Assessing the Socioeconomic Implications of Flood Risk in Ratnapura District, Sri Lanka

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ABSTRACT

The core objective of this research is to leverage geospatial technology for assessing flood risk in Sri Lanka's Ratnapura district while also examining the socioeconomic ramifications of flood occurrences in the area. Situated in Sri Lanka's central highlands, Ratnapura faces significant flood vulnerability, notably during the Southwest monsoon period spanning from May to September. Through a comprehensive consideration of influential factors in flood occurrences and the utilization of the Multi-Criteria Decision Analysis method, a flood risk map of the Ratnapura district has been constructed using ArcGIS 10.3 software. Analysis of the flood risk map indicates that 15.4% of the district is classified as having a very high flood risk, while roughly 31.5% is deemed to have low risk. Furthermore, overlaying thematic layers for road networks, buildings, land use, and settlements with the flood risk thematic layer reveals that approximately 4,000 human settlements, 1,200 main buildings, 35 schools, 100,000 acres of cultivated land, and 190 kilometres of major roads are situated in areas characterized by very high flood risk. Consequently, this scenario presents various socioeconomic challenges, including loss of life, damage to infrastructure, destruction of crops, and harm to livestock. Therefore, it is imperative to introduce effective flood mitigation measures, develop comprehensive flood management strategies, and promptly implement them. This proactive approach is crucial for minimizing the socioeconomic impact of future flood events in the region.

Keywords: flood risk, multi criteria decision analysis method, GIS, consistency ratio

INTRODUCTION

In the 21st century, floods have emerged as one of the most devastating, frequent, and widespread catastrophic events worldwide (Bishaw, K. 2012) [2], (Emmanuel, U. et al, 2015) [5]. Floods give rise to a plethora of environmental and socio-economic consequences within affected regions. Notably, floods account for a significant 31% of economic losses resulting from natural disasters (Emmanuel, U. et al, 2015) [5], underscoring the importance of studying this phenomenon. Floods, characterized by the overflow of water inundating land, can lead to damage to agricultural lands, urban areas, and even the loss of human lives (Rahmati, O. et al, 2016) [10]. These deluges can be triggered by various meteorological and hydrological events, including intense precipitation during the rainy season, excessive surface runoff, and a sharp increase in river discharge. Anthropogenic factors, such as poor urban planning, inadequately designed drainage channels, improper agricultural practices, and land-use changes, are among the dominant factors contributing to flood occurrences. A natural hazard encompasses the likelihood of catastrophic events along with their key physical attributes (Mourato, S. et al, 2012) [8]. Vulnerability refers to the conditions shaped by physical, social, economic, and environmental factors or processes that heighten the susceptibility of individuals, communities, assets, or systems to the impacts of hazards (Palliyaguru, R. et al, 2014) [9].

South Asia's geographical location renders it highly susceptible to natural disasters, making it one of the most flood-vulnerable regions globally. Moreover, countries in this region exhibit a high level of vulnerability due to a lack of resources, including adaptive and coping capacities (Rahmati, O. et al, 2016) [10]. In Sri Lanka, flood losses have significantly increased in recent decades, with major floods often associated with the two monsoon seasons. During the Southwest monsoon season (May-September), the Western, Southern, and Sabaragamuwa provinces are prone to floods. In contrast, during the Northeast monsoon (December-February), the Eastern, Northern, and North-central provinces are susceptible to flooding, rivers along the western slopes of the hilly central areas cause floods in the lower flood plains of Kalu Ganga and Kelani Ganga, particularly during these periods. Notably, Sri Lanka has experienced severe floods in recent history, including in 2003, 2011, 2012, 2016, and 2017. The 2003 floods affected 23 districts, impacting 733,479 people and resulting in the loss of 151 lives. In late May 2017, floods affected 15 districts, causing the loss of 213 lives and the displacement of 79 individuals. Additionally, these flood events incurred substantial property losses, estimated at around 70 billion rupees (Rahmati, O. et al, 2016)[10]. In Sri Lanka, the Ratnapura district has experienced the highest number of recorded flood events, followed by Kalutara, Galle, Kurunegala, and Ampara districts. Notably, flooding in Ratnapura and Kalutara is closely associated with the Kalu Ganga basin, which covers an area of 2,690 km^2 and ranks as the second-largest river basin in Sri Lanka, featuring a river channel spanning approximately 100 km (De Silva, M.M.G.T., and Kawasaki, A., 2018) [3].

According to the Department of Irrigation (2016), this basin receives an annual mean rainfall of 4,000mm, with a total annual water discharge of 7.3 billion cubic meters, most of which occurs during the southwest monsoon. While floods impact the area annually, some years witness critical floods, defined by the Irrigation Department as those exceeding 24.4 meters above sea level at the Ratnapura stream flow measuring gauge. Critical floods occurred in 1913, 1940, 1941, 1947, 2003, and 2017 (De Silva, M.M.G.T. and Kawasaki, A., 2018)[3]. While floods may be unavoidable and uncontrollable, addressing these issues through risk zone mapping and a comprehensive analysis of various criteria can enhance preparedness, prevention, and risk reduction efforts. Flood vulnerability mapping plays a pivotal role in establishing early warning systems and formulating strategies for future flood management (Rahmati, O. et al, 2016) [10]. Utilizing remote sensing and GIS techniques allows for a detailed examination of multiple criteria, facilitating a deeper understanding of the nature and behaviour of flood hazards, and the identification of vulnerable areas (Saeid, J. et al, 2021) [11]. One popular approach for assessing flood risk is the use of numerical models (Dutta, D., 2007) [4]. Several studies have employed GIS-based multi-criteria decision analysis (MCDA) to assess index-based flood hazards by examining the factors that influence floods (Kazakis, N., 2015) [6], (Wu, Y., et. al., 2015) [15]. The GIS-MCDA technique leverages GIS capabilities for processing geospatial data and the adaptability of MCDA to combine factual data such as rainfall, land use, soil type, slope, and drainage density with value-based data (Yahaya, S., et al, 2010) [16]. Despite various government initiatives to enhance disaster management in the Ratnapura area, it remains vulnerable, with numerous individuals enduring severe property damage and loss of life during major flood events. This paper's objective is to integrate GIS and multiple-criteria decision analysis (MCDA) techniques to develop a flood hazard map for the Ratnapura district in Sri Lanka. The study will also analyze flood risk in the area using the created flood hazard map.

Study Area

Ratnapura district is located within the upcountry-wet zone of Sri Lanka, an area characterized by an average annual rainfall of 3,000mm. This region faces heightened vulnerability to flash floods and riverine floods, primarily due to substantial rainfall in the upper watersheds and its positioning in the floodplains of the Kalu River. The Kalu River serves as the principal source responsible for flood occurrences in Ratnapura district (Amaraweera, P.H., et.al, 2018) [1]. Spanning an expansive area of about 2,803km^2, the Kalu River basin witnesses an annual discharge of approximately 3 million cubic meters per square kilometer per year, marking it as the highest in the country (Wickramasooriya, A.K. and Walpita, L.S., 2021) [13]. Certain parts of the upper Kalu River basin experience even more substantial rainfall depths, exceeding 5,000mm, leading to a significant volume of discharge (Liyanarachchi, P. and Chandana, P.G., 2004) [7]. The vulnerability to flooding is particularly pronounced in this region, where nearly 90% of agricultural land, predominantly paddy fields, is situated along the tributaries in the floodplain. Additionally, both commercial and residential areas in Ratnapura town are densely built up and highly susceptible to flooding (Wickramagamage, P., 2011) [12].

