): **Source**: Saaty 1990 [30].

In the present study, nine sub-criteria were identified, under three main criteria, the built environment, physical, and socio-economic characteristics, with these three being relevant to the flood vulnerability evaluation for the study area. Under the built environment, road network and buildings were chosen as sub-criteria. NDVI, slope, elevation, water bodies, and stream density were taken under physical criteria and land use and population density were taken under socio-economic criteria. All criteria required weighting and were present in the form of raster datasets. The study consists of different levels of use of criteria and combinations of different processes. When weighing the criteria, it is recommended to quantify the pairs and quantitatively calculate the extent as to which the relationship between them is relevant to the study. The flood risk assessment map was obtained by overlaying all sub-criteria maps, by using weighted overlay technology through the Arc GIS software-aided Weighted Linear Combination (WLC) method. Five risk zones could be identified, based on the standard given in flood risk assessment when creating vulnerability maps, including very high risk, high risk, moderate risk, less risk, and risk-free. On the other hand, based on the range of parameters, the flood risk level was classified into five types (7—very-high risk, 5—high risk, 3—moderate risk, 1—less risk, and 0—risk-free). All criteria were plotted and transformed into values displayed within raster cells, and used in weighting for linear combination.

In standardizing the criteria used, a reclassification was obtained, with areas not susceptible to flooding represented as Number 0 and areas susceptible to flooding represented as a range between 0 and 1 (Table 3). In the pair-wise comparison method, the analyst must specify the values for each pair of criteria that are the most significant in determining the

flood risk, and how the relationship between those criteria affects the flood vulnerability. Afterwards, the analyst must qualitatively state as to by how much their value is more substantial than another factor, as well as state the effectiveness of its quantitative expansion. By assigning quantitative weights to determinants and comparing them pairwise to obtain the composite vulnerability maps for the flood risk, weighted criteria were combined to produce a flood vulnerability map. The most significant and common method employed in flood vulnerability mapping is the weighted linear combination method. It uses a linear superposition approach, based on the importance of different factors' weight [31–33]. Linear combination converts multi-factor evaluation into a comprehensive one [34]. The procedures of WLC are expressed by the following formula, as proposed by Mendoza, [35].

$$S = \sum Wi\ Xi * \prod c\ J$$

where, $\boldsymbol{S}$ = vulnerability; $\boldsymbol{Wi}$—the weight of factor $\boldsymbol{i}$; $\boldsymbol{Xi}$; $\boldsymbol{Xi}$—criterion score of factor $\boldsymbol{i}$; $\boldsymbol{cj}$—criterion score (false/true) of constraint j; $\boldsymbol{\Pi}$—produce.

Table 3. Score values assigned to reclassify each sub-criterion map used for the stud.

Flood Criteria	**Vulnerability Class Ranges and Ratings**					
	Unit	Risk Free (0)	Less Risk (1)	Moderate Risk (3)	High Risk (5)	Very High Risk (7)
(A) Physical Environment						
NDVI	Levels	0.47–0.56	0.42–0.46	0.36–0.41	0.25–0.35	0.12–0.24
Slope	Degrees	30–57	21–29	13–20	5–12	0–5
Elevation	m	91–155	50–91	-	-	-
Distance from River	m	400–768	200–400	100–200	50–100	0–50
Stream Density	km^2	0–3.73	3.74–7.45	7.46–11.2	11.3–14.9	15–18.6
(B) Built Environment						
Distance from Road	m	600–1135	300–600	200–300	100–200	0–100
Distance from Buildings	m	800–1374	400–800	200–400	100–200	0–100
(C) Socio Economic Environment						
Land use	Class	Rock	Rubber/Dense forest/Tea	Coconut	Homestead	Paddy
Population Density	Person/km^2	48–129	129–240	240–401	401–631	631–1085

This process, known as the Analytical Hierarchy Process (AHP), is one of the most appropriate techniques for pair comparison and weight development for criteria, developed by Satty [30], in the context of multi-criteria decision-making and criterion-building relationships [36–38]. Many of the criteria in the study were chosen based on previous literature surveys, and were used in particular contexts when obtaining relevant data [39,40]. Whether the flood risk in the area is directly or indirectly determined is clear from the criteria used in the present study. Nine thematic maps (Figure 2) have been created under three main criteria. The study was carried out to generate a final flood risk map using the spatial analysis procedure (Figure 3).

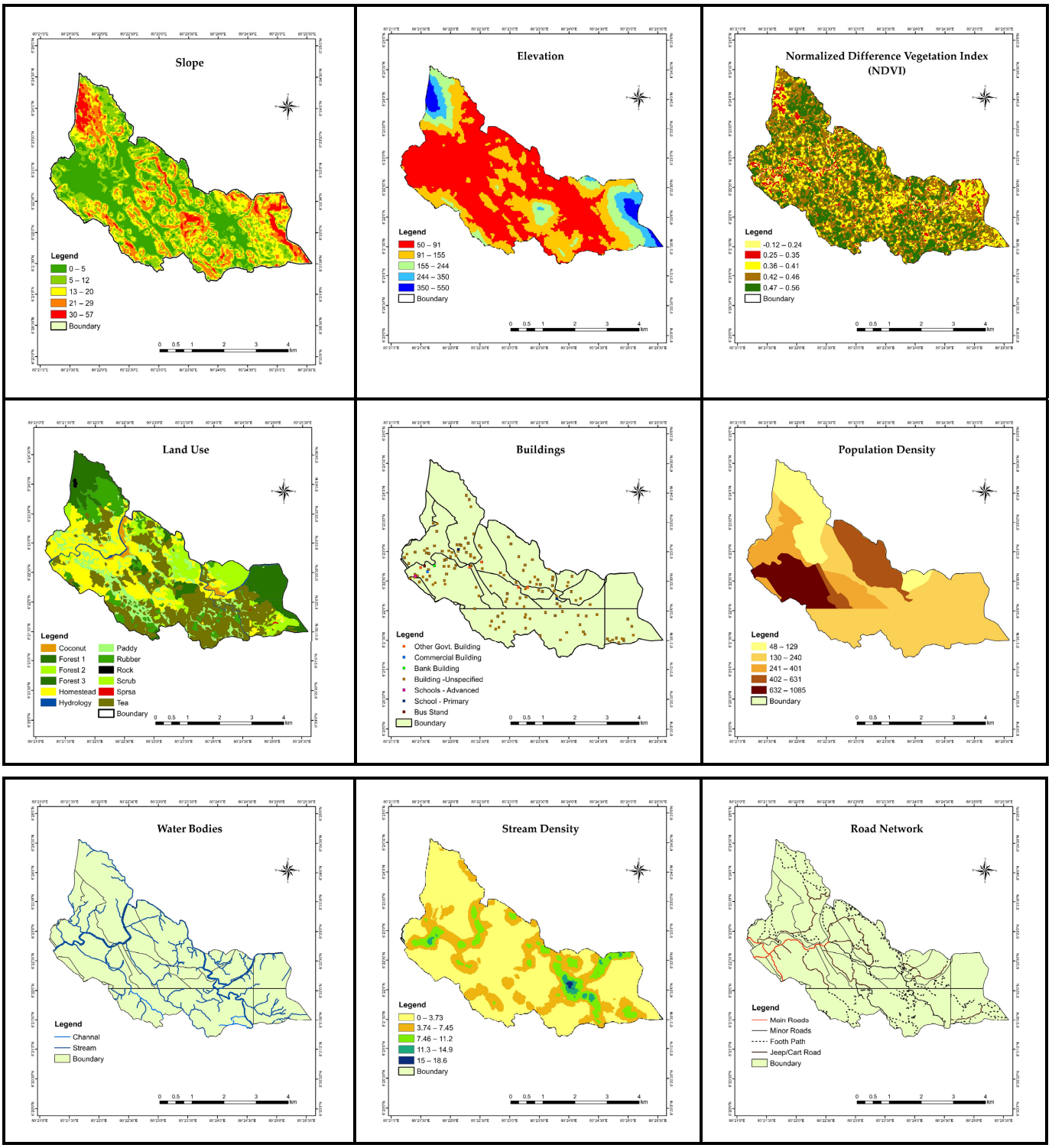

Figure 2. Sub-criterion maps used for the study.

