An Open-Source Geospatial Approach for Demarcating Landslide Susceptible and Risk Zones in Rathnapura District.

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Abstract: *Landslides constitute a significant natural hazard in Sri Lanka, particularly prevalent in the Rathnapura District where 92,757 individuals were affected and caused severe property damages during 2017 landslide event. Identifying high-risk zones in landslide-prone areas is crucial for effective disaster mitigation and management. However, local and national institutions in Sri Lanka face difficulties due to the unavailability of cost-effective methods for identifying disaster risk areas. This study employs a cost-effective, open-source geospatial methodology utilizing freely accessible satellite and open data, along with Quantum Geographic Information System (QGIS) software as a viable alternative to commercial GIS. Determinant parameters for landslide susceptibility, identified through literature, include slope, elevation, topographic wetness, vegetation cover, annual average rainfall, drainage density, and drainage network. Weighted overlay analysis of these rasters indicated that 70.37 km² of the area in Rathnapura District is highly susceptible to landslides with the Rathnapura Divisional Secretariat Division (DSD) exhibiting highest susceptibility, covering 18.41 km². Identified other highest susceptible zones includes Ayagama, Imbulpe, Kalawana and Kuruwita DSDs. Evaluating landslide vulnerability is crucial for mitigating impacts on human lives and properties. Physical features, including road network and building footprint extracted using OpenStreetMap (OSM) data, along with census population data were utilized for vulnerability analysis. The areas classified as having very high and high socio-economic vulnerability to landslides are concentrated within 27 Grama Niladari Divisions (GND) boundaries. In contrast, both very low and low socio-economic vulnerability areas are distributed across 81 GND boundaries, out of a total of 90 GNDs. Results reveled that high-risk areas are concentrated within 30 GND boundaries based on susceptibility and vulnerability analysis. The findings of this open-source geospatial approach provide a basis for decision-making in developing structural mitigation strategies in both susceptible and high-risk zones. The proposed approach offers a cost-effective, open-source solution that supports the development of proactive, non-structural mitigation measures in disaster management, aimed at preventing potential impacts from landslide hazards.*

Keywords: GIS, Open Source, Landslides, Susceptibility, Risk

Introduction

A hazard is an event with the potential to harm individuals, society, and the environment. Hazards are generally classified into two categories: natural and man-made. Natural hazards, as defined by Smith (2013), refer to environmental phenomena that pose risks to both society and the surrounding environment. Examples include landslides, cyclones, lightning, droughts, floods, avalanches, hailstorms, tornadoes, and heat waves. These events can have significant impacts on human populations and ecosystems.

Landslide is one of the major natural hazard that can occur in mountainous or hilly areas and it is defined as the movement of soil, rock, or debris down a slope that is harm to the society and the environment. Landslide hazard becomes a disaster when it happens where many people are living or have their livelihoods, causes damage to them, their property, and the ecology of the surrounding area. The term “landslide” is described as a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these by United States Geological Survey. The materials may move by falling, toppling, sliding and spreading. According to the National Geography, landslide is the movement of rock, earth, or debris down a sloped section of land due to the physical, environmental and human factors. Landslides are natural geomorphic processes occurring at locations characterized by specific environmental conditions (Beck, 1994). Landslides can be triggered by various factors, including heavy rainfall, earthquakes, human activities, and other natural causes. As Gasparetto et al.1996 landslides might move continuously with seasonal variations or only within specific periods within a given year, decade or century or they may occur only once and are then stable. Landslide susceptibility is the likelihood of a landslide occurring in an area based on local terrain conditions (Brabb, 1984). It predicts “where” landslides are likely to occur (Guzzetti et al., 2005). It is important to analyze susceptibility of the spatial distribution of landslide triggering factors as elevation, slope, topographic wetness, vegetation cover, stream density and distance since risk assessment and disaster reduction strategies depend on it to minimize the impact of landslides.

Landslides can be identified as one of the major natural hazards in Sri Lanka. Between 2000 and 2010, landslides resulted tragic loss of 350 lives and caused significant damage, leading to the destruction or severe impairment of 9,468 houses (Ministry of Disaster Management, 2014) Nearly 20,000 km^2 encompassing 10 districts are prone to landslides in Sri Lanka. It is about 30% of Sri Lanka’s land area and spread into several districts. The Rathnapura District, located in the wet zone of the Sabaragamuwa Province, is highly prone to landslide-related natural disasters. The following table illustrates the severity of landslide occurrences in the Rathnapura District. This research primarily focuses on assessing landslide susceptibility in Rathnapura, with a particular emphasis on identifying the risk in the most susceptible Divisional Secretariat Division (DSD) within the district.