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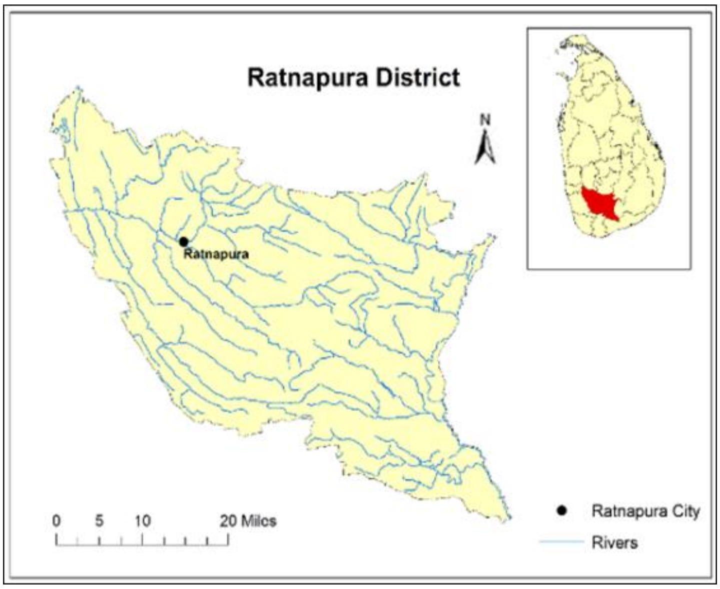

Figure 1. Ratnapura district in Sri Lanka

Road network of the study area

Figure 2 illustrates the road network within the Ratnapura district. It's worth noting that several major roads link important commercial cities such as Colombo, Batticaloa, and Kandy, and these vital transportation arteries are situated near the Kalu River. This close proximity exposes them to the risk of being impacted by potential future flood events. Moreover, the figure emphasizes the existence of numerous main roads and minor roads near the Kalu River and its branches. These areas are especially prone to flooding, posing a significant risk of inundation to the road infrastructure during flood events.

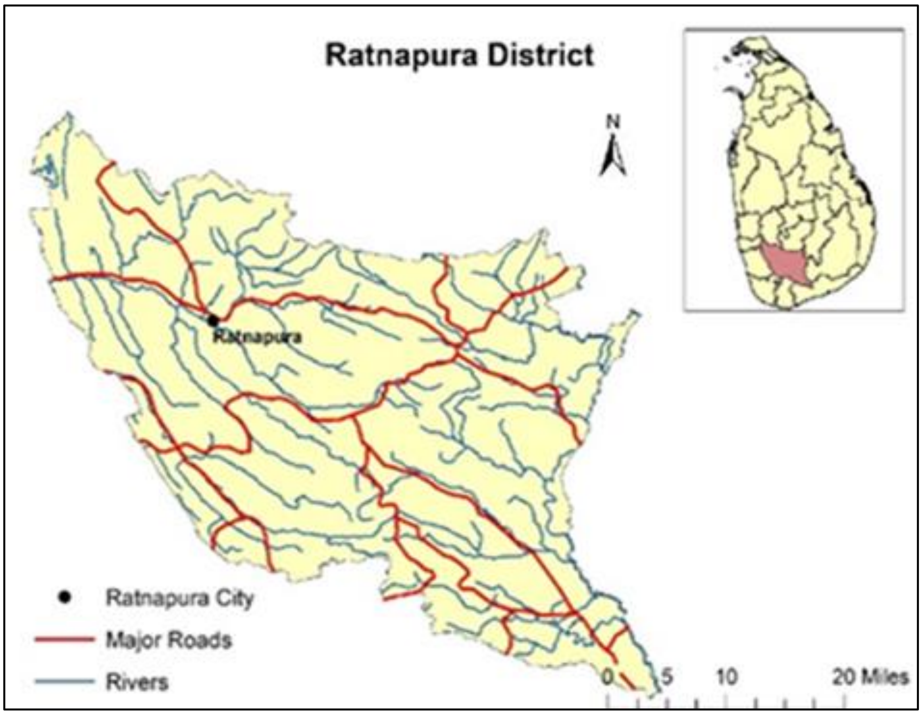

Figure 2. Road network in the Ratnapura district

Settlements in the study area

Settlements in the Ratnapura district correspond to the dispersion of the human population in the region. Figure 3 illustrates the population density across divisional secretariats in the Ratnapura district.

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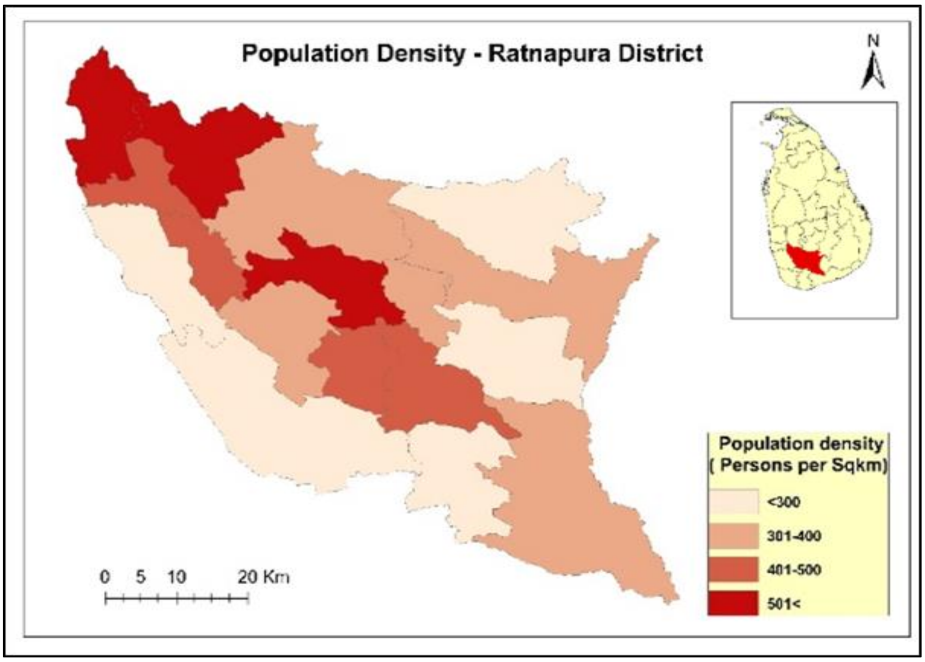

Figure 3. Population density in the Ratnapura district

Flood vulnerability in the study area

The maps indicate settlements in Ratnapura district are vulnerable to floods near the Kalu River. Current inundation maps lack socioeconomic factors, potentially underestimating impacts on settlements and roads. This study aims to analyze future flood impacts comprehensively, addressing gaps in understanding socioeconomic implications. By considering both settlements and road networks, it seeks to improve disaster management strategies for Ratnapura district.