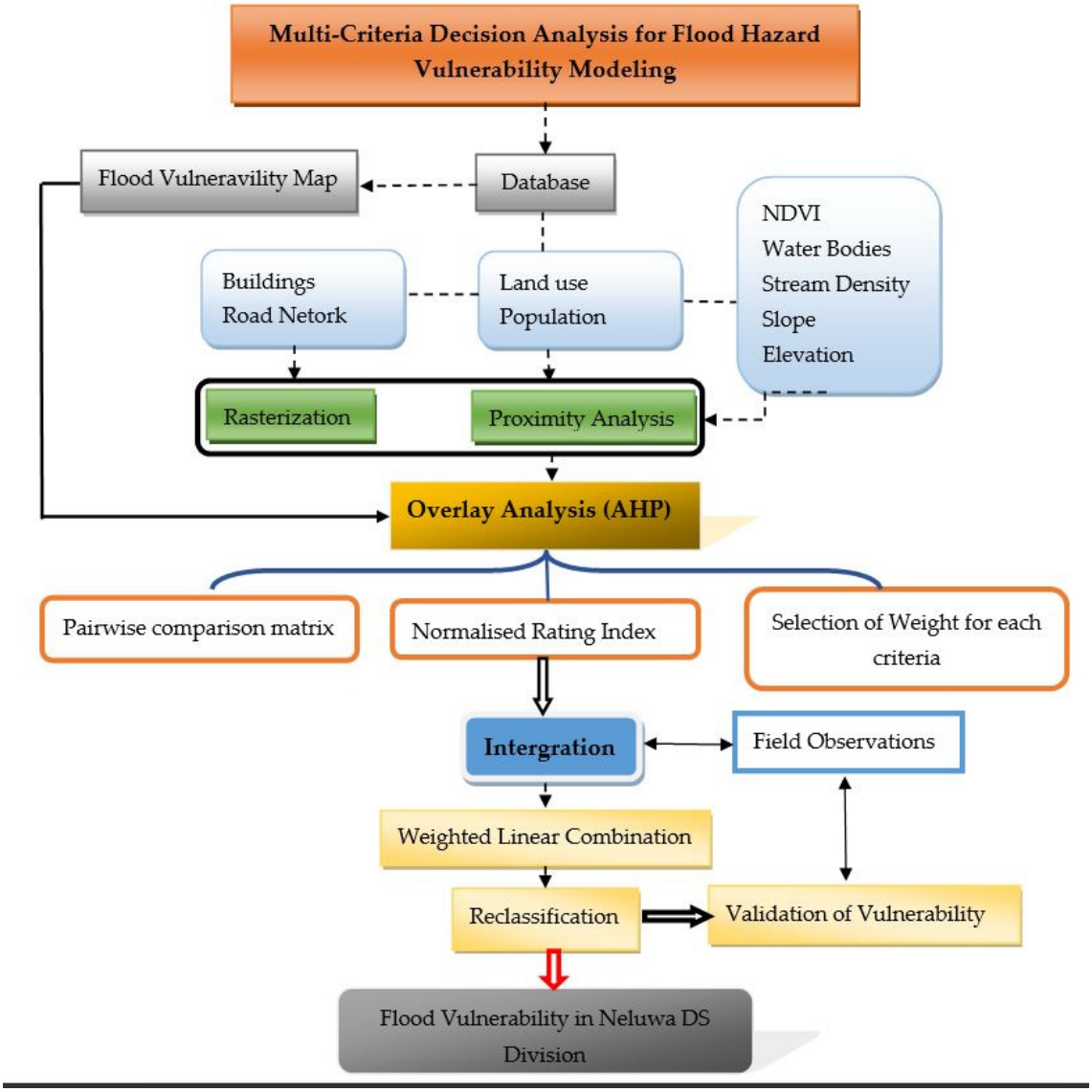

Figure 3. Spatial analysis procedure of the study.

2.4. Developing GIS Model

Model Builder has a systematic technology that can be used to edit and manage the required model. Arc GIS 10.8 version, developed by the ESRI, USA, was utilized. As a GIS analyst, anyone can use the model builder, for a variety of applications. Additionally, a model builder is used for constructing simple workflows. It is an easy and significant application for creating and running workflows, and has a simple, neat interface. When creating a model builder for any study, it is essential to pay attention to areas such as the model canvas, model diagram, model elements, variables, and tools. It also should provide advanced methods for extending ArcGIS functionality, by allowing one to create a model as a tool. Not only that, the ArcGIS model builder offers several advantages, particularly in terms of progressive processing, and easier database management. Using spatial analysis techniques in Model Builder (Figure 4), flood risk vulnerability was evaluated by applying different analytical GIS techniques, including overlaying, buffering (Euclidian), reclassifying, and Raster-to-Vector conversion based on multi-criteria decision analysis.

Figure 4. ArcGIS model for creating flood vulnerability map of the Neluwa DSD using Model Builder.

Accordingly, the knowledge of experts was used to construct a pair-wise comparison matrix, and the contribution of each criterion was examined. Then, the values in each cell were divided by the sum of each column. The process took place based on the three major criteria. Main criteria weights were constructed regarding the results of ten experts in the disaster management and GIS fields. According to the questionnaire survey, the main criteria matrix was filled as below (Tables 4 and 5).

A—Physical Environment
B—Socio-economic Environment
C—Built Environment

Table 4. Main Criteria Weight Matrix (one expert).

Criteria	A	B	C
A	1	7	1/5
B	1/7	1	1/7
C	5	7	1

Note(s): **Source**: Author calculation based on AHP and Questionnaire Survey, 2022.

Table 5. Normalized Criteria Weight Matrix for Main Criteria (one expert).

	A	B	C	Criteria Weights	Final Criteria Weight
A	0.1	0.8767	0.0588	1.0355/3	0.3451
B	0.8	0.1095	0.4705	1.38/3	0.46
C	0.1	0.0136	0.4705	0.5841/3	0.1947

Note(s): **Source**: AHP weights' calculation based on experts' opinion and Questionnaire survey, 2022.

3. Results

The research aimed to create flood vulnerability maps of the Neluwa using geo-informatics. Results of vulnerability levels and area calculations for major criteria such as the physical, socio-economic, and built environment parameters differed from each other based on their criterion values, which were assigned based on experts' opinions.