Table 1: Comprehensive overview of landslide impacts in Rathnapura District

Date (YMD)	District	Division	Deaths	Houses Destroyed	House Damaged	Affected
1982/06/08	Ratnapura	Ratnapura	3	3	0	55
1989/06/03	Ratnapura	Eheliyagoda	9	0	6	30
1997/11/15	Ratnapura	Balangoda	1	0	1	5
1999/10/13	Ratnapura	Ayagama	2	0	1	5
2001/01/18	Ratnapura	Imbulpe	1	0	1	5
2003/05/17	Ratnapura	Elapatha	56	28	45	585
2003/05/17	Ratnapura	Godakawela	1	7	0	35
2003/05/17	Ratnapura	Kolonna	2	86	187	1250
2003/05/19	Ratnapura	Elapatha	56	574	1652	11090
2003/05/20	Ratnapura	Ratnapura	6	58	280	1750
2014/06/02	Ratnapura	Ratnapura	1	2	32	752
2017/05/24	Ratnapura	Kalawana	21	30	89	5075
2017/05/24	Ratnapura	Nivithigala	11	4	6	6998
2017/05/26	Ratnapura	Ayagama	17	0	5	16155
2017/05/26	Ratnapura	Eheliyagoda	29	56	115	10563
2017/05/26	Ratnapura	Elapatha	1	16	14	28070
2017/05/26	Ratnapura	Kiriella	2	1	50	13141
2017/05/26	Ratnapura	Palmadulla	0	60	472	12755
Total			**219**	**925**	**2956**	**108319**

Source: Disaster Management Center

Landslides pose a significant threat to both human life and infrastructure, as the materials involved can move through mechanisms such as falling, toppling, sliding, and spreading. These events may lead to fatalities or injuries, as individuals can become buried under debris or trapped in collapsed buildings. The force and speed with which mud, rocks, and rubble descend can result in the destruction or severe damage of homes and personal property, in addition to obstructing roads. Furthermore, land covered by debris becomes unsuitable for cultivation, and livestock may also suffer injury or death as a consequence of these disasters. Therefore assessing the vulnerability of the landslide is crucial for mitigating the risk of such events escalating into disasters. The concept vulnerability is defined in natural hazards terminology as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. Vulnerability can be classified as ecological vulnerability which is integrated by biodiversity, conservation status and habitat fragmentation, and socio-economic vulnerability that is integrated by population density building density and surround infrastructure. Therefore, in this research study the landslide vulnerability assessment can be created by integrating information of the spatial distribution of the susceptibility of landslide triggering factors that affecting physical surface of the area instability with the factors of socio-economic in Rathnapura District.

A risk assessment is a method to determine the nature and extent of risk, by also integrating the likelihood of events. Risk assessment evaluates the results of risk analysis in light of value judgments and risk acceptance standards (Fell et al., 2005). This is done by analyzing the susceptibility of hazard events and evaluating conditions of exposure / vulnerability that together could potentially harm exposed people, assets, and the environment. The risk of landslides in this research study based on the integration of susceptibility and socio-economics vulnerability of Landslides.

This research focuses on landslide susceptibility in the Rathnapura District and assesses the risk within its most susceptible Divisional Secretariat Division (DSD), using open-source geospatial techniques. A geospatial approach is essential for accurately collecting, analyzing, and presenting locational data to identify landslide susceptibility and risks before they escalate into disasters. In developing countries, where landslides frequently cause damage, there is an urgent need for risk assessment tools that prioritize prevention through the use of freely available geographic data and appropriate models.

This study leverages open-source geospatial techniques and remote sensing analysis for the spatial analysis of landslide susceptibility, vulnerability, and risk, with the goal of producing dynamic maps for effective visualization. Quantum Geographic Information System (QGIS) is employed as a competitive alternative to commercial software such as ArcGIS. Due to its open-source nature, QGIS is accessible to local governments and non-profit organizations, allowing them to develop early warning systems cost-effectively. The software supports remote sensing and machine learning tasks through various plugins, enabling users in developing countries to conduct sophisticated spatial analyses such as land cover classification and vegetation monitoring without the need for expensive proprietary software.