MATERIALS AND METHODOLOGY

Material

Secondary digital data at a 1:50,000 scale was obtained from the Survey Department of Sri Lanka, as outlined in Table 1. This dataset served as a primary source of geographic information for the study

Table 1. Data types and data sources

Data Type	Scale	Source
Contour	1:50,000	Survey Department of Sri Lanka
Land use	1:50,000	Survey Department of Sri Lanka
Road	1:50,000	Survey Department of Sri Lanka
Settlements	1:50,000	Survey Department of Sri Lanka

The study on Ratnapura incorporated various data sources. Apart from primary data, it utilized the Ratnapura development plan by the Urban Development Authority, Google images, Landsat images, population data from the Census and Statistical Department, settlement information from the Urban Development Authority of Sri Lanka, and past flood inundation maps from the Ministry of Defense. These diverse sources ensured accuracy and reliability in the study's outcomes.

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Methodology

The primary objective of this study is to identify the areas in the Ratnapura district with the highest and lowest flood risk. This goal is accomplished through a series of sequential steps, outlined in Figure 4.

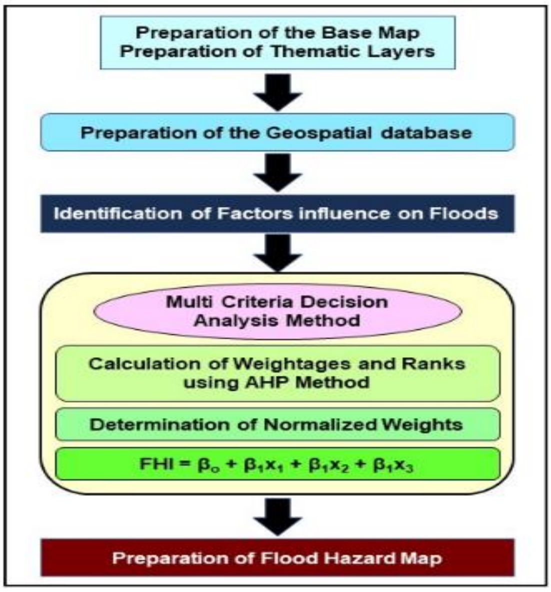

Figure 4. Summary of the research methodology

The primary steps of the study can be summarized as follows:

- Preparation of Georeferenced Digital Maps: This step entails utilizing the collected digital maps to generate georeferenced maps and compiling a database containing digital thematic layers essential for flood hazard analysis.
- Weightage Calculation for Factors: Utilizing the Pairwise Comparison Method, specifically the Analytical Hierarchy Process (AHP), weightages are computed for the various factors influencing flood hazards in the area. These criteria are determined following the guidelines provided by the Disaster Management Centre.
- Rank Assignment for Factors:Different conditions within these factors are assigned ranks based on a scale introduced by Saaty, T. L. in 1988. This step is crucial for understanding the relative importance of each factor concerning flood hazards.
- Flood Hazard Map Preparation:Using the Multi-Criteria Decision Analysis Method and a weighted overlay analysis approach, a flood hazard map is prepared for the study area. This map integrates the factors, weightages, and rankings to identify and visualize areas with varying degrees of flood risk within the Ratnapura district.

Preparation georeferenced thematic layers and database

A meticulously constructed digital database has been assembled, comprising essential digital thematic layers necessary for analyzing flood risk within the area. These digital layers serve as crucial resources for conducting geographical information systems (GIS) applications and making informed decisions. Sourced from various institutions such as the Department of Survey and the Disaster Management Centre of Sri Lanka, the digital thematic layers have been standardized to a consistent scale of 1:50,000, georeferenced, and converted into raster format. This ensures compatibility with ArcGIS software for seamless analysis and utilization. Such meticulous preparation of the digital database lays the foundation for the comprehensive assessment of flood risk in the Ratnapura district.

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Calculation of weightages for factors or parameters

In the process of preparing the flood hazard map for the study area, the expertise of key departments, including the Department of Irrigation, Department of Meteorology, and Disaster Management Centre, was leveraged. These experts provided valuable insights into the main factors that influence the creation of floods and the relative importance of these factors in contributing to flood events. The primary factors considered in the analysis of flood hazard were:

- Topography and Elevation: Analyzing the terrain elevation and slope characteristics to identify low-lying areas prone to flooding and to understand the flow of water during flood events.
- Land Use and Land Cover: Examining the types of land use and land cover within the study area to understand how human activities impact flood vulnerability and to identify areas susceptible to urban flooding.
- Infrastructure and Drainage Systems: Assessing the effectiveness of existing infrastructure, including drainage networks and flood control measures, in mitigating flood risk and protecting communities.

By incorporating insights from these key departments and considering these primary factors, the flood hazard map aims to provide a comprehensive understanding of flood risk within the Ratnapura district.

To create a comprehensive flood hazard map, different weightages were calculated for each of these three factors. These weightages were determined based on their relative importance, utilizing the square pair-wise comparison method, as detailed in Table 2. This approach allowed for a more accurate assessment of flood risk within the study area, considering the varying influences of these key factors.

Table 2. Square pairwise comparison matrix of analysing weightages

	Water buffer	Land use	Elevation
Water buffer	1	4	2
Land use	0.25	1	0.25
Elevation	0.50	4	1
Total	1.75	9	3.25

The preparation of the flood hazard map for the study area benefitted from the expertise of professionals in flood hazard, vulnerability, and risk analysis from key institutions, including the Department of Irrigation, Department of Meteorology, and the Disaster Management Centre. These experts played a pivotal role in identifying the primary factors that contribute to the occurrence of floods and assessing the relative importance of these factors in the context of flood creation. Their insights and expertise were invaluable in ensuring the accuracy and reliability of the flood hazard map, contributing to a comprehensive understanding of flood risk within the study area.

This collective knowledge and expertise formed the foundation of the flood hazard map, ensuring a thorough and well-informed assessment of flood risk within the study area. The analysis of flood hazard in the study area focused on three primary factors: elevation, distance from the main river and its tributaries (water buffer), and land use types within the region. These factors were considered central to understanding and assessing flood risk within the area. To quantify the relative importance of these three factors, different weightages were calculated for each of them. This calculation was conducted using the square pair-wise comparison method, as indicated in Table 2. Assigning weightages to these factors is a fundamental step in comprehensively evaluating flood risk, as it provides a structured and data-driven approach to understanding the significance of each factor in contributing to the creation of floods in the study area.

Calculation of normalized weightage values

The initial weightings for the three primary factors affecting flood hazard underwent additional processing to improve analysis accuracy. This processing included normalization, leading to the values outlined in Table 3. Normalization is a standard procedure in multi-criteria decision analysis (MCDA), ensuring all factors share a consistent scale for direct comparison, thereby refining analysis precision. These normalized values are crucial for a more precise and detailed evaluation of flood risk within the study area.