3.1. Weights for the Criteria

When using the pairwise comparison matrix and factor maps, weighting and ranking procedures are followed. Representing weight values between zero and one is based on priority. Accordingly, using the weighted linear combination, the sum of the weights is calculated as one. This then allows assigning weights to the major criteria and sub-criteria, and a standardized eigenvector is then extracted from the comparison theorem by entering each criterion. The final flood vulnerability map is the outcome of the overlaying major criterion maps. The results of the AHP weight calculation are shown in Table 6. Higher weight values of criteria indicate greater impact and propensity for disasters. We observed that the criteria used for the study revealed a high priority for flood risk. It can be identified that the physical environment affects flood risk the most, as the most weighted criterion. The subsequent risk maps will be created depending upon the manner in which the ranking decision is derived, and the quantitative values will be obtained for each criterion.

Table 6. Weights assigned for each major and minor criterion of the study.

	Main Criteria	Weights	%	Sub Criteria	Weights	%
A	Physical Environment	0.4081	40.8	NDVI	0.1421	14.2
				Stream Density	0.2507	25.0
				Elevation	0.1638	16.3
				Slope	0.2027	20.2
				Water Bodies	0.2445	24.4
B	Socio-economic Environment	0.2956	29.5	Land use	0.2705	27.0
				Population Density	0.7293	72.9
C	Built Environment	0.2940	29.4	Buildings	0.6293	62.9
				Roads	0.3706	37.0

Note(s): **Source**: AHP weight calculations using experts' opinions.

3.2. Flood Vulnerability Levels for Minor Criteria

The best available proxies for catastrophic occurrences must be explicitly chosen as indicator variables, as per the approach of the study. Any form of thorough vulnerability assessment requires the indicators chosen for each of these components to be crucial factors. The composite vulnerability index approach was used to map the Neluwa areas that are vulnerable to natural and climate-induced disasters. Vulnerability indices were calculated by using data from selected vulnerability areas. The highest and lowest vulnerability regions have been classified using the vulnerability index in the Neluwa area. All of the selected sub-criteria are the most significant criteria in flood risk assessment. The NDVI criterion was used in terms of physical characteristics and is currently being used in many studies. Values obtained from the NDVI map, created by region-based satellite imagery, range from −0.12 to 0.24. After re-classification, four vulnerability areas were identified, with the −0.12–0.24 zone being labeled the very-high-risk zone and the 0.47–0.56 being the risk-free area. The area has minor hilly features, and after reclassifying the elevation map, it was divided into two zones: risk-free and less-risk areas. The elevation of the area ranges from 0 to 155 m. The reclassified slope map identified five classes: risk-free, low risk, moderate risk, high risk, and very-high risk. Low-slope areas have been identified as very-high-risk areas and exalted slope areas were identified as risk-free areas. The majority of the study area has water bodies.

The Gin River, Dellawa Ela, and other tributaries have caused flooding in the area. According to the reclassified hydrology map, the majority of the area was classified as very-high risk. On the other hand, when reclassified in terms of the stream density map, four classes were realized: low risk, moderate risk, high risk, and very-high risk. In the reclassified distance from the building map, four vulnerability levels have been considered: risk-free, low risk, moderate risk, and high risk. There is an extensive road network in the area, extending from 0 to 1374 m. The area between 0 and 100 m is a high-risk area and the zone between 600 and 1374 m has also been identified as a risk-free area. Population density and land use have been identified under socio-economic criteria. Land use was a significant factor that determines the flood situation in the area. In this study, there are eleven types of land use that have been considered. Paddy and water areas were observed as very-high-risk areas for flooding. Among them, roads and forest areas were identified as risk-free areas. Apart from that, the study area has a sizeable population, and densely populated areas were identified as very-high-risk zones.

3.3. Flood Vulnerability Levels for Major Criteria

The final flood vulnerability map in the study area has been generated, overlaying three major criterion maps, which include those of the physical environment, socio-economic environment, and built environment. The final analysis revealed five vulnerability classes for flooding in the study area (Figure 5). The final results obtained from the flood vulnerability modeling revealed that 0.69% (0.15 km^2) and 6.84% (1.48 km^2) of land in the area is very-high risk and risk-free, respectively, in terms of flood vulnerability. After comparing all the criteria in the physical environment, it was found that there is a moderate-risk area (10.8 km^2). After overlaying all socioeconomic criteria maps, it was revealed that there are four vulnerability levels. Based on population density and land use, 0.41% (0.09) of the area has been indicated as very-high risk, 30.61% (6.62 km^2) as a high-risk area, and 48.19% (10.42 km^2) as a low-risk area. Under the built environment, the highest risk area was identified as comprising 25.12% (5.15 km^2) of the area, and 6.34% (1.30 km^2) was risk-free. The results obtained upon combining the main criteria maps reveals the distribution of flood risk in the area.