Table 3. Normalized Matrix

	C1	C2	C3	Weightage
C1	0.571428571	0.44444	0.615384615	0.544
C2	0.142857143	0.11111	0.076923077	0.110
C3	0.285714286	0.44444	0.307692308	0.346
Total	1	1	1	1

The Analytical Hierarchy Process (AHP) was used to assign weights to factors affecting flood formation: river proximity (water buffer), elevation, and land use. Weights allotted were 0.544, 0.346, and 0.110, respectively. These weights are pivotal in gauging factors' importance in flood risk assessment. To validate reliability, a Consistency Ratio (CR) analysis was conducted. CR evaluates consistency in weight allocation, indicating deliberate judgment in pairwise comparisons. $CR \leq 0.1$ is deemed acceptable, suggesting a consistent matrix; $CR > 0.1$ necessitates matrix revision due to potential inconsistency. This analysis ensures weight validity for subsequent flood risk assessments.

Analysis of Consistency Ratio (CR)

The accuracy of created weightages are anslysed using Consistency Ratio equation given in below.

$$CR = CI / RI \tag{1}$$

Where, CR is the Consistency Ratio and CI is the Consistency index

$$CI = (\lambda_{max} - n) / (n - 1) \tag{2}$$

Where, λ_{max} is the Principal Eigen Value, n is the Number of criteria and RI is the Random Consistency Index (RI) which can be obtained using the standard values given in the Table 4.

Table 4. Random Indices for matrices of various sizes

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51	1.52	1.54	1.56	1.58	1.59

Source: GIS-based Multi-Criteria Decision Analysis (Estoque, R, C, 2011). (n – no of indices in the matrix)

The analysis involves three indices (n = 3) in the matrix, and the Random Index (RI) for this case is determined to be 0.58. To calculate the Consistency Index (CI) for the analysis, the following steps are typically followed. However, the specific calculation is not provided in your message. The formula to calculate CI is as follows:

$$CR = CI / RI = 0.05912032 \tag{3}$$

$$CI = (\lambda_{max} - n) / (n - 1) = 0.0342898 \quad (4)$$

With a Consistency Ratio (CR) of 0.05912, well below the 0.1 threshold, the weight calculation process demonstrates strong consistency. This assures the reliability of assigned weights for factors (distance from river, elevation, land use type) in flood hazard analysis. Such consistency fortifies the accuracy and validity of flood risk assessment, ensuring a sturdy analytical base.

Assign ranks for different conditions within factors

Recognizing the limitations of applying uniform weightage to factors in addressing their diverse conditions, the study has introduced tailored ranking systems for each condition's specific impact on flood formation. This customized approach is vital because varying conditions within a factor can exert differing degrees of influence on flood hazards. For instance, areas near rivers may face greater flood risks than those farther away. Thus, it's essential to assign varying weightage to significant conditions within each factor. To accomplish this, three ranking systems calibrated to address specific conditions within the factors have been developed. These systems follow Saaty's 9-point scale, where a rating of 9 indicates the highest influence on flood creation, and 1 suggests minimal impact. By incorporating these customized ranking systems delineated in Tables 5, Table 6, and Table 7, a more nuanced and precise evaluation of flood hazard in the study area is facilitated. This approach acknowledges the diverse impacts of different conditions within the factors, thereby enhancing the accuracy of flood hazard assessment.

Table 5. Distance from the drainage network (water buffer)

Class	Distance from the river (m)	Rank
1	<200	9
2	200 - 500	8
3	500 - 1000	6
4	1000 - 1500	2
5	>1500	1

Table 6. Elevation

Class	Elevation (m)	Rank
1	<200	9
2	201 - 500	5
3	501 - 1000	4
4	> 1000	2

Table 7. Land use type

Class	Land use type	Rank
1	Water	9

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2	Paddy	7
3	Chena, Home Gardens and Other Croplands	5
4	Rubber	4
5	Coconut, Tea	3

The absence of certain relative scales in the analysis indicates either the non-existence of specific conditions or their negligible impact on flood hazard analysis within the study area. Consequently, ranks such as 7, 5, 4, and 3 for distance from the drainage network, ranks 8, 6, 2, and 1 for land use, and ranks 8, 6, 5, 3, and 1 for elevation were omitted from consideration.

This exclusion likely stems from the understanding that these ranks either do not exist in the study area or have minimal influence on flood hazard analysis. It was decided to exclude them as the conditions they represent are believed to have effects similar to other conditions within their respective factors, rendering their individual consideration unnecessary for the analysis. As a result, the study chose to consolidate some relative ranks to streamline the assessment process.

Preparation of flood hazard map

The flood hazard map was crafted by integrating Geographical Information Systems (GIS) applications with the Multi-Criteria Decision Analysis (MCDA) system. MCDA, a widely adopted decision-making method, utilizes digital maps to bolster decision-making processes. It serves as a robust tool for analyzing spatial data and facilitating informed decisions.

In this analysis, the weighted pixels of all three factors i.e. distance from the river, elevation, and land use were superimposed using ArcGIS software. This integration yielded a Flood Hazard Index (FHI) for all pixels on the map. The FHI values, expressed as percentiles, can be computed using the following equation:

$$FHI = \sum W_i R_j \quad (3)$$

$$FHI = W_1 * R_j + W_2 * R_j + W_3 * R_j \quad (4)$$

FHI - Flood Vulnerability Index, W - Weightage assigned for factor, R - Rank assigned for conditions within a factor (from 1 to 9), i - No of factors, j - Appropriate rank of the factor

FHI = [(Elevation Weight × Elevation Rank) + (Distance from the River Weight × Distance from the River Rank) + (Land Use Weight × Land Use Rank)] (5)

This formula amalgamates the weighted values of each factor with the corresponding ranks assigned to the conditions within those factors. The resultant Flood Hazard Index (FHI) values offer a numerical gauge of flood hazard, ranging from 1.00 to 9.00. This quantitative representation enables the assessment of flood risk levels across different areas of the study region.

The creation of the flood hazard map for the study area entailed the utilization of both fuzzy overlay and weighted overlay methods. These techniques are frequently employed in geographic information systems (GIS) and spatial analysis to generate comprehensive thematic maps that offer insights into various aspects of the landscape.

The procedure included the preparation of three distinct ranked thematic layers, each corresponding to one of the factors considered in the study:

- Ranked Distance to the River or Water Buffer Thematic Layer: This layer assesses the proximity of areas to the river or water buffer, considering the various conditions and their influences on flood hazard.

- Ranked Elevation Thematic Layer: This layer focuses on the elevation of different areas within the study region and how it impacts flood hazard.

- Ranked Land Use Thematic Layer: This layer considers the types of land use in the area and their respective effects on flood hazard.

The thematic layers were constructed according to the ranking systems devised for each factor, as detailed in the study. Alongside these thematic layers, the previously calculated weightages for each factor, as discussed earlier, were considered. These weightages serve a crucial role in determining the relative significance of each factor in the overall flood hazard assessment. By incorporating both the ranked thematic layers and the assigned weightages, the flood hazard map for the Ratnapura district was generated. The process of overlay analysis is illustrated in the Figure 5. This map provides a visual depiction of the diverse flood risk levels throughout the district, considering the impact of the selected factors and their respective conditions.

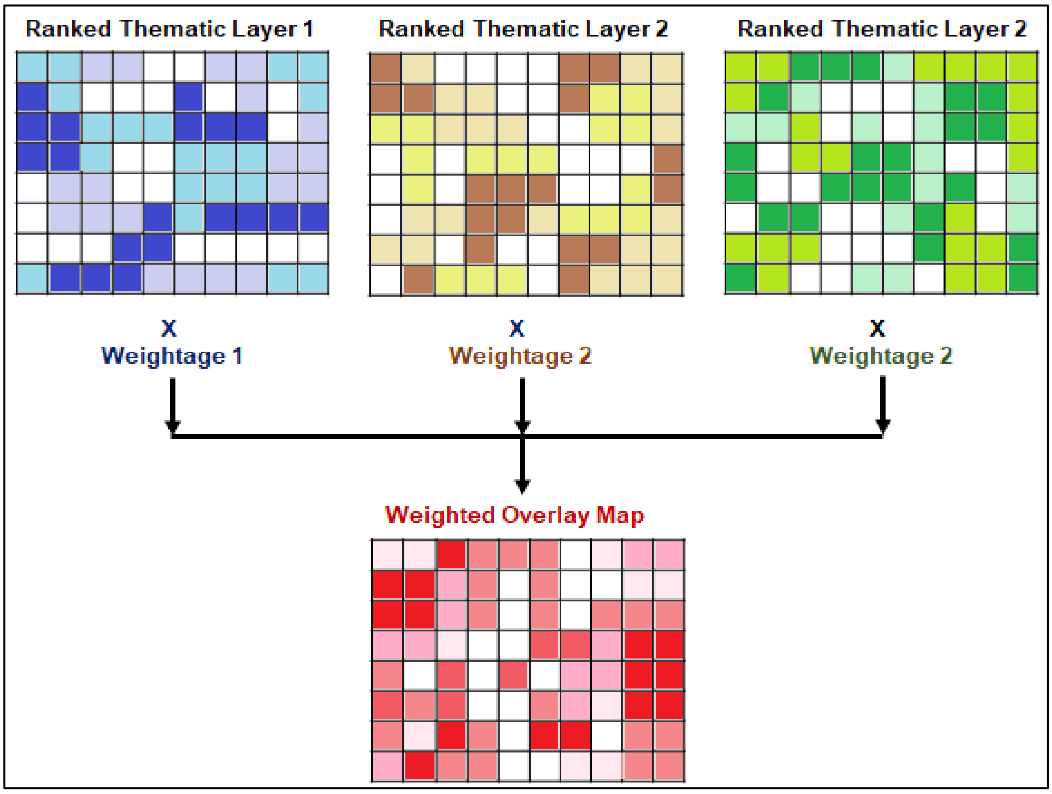

Figure 5. Weighted Overlay analysis method

RESULTS AND DISCUSSION

Preparation of ranked water buffer thematic layer

The weighted water buffer thematic layer for the Ratnapura district was developed based on the drainage network, as illustrated in Figure 1. This thematic layer evaluates flood hazard by considering the proximity to rivers and their tributaries. The water buffer zones were categorized into five classes, each representing varying distance ranges: less than 200m, between 200m - 500m, between 500m - 1000m, between 1000m - 1500m, and greater than 1500m. To assign ranks to these classes, a scale derived from Saaty's 9-point scale was employed. However, it's worth noting that not all ranks on the 9-point scale were utilized in the criteria. Ranks 7, 5, 4, and 3 were omitted, attributed to the absence of conditions represented by these ranks in the study area or their combination due to similar behaviour concerning their impact on flood hazard. The incorporation of this water buffer thematic layer, alongside the assigned ranks, contributes to the assessment of flood hazard in the Ratnapura district. It provides detailed insights into how proximity to water bodies influences flood risk in different regions, as depicted in Figure 6.

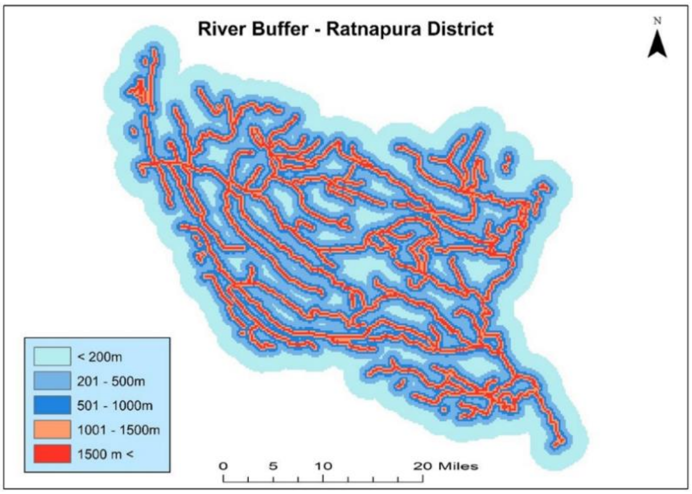

Figure 6. Ranked water buffer map

Preparation of the ranked elevation thematic layer

In the study area, elevation was categorized based on criteria assessing its role in flood formation. Four elevation classes were established, with each class assigned a relative rank to signify its influence on flood hazard. The ranks assigned to different elevation classes, namely less than 200m, between 200m to 500m, between 500m to 1000m, and greater than 1000m, are 9, 5, 4, and 2, respectively.

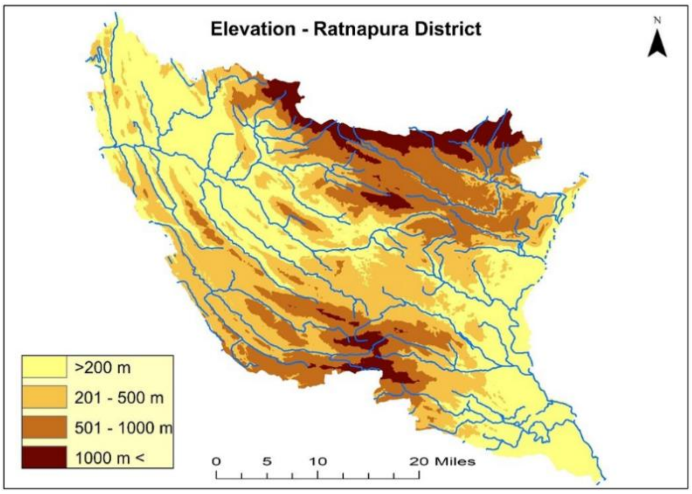

Figure 7. Ranked elevation map

These ranked elevation classes were used to create the ranked elevation thematic layer, as shown in Figure 7. This thematic layer provides valuable information for the flood hazard assessment, helping to understand how varying elevations in different areas of the study region influence flood risk.