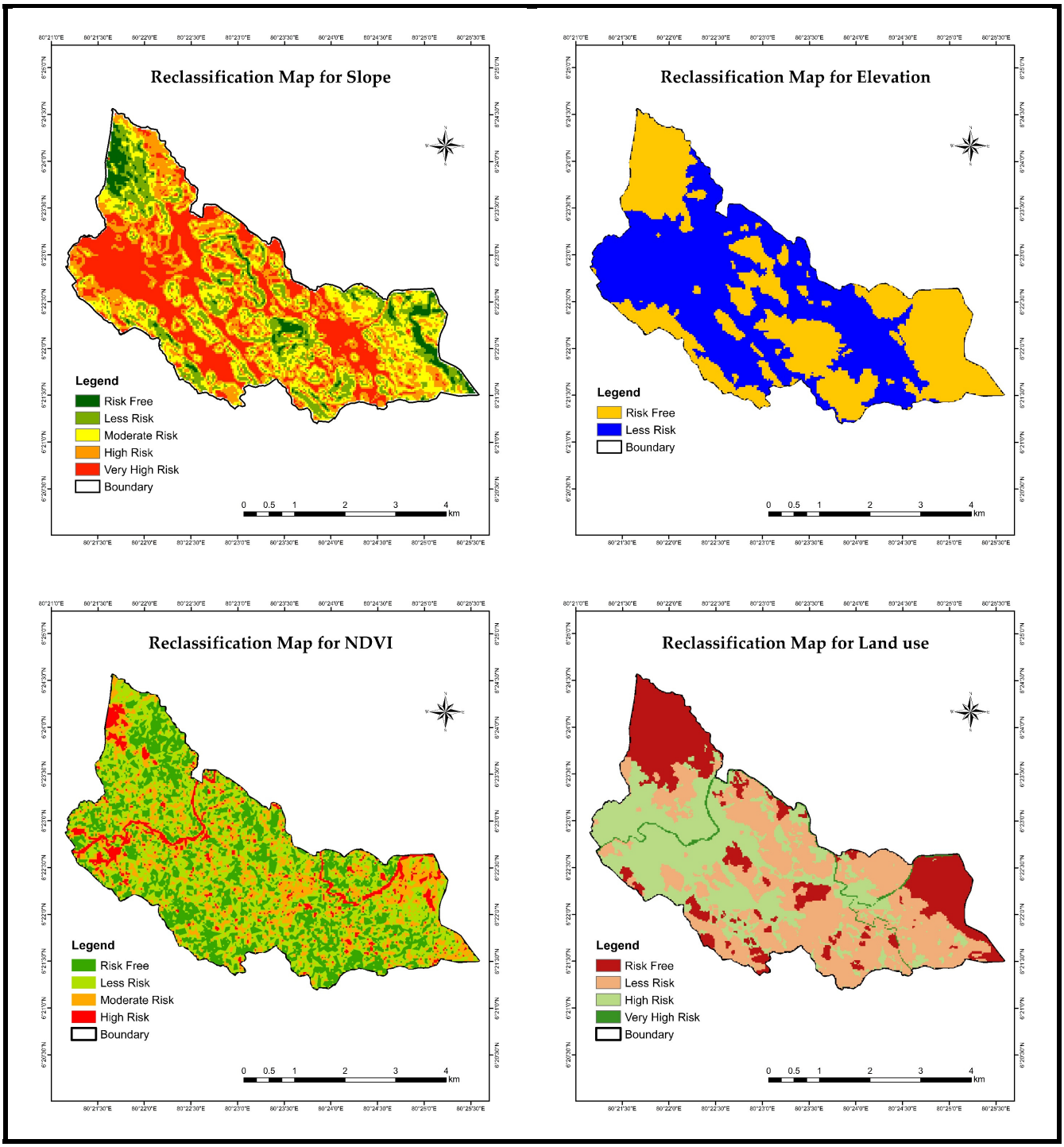

Figure 5. *Cont.*

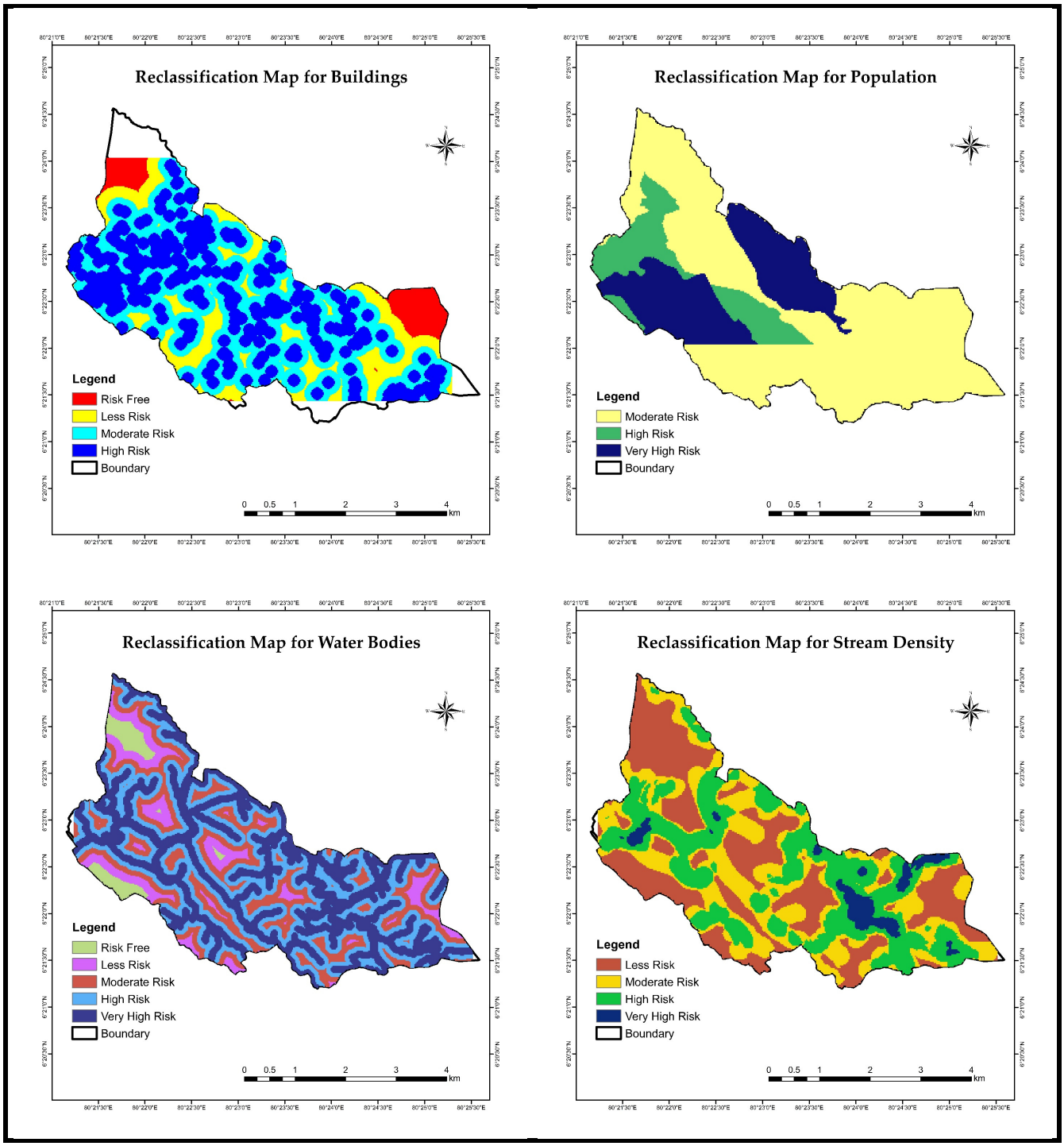

Figure 5. *Cont.*

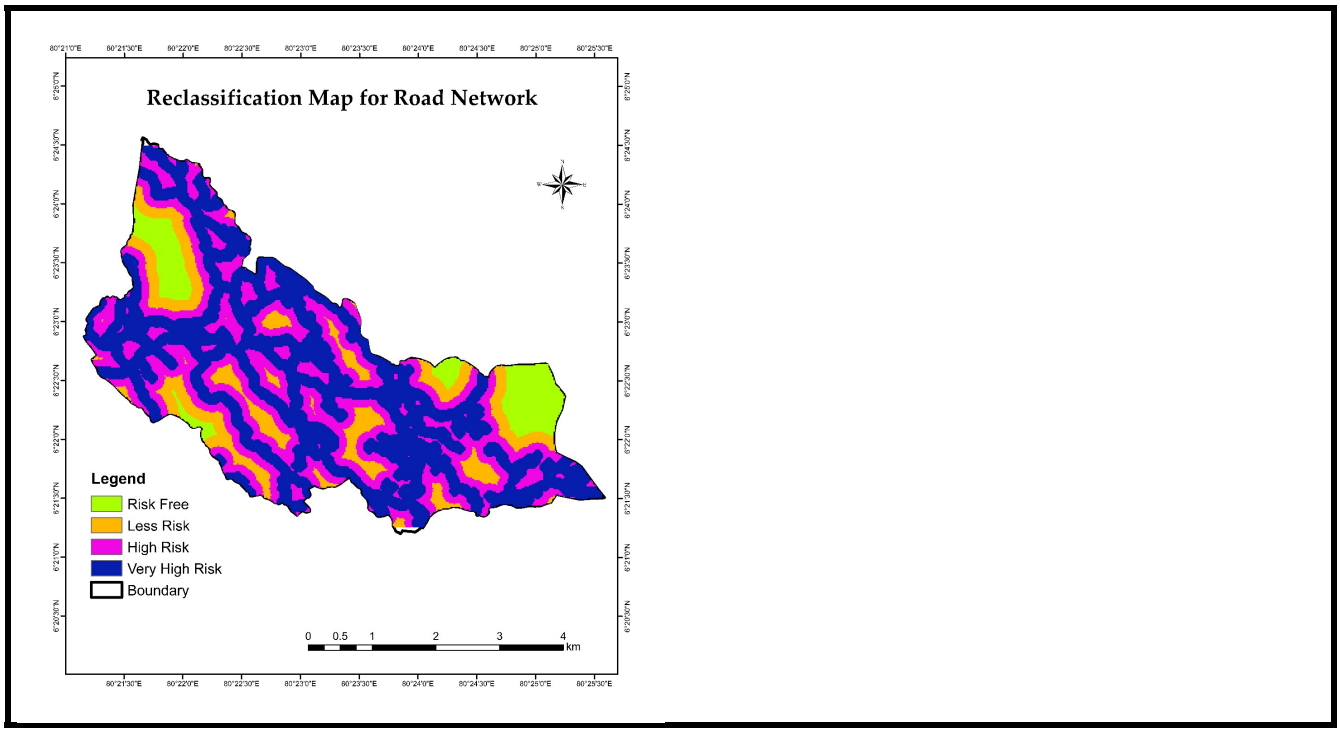

Figure 5. Reclassified Flood Vulnerability potential maps.

After overlaying the final weights for each major criterion map, it was revealed that 14.24% (2.92 km^2) was very high risk and 5.17% (1.06 km^2) of the study area was risk-free for flood hazards. Out of 21.62 km^2, 30.24% (6.20 km^2) is at high risk for flood in the area. The results also indicated that 22.58% (4.63 km^2) of the total area is a moderate risk prone area as demonstated in Figures 6 and 7 and Table 7. The risk of flooding is very high in the western part (Neluwa, Mavita East, and Koswatta) of the study area as the population and buildings associated with those areas are also extensive. Kosmulla and Ehelapitiya areas in the eastern parst of the area have also been identified as very high-risk areas. The Gin River flows through the area as the main source of water and there is a risk of associated flood hazards.

Table 7. Area coverage of flood vulnerability classes.

Criteria	Vulnerability Classes									
	Very High Risk (Sq.km)	%	High Risk (Sq.km)	%	Moderate Risk (Sq.km)	%	Less Risk (Sq.km)	%	Risk Free (Sq.km)	%
Physical Environment	0.15	0.69	3.58	16.5	10.8	50.1	5.56	25.71	1.48	6.84
Built Environment	5.15	25.12	5.78	28.19	6.61	32.2	1.41	6.87	1.30	6.34
Socioeconomic Environment	0.09	0.41	6.62	30.61	4.49	20.76	10.42	48.19	-	-
Overall	2.92	14.24	6.20	30.24	4.63	22.58	5.69	27.75	1.06	5.17

Note(s): **Source:** Arc Map 10.8 based area calculations, 2022.

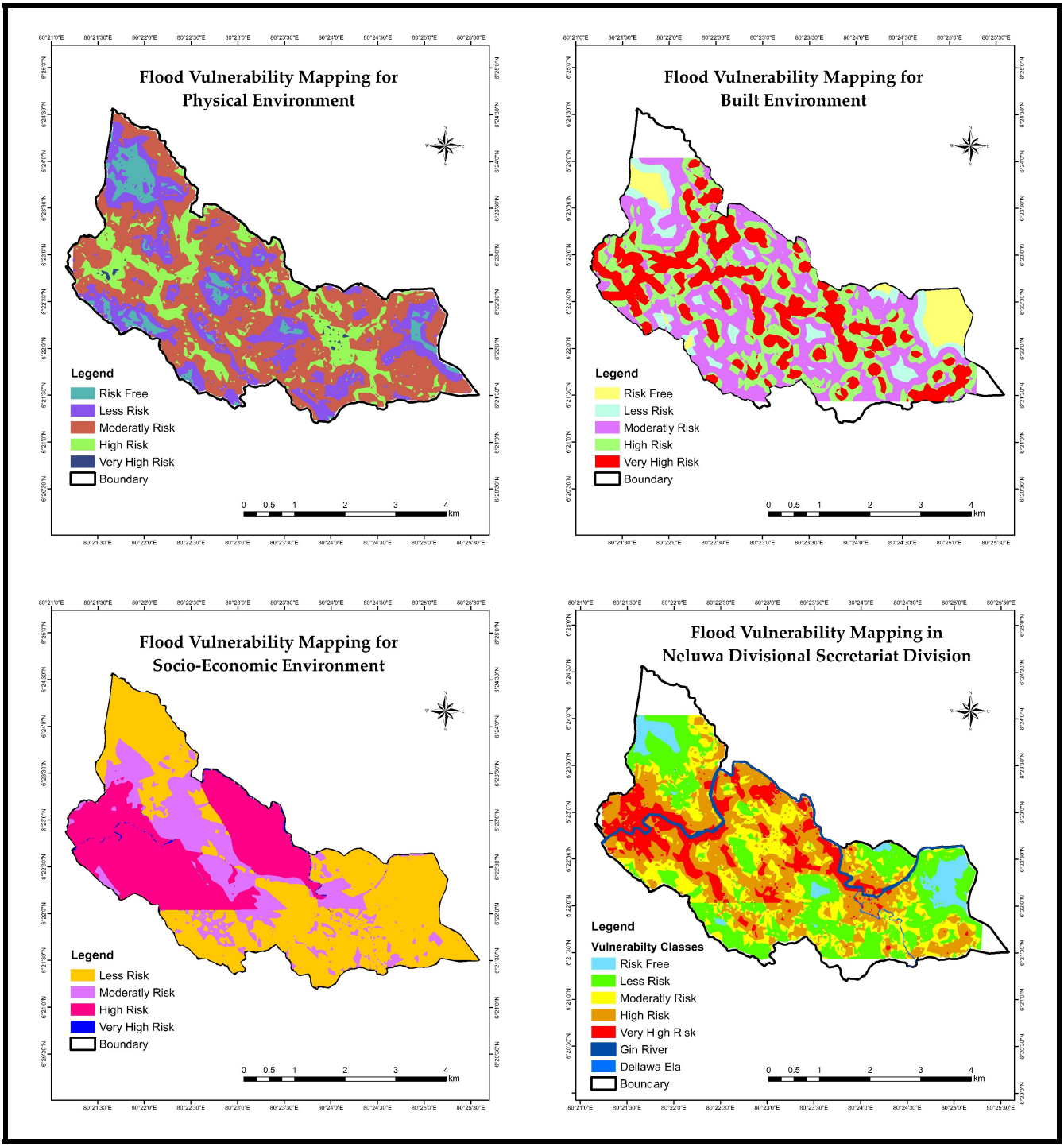

Figure 6. Flood Vulnerability Mapping in Neluwa area.

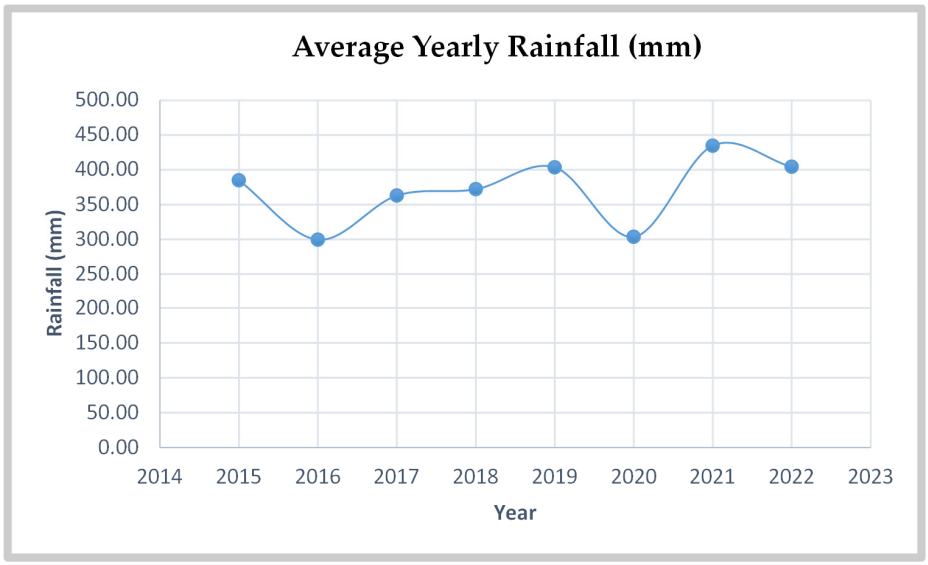

Figure 7. Annual Rainfall Distribution in Neluwa Area from 2015 to 2022. **Source:** Meteorological Department in Sri Lanka, 2022.