Preparation of ranked land use thematic layer

The land use types in the Ratnapura district were classified into five classes based on criteria designed to analyze flood hazard. Ranks for these land use classes, reflecting their influence on flood hazard are Water - 9, Paddy Lands - 7, Chena, Home Gardens, and Other Cropland - 5, Rubber, Coconut, and Tea Lands - 4, and Other Land Uses – 3. As illustrated in Figure 8, the distribution pattern of these land use types across the study area plays a significant role in flood hazard analysis. For instance, paddy lands, mainly situated in low-lying areas and near rivers and their tributaries, are correlated with elevated flood risk. Conversely, tea lands, positioned in higher elevated regions, are associated with reduced flood risk. This insight into land use types and their respective ranks enriches our understanding of how various land uses influence flood hazard in the Ratnapura district.

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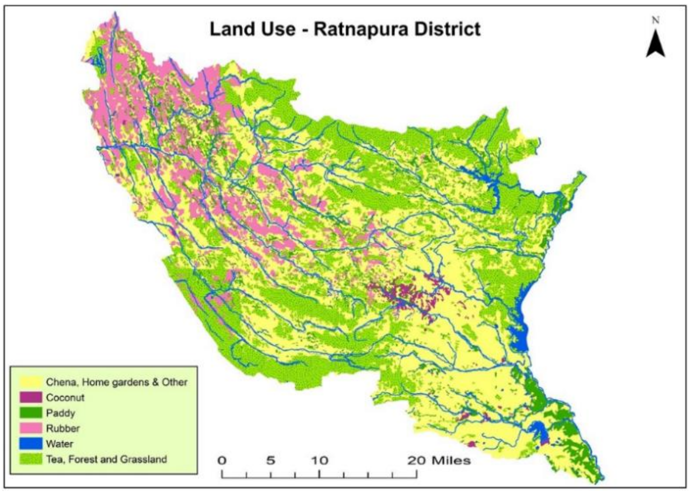

Figure 8. Ranked land use map

Preparation of Flood Hazard Map

In the methodology section, the detailed process of creating the flood hazard map for the Ratnapura district is outlined. The map was generated by incorporating the ranked thematic layers of water buffer, elevation, and land use. Furthermore, the digital georeferenced road network and settlement layers were employed to evaluate flood vulnerability in the Kalutara district.

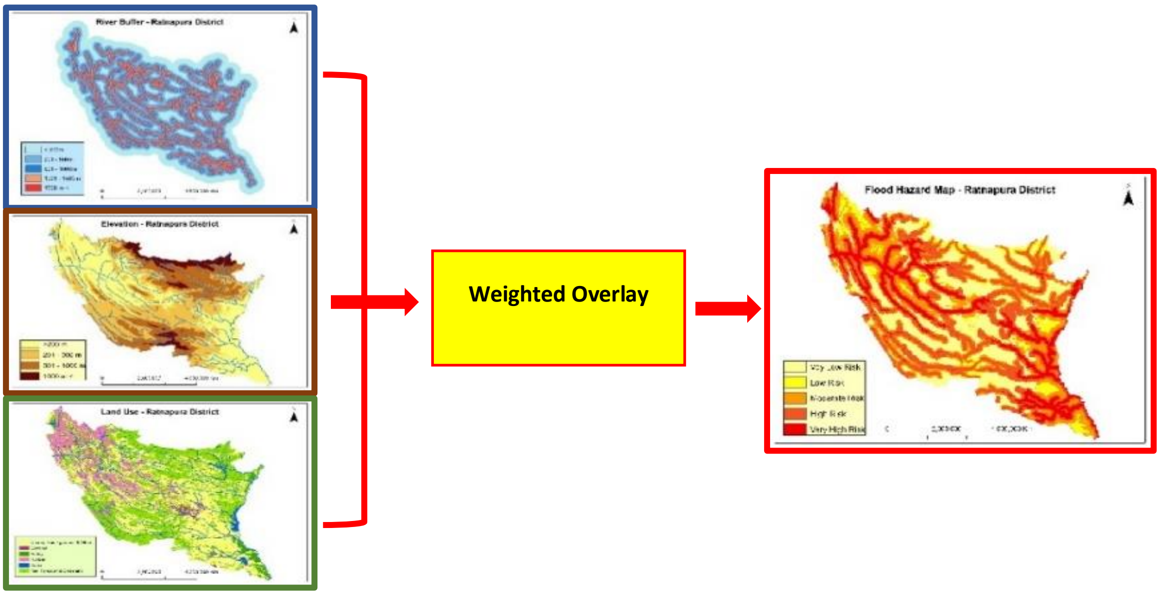

Figure 9. Preparation of Flood Hazard Map using weighted overly procedure

The weightages allocated to the three factors i.e. water buffer, elevation, and land use were computed using the pairwise comparison method, resulting in the following values: 0.544 for water buffer, 0.346 for elevation, and 0.110 for land use. These weightage values, along with the relative ranks assigned to different conditions within each factor, were taken into consideration during the application of the weighted overlay procedure, as illustrated in Figure 9.

The weighted overlay analysis technique, available within the ArcGIS software, was utilized to generate the flood hazard map for the Ratnapura district, as depicted in Figure 10. This technique facilitates the integration of various factors, each assigned with its respective weightage and ranked conditions, to produce a comprehensive map representing flood hazard across the district. The flood hazard map categorizes flood-prone areas in the Ratnapura district into different risk levels, including very high risk, high risk, moderate risk, low risk, and very low risk. A summary of the findings based on the map is provided in Figure 11.

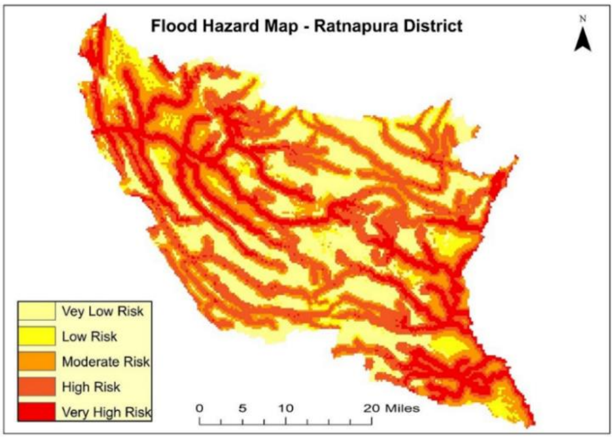

Figure 10. Flood Hazard Map of the Ratnapura District

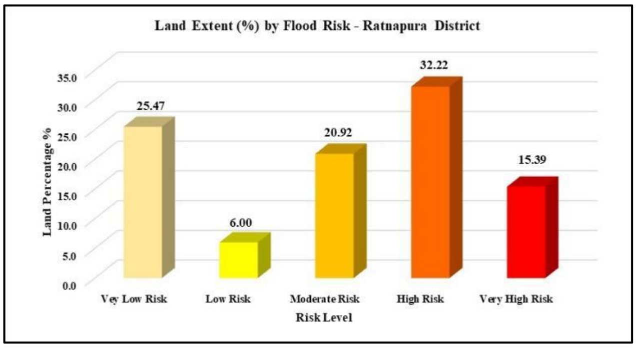

Figure 11. Flood hazard situation in the Ratnapura district

Very High Flood Hazard Areas: These areas are primarily located along the sides of the main rivers and their tributaries, situated in the Southeast and Northwest regions of the district. They are at the highest risk of flooding.