3.4. Rainfall Distribution in the Area

The Neluwa area is unique in identifying flood risk areas in Sri Lanka. Flooding can be identified as an inherent natural hazard in the region, and flooding situations occur whenever there is heavy rainfall. Based on monthly rainfall values from 2015–2022, the area was identified as a high rainfall area. Heavy rainfall is the main cause of floods. Flooding occurs when the natural water bodies are unable to carry the excess water of the heavy rainfall in the area. In the upper catchment areas, there is very heavy rainfall. According to the rainfall data obtained from the Batuwangala Meteorological Center, this region shows very heavy rainfall (Figure 7). An average monthly rainfall of over 250 mm/year is recorded every year. In the year 2022, a rainfall of 434.72 mm/year has been detected, which means that in May, with the onset of the southwest monsoon, a very large flood occurred in the Neluwa area. During that month, the monthly rainfall was recorded to be 934.7 mm. A gradual increase in rainfall intensity can be detected, and although it decreased by 2020, an average monthly rainfall value of 303.45 mm was recorded. One of the major flood zones in Sri Lanka, the Neluwa area, has been facing major flood conditions for several years now. Due to this, the society, economy, and infrastructure of the area are affected by the disaster.

Role of traditional knowledge in water management, monitoring of climatic changes and productivity of land is to be focused while planning the flood in the study area [41–43]. Recently, role of drones and other techniques have also been widely used in assessing the information and decision support for sustainable management of flood hazard [44–46].

4. Discussion

4.1. Validation of Vulnerability Assessment

AHP was based on risk assessment in verifying and evaluating the consistency of the theoretical results. This helped us to ascertain the relevance of each criterion in flood risk. A better analysis of the risk index could be achieved, and it was possible to obtain the specific and real weight of each criterion. This allows for the reliable mapping of flood-prone areas. In the study, a qualitative validation method was adopted in the assessment of the spatial risk maps and the evaluation of the results. By seeking people's opinions on the risk maps, created under the qualitative approach, observations and discussions were conducted with 50 people, consisting of local people, meteorological station officials, town planners, land-use planners, and experts. Their opinion was asked for regarding the accuracy of the risk map, and through the qualitative approach, it was possible to identify the vulnerable areas through those maps. Discussions with the residents of the area revealed that the

area constantly faces floods. The discussions also highlighted that continuous floods in the Neluwa area, including the recent flood in May 2022, have huge negative ramifications on the residents of the area.

Accordingly, the areas where the past floods occurred regularly were observed, and the respondents were classified under five categories while obtaining information in the field. About 29 (58%) of the 50 respondents were highly satisfied with the proposed results, and 14 (28%) respondents were satisfied with the results. Seven (14%) of the respondents were not satisfied with the results obtained from the flood risk maps (Table 8). The Neluwa urban area, i.e., the central part of the map, can be identified as a very high-risk zone and is vulnerable to floods, with rainfall exceeding 100 mm every year. It is not possible to identify very high slope angles in that region, and the flood conditions are constantly increasing, with the rain falling on the hilly regions of the area that join the river, with a large body of water along the slopes. With the flood situation in 2017, this region was also revealed as a high-risk area. Low-risk and moderate-risk areas were largely unaffected during the recent floods. The vulnerability can be further confirmed when the risk map is compared with the divisional secretariat disaster reports. In those reports, a zone, with a buffer of 100 m around these identified areas, has been detected as a flood-prone areas by the institute disaster officials also. According to the people, Neluwa area is prone to flood hazards often once or twice a year.

Table 8. Feedback from the people during the field verification of vulnerability assessment.

Category of People	Total Number of Respondents	Comments of Respondents		
		Highly Satisfied	Satisfied	Not Satisfied
Land Use Planners	02	01	01	0
Experts	04	02	01	01
Meteorologists	02	01	01	0
Town Planner	02	01	0	01
Local people in the area	40	24	11	05
Total	50 (100%)	29 (58%)	14 (28%)	07 (14%)

Note(s): **Source**: Field Verification, 2022.

4.2. Local Community's Experience of Flood Hazards

The distance from the river to the house determines the impact of the flood hazard. When investigating the distance from flood-prone houses to the river during the field study, more houses within a distance of 100–200 m from the river were identified. As the distance from the river to the house decreases, the impact of flooding increases. People living within this zone can be identified as belonging to a high-risk category. The responses of the local people also revealed that the existing houses in the region between 200–250 m were more affected. The nature of the impact of the hazard can be investigated and identified in several ways. It can be divided into full damage, partial damage, and minor damage. Overall, partial damage is more common than full damage in the study area. Apart from that, minor damage can also be seen. During the 2017 flood situation, there was a large rise of 6 to 10 feet. Almost all the buildings in the Neluwa urban area were damaged (Figure 8). The responses of the people regarding their coping mechanisms during such events were that they moved to safe places, such as relatives' houses, displacement camps, and temples. They also revealed that people who had two-story houses stay in their houses. Awareness of the people can be specified as one of the main actions in flood hazard management. To minimize the impact on the people, making them aware of flooding has become an essential factor. Subsidies and compensations are provided as post-event measures in case of flood hazards. The residents revealed that they received subsidies, such as rations, educational equipment, medicines, soft goods, sanitary materials, and kitchen equipment. Compensation under post-flood hazard management is based on an assessment of the

damage caused by the flood. The interviews conducted with the people in the study area revealed that the floods that occurred in May 2003 and 2017 were large, catastrophic events and resulted in a high amount of damage.

(**A**) (**B**) (**C**) (**D**) (**E**) (**F**)

Figure 8. Flood Situation of Neluwa Area in 2022/2017, (**A**)—26.05.2017 flood situation, (**B**)—26.05.2017 flood situation, (**C**)—26.05.2017 flood situation, (**D**)—27.05.2022 flood situation, (**E**)—27.05.2022 flood situation, (**F**)—27.05.2022 flood situation.

5. Conclusions

In this study, the effectiveness of providing accurate and detailed flood risk and flood vulnerability analysis has been demonstrated along the Gin River, by using GIS, AHP, and MCDA. The main criteria used included, the socio-economic environment, built environment, and physical environment, were very useful in identifying the overall spatial flood risk assessment in the area. This study presented an effective method for spatial risk assessment of flood impacts by integrating multi-criteria using geospatial techniques at the

local scale. A qualitative validation approach was used in validating the developed risk maps and this was done based on direct observations from the field, as well as feedback from the community, disaster management officers, meteorologists, and land-use planners. The results of flood hazard map showed that 14.24% (2.92 km^2) was under very-high risk, 30.24% (6.20 km^2) is at high risk and 5.17% (1.06 km^2), area was risk-free for flood hazards. The results also indicated that 22.58% (4.63 km^2) of the total area is a moderately flood-prone area, as demonstrated in Figure 6 and Table 7. The results indicated that very-high- and high-risk areas cover an area of 9.12 km^2 from the central, southern, and eastern portions of the study area. Based on temporal and spatial perspectives, this area shows great variability in the probability and occurrence of inundation. The very-high-flood-risk area is characterized by low elevation and slope, the presence of the Neluwa urban area, high rainfall intensity, and proximity to water bodies.