High Flood Hazard Areas: High-risk areas are characterized by paddy and rubber lands, which are relatively flat and situated at lower elevations near water bodies. These areas have a significant risk of flooding.

Moderate Flood Hazard Areas: These areas are distributed in the district, with some variability in elevation and distance from water bodies.

Low Flood Hazard Areas: Low-risk areas are found in the North-eastern and South-western elevated parts of the district, which are situated farther away from water bodies.

Very Low Flood Hazard Areas: These areas are also located in the North-eastern and South-western elevated regions, and they are the least susceptible to flooding.

Notably, the city of Ratnapura, the main urban centre in the district, falls within the high flood hazard zone. According to the flood hazard map, the distribution of these risk categories in the Ratnapura district is as follows:

Very Low Hazardous	: 25.47%
Low Hazardous	: 6.00%
Moderate Hazardous	: 20.92%
High Hazardous	: 32.22%
Very High Hazardous	: 15.39%

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This information provides a clear understanding of the varying levels of flood risk across different parts of the Ratnapura district, which can be valuable for disaster preparedness and urban planning

Analysis of socioeconomic impact due to flood risk in Ratnapura district

This study had a primary focus on analyzing the social and economic impacts resulting from flood risk in the Ratnapura district. To carry out this analysis, three critical socioeconomic vulnerability indicators were taken into consideration. These indicators are:

- Road Network: The condition and resilience of the road network in the district, particularly in flood-prone areas, were evaluated to understand the impact of flooding on transportation infrastructure.
- Human Settlements: The vulnerability of human settlements to flood events was assessed, including factors like population density and proximity to flood-prone areas.
- Agricultural Production: The study examined the impact of flooding on agricultural activities, particularly focusing on the production of crops, which is a vital component of the local economy.

By considering these three key socioeconomic vulnerability indicators, the study aimed to provide a comprehensive understanding of the social and economic consequences of flood risk in the Ratnapura district. This information is crucial for developing effective disaster management and mitigation strategies to reduce the impact of floods on the local community and economy.

Flood impact associated with road network

To assess the flood impact on the road network in the Ratnapura district, a detailed analysis was conducted to identify areas with high flood risk that intersect with major and minor roads. The flood hazard map provided insights into this analysis, and as a result, three distinct zones with very high to high impact areas were demarcated, as shown in Figure 12.

These zones encompass sections of key roadways, including the Colombo – Batticaloa main road (A4), Panadura – Ratnapura (A8) main road, Galle-Deniyaya (A17) main road, Palmadulla – Embilipitiya (A18) main road, and certain segments of class B major roads. Notably, the majority of the very high and high flood risk areas are closely situated near the tributaries of the Kalu River, as well as some tributaries of the Walawe River. The three high-hazard zones are predominantly situated in low-lying floodplains, significantly contributing to the very high flood risk and potential impact on the road network in these areas.

This information is pivotal for disaster management and road infrastructure planning, as it identifies vulnerable areas where flood-related disruptions to transportation routes can be anticipated during flood events.

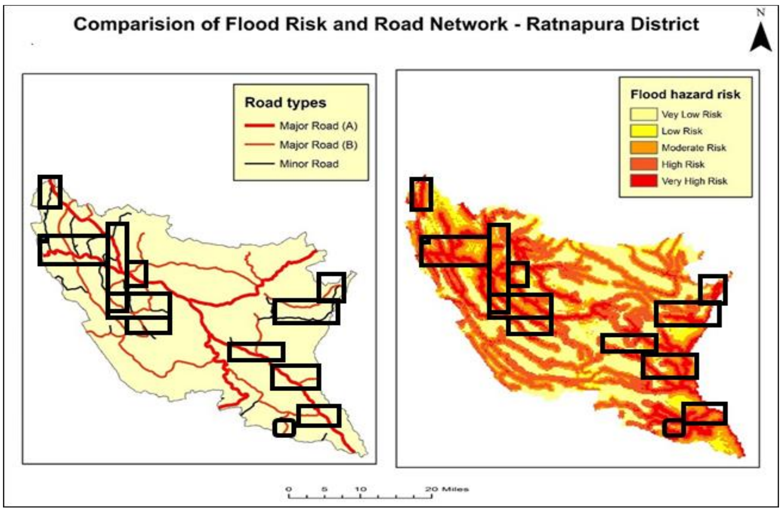

Figure 12. Flood risk in road network in the Ratnapura district

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Flood impact associated with human settlements

The study identified three regions within the study area facing very high to high flood risk, encompassing Eheliyagoda, Kuruwita, Kiriella, Elapatha, and Palmadulla District Secretary divisions. These areas are particularly susceptible to flooding, emphasizing the necessity of implementing flood mitigation and preparedness measures. Furthermore, by overlaying settlement maps with the flood hazard map, the study pinpointed several settlements situated in high flood risk areas. Approximately 4000 human settlements, 1200 main buildings, and 35 schools are located in these high-risk areas. This information underscores the potential impact on the local population, infrastructure, and educational facilities in the event of a flood (Figure 13).

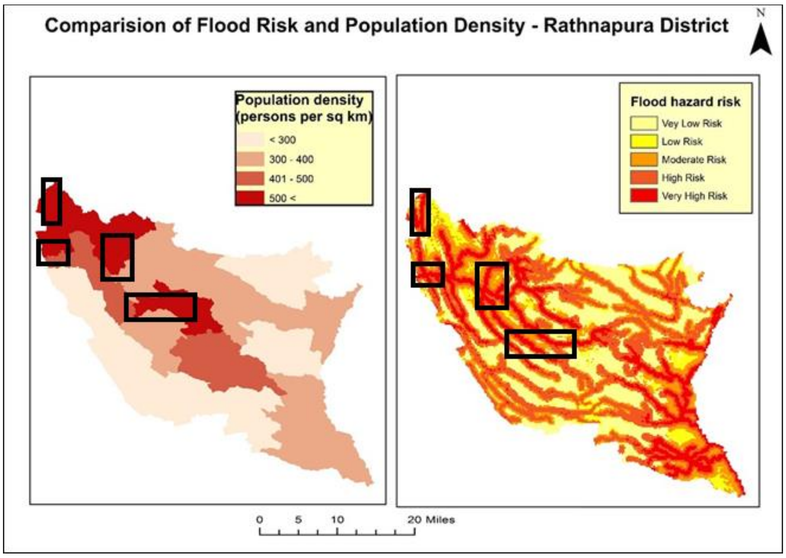

Figure 13. Flood risk in settlement densities in the Ratnapura district

Understanding the vulnerability of these settlements is crucial for disaster management and preparedness, emphasizing the importance of implementing strategies to safeguard lives and property in high-risk areas within the Ratnapura district.