The results of the study, if implemented well, shall provide an opportunity to control the flood situation in the Neluwa area. Apart from that, other measures, such as the proper implementation of flood monitoring and early warning systems, restricting the expansion of residential zones in high-risk areas, planting of riparian vegetation on both sides of banks of the river to control flood flow velocity, and use of structured and semi-structured measurement methods, are suggested. Awareness and information dissemination about flood at community level should be prioritized. Proper use of such recommendations and suggestions will be a guide to control future flood situations scenarios. The results obtained after linking MCDA–AHP–GIS methods in the study area can be identified as an effective tool in flood risk assessment for engineers, land-use planners, urban policymakers, and disaster managers. Such decision-making techniques can be used successfully in other fields of geography and any area.

Author Contributions: Conceptualization, W.M.D.C.W. and P.K.M.; Methodology, W.M.D.C.W., P.K.M., K.A., A.T. and M.S.F.; Software, W.M.D.C.W. and S.T.; Validation, W.M.D.C.W.; Formal analysis, P.K.M. and S.T.; Investigation, K.A. and A.T.; Resources, W.M.D.C.W. and P.K.M.; Data curation, W.M.D.C.W., S.T., K.A. and A.T.; Writing—original draft, W.M.D.C.W., P.K.M. and S.T.; Writing—review & editing, W.M.D.C.W., P.K.M., K.A., A.T. and M.S.F.; Visualization, W.M.D.C.W.; Supervision, P.K.M., K.A. and M.S.F.; Project administration, K.A. and M.S.F.; Funding acquisition, K.A. and M.S.F. All authors have read and agreed to the published version of the manuscript.

Funding: Deep thanks and gratitude to the Researchers Supporting Project (RSP2023R351), King Saud University, Riyadh, Saudi Arabia for funding the research article.

Data Availability Statement: Not applicable.

Acknowledgments: We are thankful to Survey Department and Metrological Department of Sri Lanka, for providing necessary data used in this study. We would also like to acknowledge the United States Geological Survey (USGS) for providing Landsat satellite data with free access. Our gratitude to everyone who participated in the field survey and answered our questionnaires.

Conflicts of Interest: The authors declare that there are no known competing financial interest or personal relationship that could have appeared to influence the work reported in this article.

References

1. Alexander, D.E. *Natural Disasters*; Springer Science & Business Media: New York, NY, USA, 1993. Available online: https://books.google.tn/books/about/NaturalDisasters.html?id=gWHsuGTcF34C&rediresc (accessed on 5 September 2022).
2. Baky, M.A.A.; Islam, M.; Paul, S. Flood hazard, vulnerability and risk assessment for different land use classes using a flow model. *Earth Syst. Environ.* **2019**, *4*, 1–20. [CrossRef]
3. Hoque, M.A.; Tasfia, S.; Ahmed, N.; Pradhan, B.B. Assessing Spatial Flood Vulnerability at Kalapara Upazila in Bangladesh Using an Analytic Hierarchy Process. *Sensors* **2019**, *19*, 1302. Available online: www.mdpi.com/journal/sensors (accessed on 5 September 2022). [CrossRef]
4. Mundhe, N. Multi-criteria decision making for vulnerability mapping of food hazard: A case study of Pune city. *J. Geogr. Study* **2019**, *2*, 41–52. [CrossRef]

5. Intergovernmental Panel on Climate Change [IPCC]. Chapter 1, Overview of impacts, adaptation, and vulnerability to climate change. In *Climate Change 2001: Impacts, Adaptation & Vulnerability: Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*; McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S., Eds.; Cambridge University Press: Cambridge, UK, 2001; pp. 75–104.
6. Adger, W.N. Vulnerability. *Glob. Environ. Chang.* **2006**, *16*, 268–281. [CrossRef]
7. Eakin, H.; Bojorquez-Tapia, L.A. Insights into the composition of household vulnerability from multicriteria decision analysis. *Glob. Environ. Chang.* **2008**, *18*, 112–127. [CrossRef]
8. Moss, R.H.; Brenkert, A.L.; Malone, E.L. Vulnerability to climate change: A quantitative approach. In *Prepared for the US Department of Energy*; (PNNL-SA-33642); Pacific Northwest National Laboratory; Battelle Institute: Washington, DC, USA, 2001.
9. Luers, A.L.; Lobell, D.B.; Sklar, L.S.; Addams, C.L.; Matson, P.A. A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Glob. Environ. Chang.* **2003**, *13*, 255–267. [CrossRef]
10. Nuwanka, M.W.R.; Withanage, W.K.N.C. A GIS-based framework for flood hazard vulnerability evaluation in Thudawa area, Sri Lanka. *Int. J. Inf. Decis. Sci.* **2021**, 1–19. Available online: https://www.inderscience.com/info/ingeneral/forthcoming.php?jcode=ijids (accessed on 5 September 2022).
11. Birkmann, J. *Measuring Vulnerability to Natural Hazards*; Alexander, D., Handmer, J., McBean, G., Eds.; United Nation University Press: Tokyo, Japan, 2013; pp. 9–699, ISBN 9789280812022.
12. Fernandez, P.; Mourato, S.; Moreira, M. Social Vulnerability Assessment of Flood Risk Using GIS-Based Multicriteria Decision Analysis. A Case Study of Vila Nova de Gaia. *Geomat. Nat. Hazards Risk* **2016**, *7*, 1367–1389. [CrossRef]
13. Etkin, D. *Disaster Theory: Hazard, Vulnerability, and Resilience*; Scott, S., LaFleur, M., Purushothaman, V., Eds.; ButterworthHeinemann (Elsevier): Kidlington, UK; Oxford, UK, 2016; ISBN 9780128002278.
14. Giordan, D.; Notti, D.; Villa, A.; Zucca, F.; Calo, F.; Pepe, A. Low cost, multiscale and multi-sensor application for flooded area mapping. *Nat. Hazards Earth Syst. Sci.* **2018**, *18*, 1493–1516. [CrossRef]
15. Saaty, T.L. A scaling method for priorities in hierarchical structures. *J. Math. Psychol.* **1977**, *15*, 234–281. [CrossRef]
16. Ju, C.Y.; Jia, Y.G.; Shan, H.X.; Tang, C.W.; Ma, W.J. GIS-based coastal area suitability assessment of geo-environmental factors in Laoshan district, Qingdao. *Nat. Hazards Earth Syst. Sci.* **2012**, *12*, 143–150. [CrossRef]
17. Mishra, P.K.; Rai, A.; Rai, S.C. Land Use and Land Cover Change Detection using Geospatial Techniques in Sikkim Himalaya, India. *Egypt. J. Remote Sens. Space Sci.* **2020**, *23*, 133–143. [CrossRef]
18. Mishra, P.K.; Rai, A. Role of Unmanned Aerial Systems for Natural Resource Management. *J. Indian Soc. Remote Sens.* **2021**, *49*, 671–679. [CrossRef]
19. Mishra, P.K.; Rai, A.; Abdelrahman, K.; Rai, S.C.; Tiwari, A. Land Degradation, Overland Flow, Soil Erosion, and Nutrient Loss in the Eastern Himalayas, India. *Land* **2022**, *11*, 179. [CrossRef]
20. Wang, Y.; Li, Z.; Tang, Z.; Zeng, G. A GIS-based spatial multi-criteria approach for flood risk assessment in the Dongting Lake Region, Hunan, Central China. *Water Resour. Manag.* **2011**, *25*, 3465–3484. [CrossRef]
21. Ouma, Y.O.; Tateishi, R. Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment. *Water* **2014**, *6*, 1515–1545. [CrossRef]
22. Vignesh, K.S.; Anandakumar, I.; Ranjan, R.; Borah, D. Flood vulnerability assessment using an integrated approach of multi-criteria decision-making model and geospatial techniques. *Model. Earth Syst. Environ.* **2021**, *7*, 767–781. [CrossRef]
23. Feloni, E.; Mousadis, I.; Baltas, E. Flood vulnerability assessment using a GIS-based multi-criteria approach—The case of Attica region. *Int. J. Flood Risk Manag.* **2020**, *13* (Suppl. 1). [CrossRef]
24. Swain, K.C.; Singha, C.; Nayak, L. Flood Susceptibility mapping through the GIS-AHP techniques using the cloud. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 720. [CrossRef]
25. Souissi, D.; Zouhri, L.; Hammami, S.; Msaddek, M.H.; Zghibi, A.; Dlala, M. GIS-based MCDM—AHP modeling for flood susceptibility mapping of arid areas, southeastern Tunisia. *Geocarto Int.* **2019**, *35*, 991–1017. [CrossRef]
26. Neluwa Divisional Secretariat Division (DSD). *Resource Profile*; Neluwa DSD: Gallen, Switzerland, 2020; pp. 8–155.
27. Tucker, C.J. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sens. Environ.* **1979**, *8*, 127–150. [CrossRef]
28. Stitch, B.; Holland, J.H.; Noberga, R.A.; Hara, C. Using multi-criteria decision making to highlight stakeholders' values in the corridor planning process. *J. Transp. Land Use* **2011**, *4*, 105–118.
29. De Brito, M.M.; Evers, M. Multi-criteria decision-making for flood risk management: A survey of the current state of the art. *Nat. Hazards Earth Syst. Sci.* **2016**, *16*, 1019–1033. [CrossRef]
30. Saaty, T.L. How to make a decision: The analytic hierarchy process. *Eur. J. Oper. Res.* **1990**, *48*, 9–26. [CrossRef]
31. Mondal, B.K.; Kumari, S.; Ghosh, A.; Mishra, P.K. Transformation and Risk Assessment of East Kolkata Wetlands (India) using Fuzzy MCDM Method and Geospatial Technology. *Geogr. Sustain.* **2022**, *3*, 191–203. [CrossRef]
32. Mondal, B.K.; Sahoo, S.; Das, R.; Mishra, P.K.; Abdelrahman, K.; Acharya, A.; Lee, M.; Tiwari, A.; Fnais, M.S. Assessing Groundwater Dynamics and Potentiality in the Lower Ganga Plain, India. *Water* **2022**, *14*, 2180. [CrossRef]
33. Acharya, A.; Mondal, B.K.; Bhadra, T.; Abdelrahman, K.; Mishra, P.K.; Tiwari, A. Geospatial Analysis of Geo-Ecotourism Site Suitability using AHP & GIS for Sustainable and Resilient Tourism Planning in West Bengal, India. *Sustainability* **2022**, *14*, 2422.
34. Chen, W.; Han, H.; Huang, B.; Huang, Q.; Fu, X. Variable-Weighted Linear Combination Model for Landslide Susceptibility Mapping: Case Study in the Shennongjia Forestry District, China. *ISPRS Int. J. Geo-Inf.* **2017**, *6*, 347. [CrossRef]

35. Mendoza, G. A GIS-based multi-criteria approach to land use suitability assessment and allocation. In Proceedings of the 7th Symposium on Systems Analysis in Forest Resources, GTR-NC-205; Traverse City, MI, USA, 28–31 May 1997, Vasievich, J.M., Fried, J.S., Leefers, L.A., Eds.; U.S. Forest Service: St. Paul, MN, USA, 1997.
36. Dewan, A.; Islam, M.M.; Kumamoto, T.; Nishigaki, M. Evaluating flood hazard for land-use planning in Greater Dhaka of Bangladesh using remote sensing and GIS techniques. *Water Resour. Manag.* **2007**, *21*, 1601–1612. [CrossRef]
37. Finn, M.P.; Thunen, D. Recent literature in cartography and geographic information science. *Cartogr. Geogr. Inf. Sci.* **2014**, *41*, 393–410. [CrossRef]
38. Ghanbarpour, M.R.; Salimi, S.; Hipel, K.W. A comparative evaluation of flood mitigation alternatives using GIS-based river hydraulics modeling and multicriteria decision analysis. *J. Flood Risk Manag.* **2013**, *6*, 319–331. [CrossRef]
39. Green, C.H.; Parker, D.J.; Tunstall, S.M. Assessment of Flood Control and Management Options. Thematic Review IV.4 Prepared as an Input to the World Commission on Dams, Cape Town. 2010. Available online: http://www.dams.org (accessed on 26 August 2022).
40. Liu, Y.B.; Gebremeskel, S.; De Smedt, F.; Hoffmann, L.; Pfister, L. A diffusive transport approach for flow routing in GIS-based flood modeling. *J. Hydrol.* **2003**, *283*, 91–106. [CrossRef]
41. Meyer, V.; Becker, N.; Markantonis, V.; Schwarze, R.; Bergh, J.; Bouwer, L.; Bubeck, P.; Ciavola, P.; Genovese, E.; Green, C.; et al. Assessing the costs of natural hazards—State of the art and knowledge gaps. *Nat. Hazards Earth Syst.* **2013**, *5*, 1351–1373. [CrossRef]
42. Mishra, P.K.; Rai, A.; Rai, S.C. Indigenous knowledge of terrace management for soil and water conservation in the Sikkim Himalaya, India. *Indian J. Tradit. Knowl.* **2020**, *19*, 475–485. Available online: http://op.niscair.res.in/index.php/IJTK/article/view/41446 (accessed on 26 August 2022).
43. Mishra, P.K.; Rai, A.; Abdelrahman, K.; Rai, S.C.; Tiwari, A. Analyzing Challenges and Strategies in Land Productivity in Sikkim Himalaya, India. *Sustainability* **2021**, *13*, 1112. [CrossRef]
44. Schmidt, G.; Subah, A.; Khalif, N. Climatic changes and water resources in the Middle East and North Africa. *Environ. Sci. Eng.* **2018**, *23*, 2941–2963.
45. Yahaya, S.; Ahmad, N.; Abdalla, R.F. Multi-criteria analysis or flood vulnerable areas in Hadejia Jama'are River basin, Nigeria. *Eur. J. Sci. Res.* **2010**, *42*, 71–83.
46. Mishra, V.; Avtar, R.; Prathiba, A.P.; Mishra, P.K.; Tiwari, A.; Sharma, S.K.; Singh, C.H.; Yadav, B.C.; Jain, K. Uncrewed Aerial Systems in Water Resource Management and Monitoring: A Review of Sensors, Applications, Software, and Issues. *Adv. Civ. Eng.* **2023**. [CrossRef]