Flood impact associated with cultivated lands

To evaluate the flood impact on agricultural lands in the Ratnapura district, an overlay analysis was conducted to identify areas with high flood risk intersecting with agricultural zones. Insights from the flood hazard map guided this analysis, revealing two major zones with very high to high impact areas, as depicted in Figure 14.

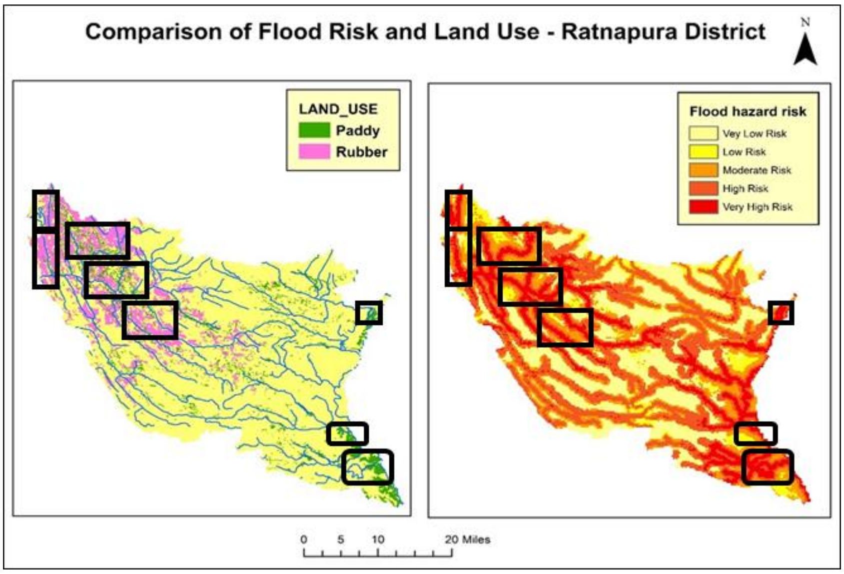

Figure 14. Flood risk in Paddy and Rubber lands in the Ratnapura district

These zones primarily comprise paddy and rubber lands, situated in relatively flat and low-elevated areas along the tributaries and floodplains of the Kalu and Walawe Rivers. These areas are concentrated in the North-western and South-eastern parts of the district. The primary factor contributing to the very high flood risk and potential impact on agriculture in these zones is their low elevation and proximity to water bodies. Consequently, these very high and high flood risk areas are highly vulnerable to flooding, posing significant socioeconomic challenges, particularly concerning the loss of crop production and livestock. Understanding the vulnerability of these agricultural lands is imperative for implementing strategies to mitigate the economic impact of floods on the local agricultural sector.

Validation of the created flood model

For model validation, we compared the generated flood hazard map with a range of secondary datasets. For that, historical flood inventory, inundation maps and water-level reports obtained from the Disaster Management Centre (Disaster Management Centre, n.d.) and satellite-derived inundation maps Using TerraSAR-X Satellite Data (IWMI and Disaster Management Centre Sri Lanka, 2017) were compared with the generated hazard map. Generated flood hazard maps were also cross-validated using findings from previous research on flood-inundation patterns within the Rathnapura Municipal Council, which provides evidence on recurrent flood-prone areas in the district (Jayaprakash, Jayathilake & Munasinghe, 2016).

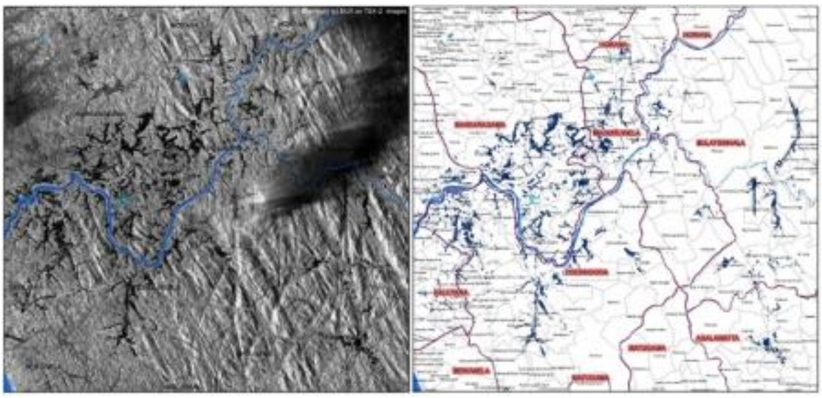

Figure 15. Mapping inundation extent for Kalu ganga basin in the Western province of Sri Lanka using TerraSAR-X Satellite data

To strengthen the socioeconomic dimension of the analysis GN level census and administrative indicators obtained from the Department of Census and Statistics, including population counts, settlement distributions and major income sources (Department of Census and Statistics Sri Lanka, 2020). Data on road networks and land use were derived from the Disaster Management Centre, Sri Lanka (Disaster Management Centre, n.d.). It provide more comprehensive representation of both physical and socioeconomic vulnerability patterns across Ratnapura District.

CONCLUSION

The Ratnapura district, nestled in the central highlands of Sri Lanka, faces recurrent floods, particularly during the Southwest monsoonal period spanning from May to September. These inundations pose significant socioeconomic hurdles, especially in the low-lying floodplains adjacent to the Kalu River. This research endeavors to unravel the distinctive flood risk landscape in the Ratnapura district, focusing on pivotal flood-contributing factors: proximity to the drainage network, elevation, and prevailing land use patterns within the area. Employing the weighted overlay analysis method in ArcGIS 10.3 software, the study crafted a comprehensive flood risk map for the Ratnapura district.

The resultant map delineated regions into five categories: very low hazardous, low hazardous, moderate hazardous, high hazardous, and very high hazardous, encompassing approximately 25.47%, 6.00%, 20.92%, 32.22%, and 15.39% of the total district area, respectively. Yet, the study's ambit extended beyond mere identification of flood-prone zones; it juxtaposed the flood hazard map with data on road networks, human settlements, and land use patterns within the study domain.

This exhaustive analysis unveiled specific roads, such as segments of the Colombo – Batticaloa main road (A4), Panadura – Ratnapura (A8) main road, Galle-Deniyaya (A17) main road, and Palmadulla – Embilipitiya (A18) main road, as being particularly vulnerable to flooding. Furthermore, densely inhabited District Secretary divisions, including Eheliyagoda, Kuruwita, Kiriella, Elapatha, Palmadulla, along with certain individual settlements, emerged as highly susceptible to flood hazards. Moreover, paddy fields and rubber plantations, situated in flat, low-lying areas along the tributaries and floodplains of the Kalu and Walawe Rivers, were identified as flood-prone territories. Inundations in these regions possess the potential to unleash diverse socioeconomic ramifications in the Ratnapura district, particularly concerning the road infrastructure, human habitation, and agricultural output.

In light of the identified high and very high flood risk areas, the implementation of effective flood mitigation strategies becomes imperative to curtail the socioeconomic fallout in the Ratnapura district and bolster resilience against future flood events.

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