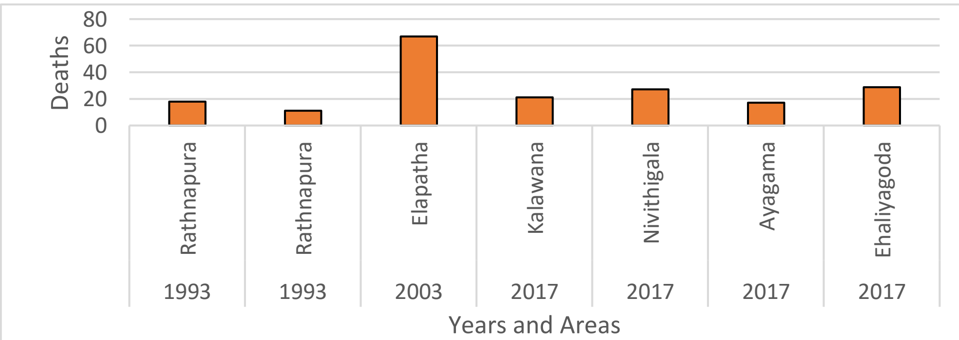
Through this study, landslide susceptibility and risk zones in the Rathnapura District will be delineated using these open-source geospatial approaches, demonstrating the viability and efficiency of free, publicly accessible geospatial tools for disaster risk management.

Literature Review

Rathnapura District is a wet zone which is located under Sabaragamuwa Province and it is highly prone to landslide natural disaster. In 1993, 1994, 1997, 1999 and 2001 more occurrences of varying magnitude of landslides have been reported, particularly from the high altitudes of Central and Sabaragamuwa provinces which is provided by National Building Research Organization (NBRO) 1996, 2002. May 2003 landslides in Rathnapura District once again demonstrated the great vulnerability of the local population. Rathnapura experienced 347.2 mm of unusually heavy rainfall in 24 hours on May 17, 2003. Numerous landslide incidents have been recorded in the Rathnapura district, which is next to the municipality. 77 deaths and 12 injured have been recorded from Rathnapura, Ehaliyagoda, Kiriella, Kahawatta, Ayagama, Kalawana Divisional Secretariat Divisions (DSD) areas by landslides in Rathnapura district which is provided by Disaster Management Center (DMC), 2017

The recent severe landslide occurring and the death of it describes that it is essential for identification landslide susceptibility zones, vulnerability of high susceptible areas and risk to demarcate suitable areas for the distribution of settlements.

Figure 1: Number of Spatial Landslides and Fatalities



Source: Disaster Management Center

Numerous natural and/or anthropogenic parameters determine the appearance and development of landslide movements (topography, geology, hydrology, hydrogeology, rapid erosion of the foot of certain slopes, urbanization, etc.). Landslides occur in fine scree, moraines, or highly fractured and altered rocks, which are particularly sensitive to landslides, such as clays, marls, gypsum or superficial formations of alterities. According to (Ramakrishnan et al.) the occurrence of landslide is mainly due to the presence of huge thickness of loose soils and when mixed with rainwater, it triggers the landslide. Land use is a major factor in mapping landslide susceptibility. Population-related variables such as the transfer of agricultural and forest land to urban areas, the conversion of forest to agriculture, and the decrease of the forced or unethical slope for infrastructure developments all have an impact on how land is used in order to (Jazouli et al., 2019).

Slope angle considered a main causal factor, is frequently used to map the susceptibility in landslides (Wei Chen et al. 2017; Nourani et al., 2014) Landslide Susceptibility Zonation (LSZ) relies on a rather complex knowledge of slope movements and their controlling parameters that above mentioned. Through a number of methods, trees and forests play significant roles in lowering the danger of landslides. Tree roots act as buttresses against soil movement, strengthen soil layers, and anchor the soil to bedrock. By lowering soil moisture levels, trees also minimize the risk of landslides. Interception, evaporation, and transpiration are the main mechanisms. The rainfall pattern with rainfall intensity peak at the later stage is more likely to induce landslide. Meteorological phenomena, however, seem to cause the greatest number of landslide events. (Althuwaynee and Pradhan 2016; Hong et al., 2015, Shahabi et al., 2015). In order to that analyzing the slope, elevation, topographic wetness, vegetation cover, rainfall, drainage density and drainage distance is crucial when there is integration of above each factors for landslide susceptibility.

Landslide socio-economic vulnerability approach considers the integration of two factors: building density and road density mainly . The amount of urban infrastructure space that exists in a given region is known as building density. Since it is reasonable to assume that high construction density may be correlated with high population density, zones with high building density may therefore be more vulnerable. Densities of residential buildings provide insight on the distribution of inhabitants in an area. The overall length of roads in a specific area is referred to as road density, and it is usually measured in kilometers of roads per square kilometer of land. Road density high areas referred as the development of infrastructure as roads are a fundamental component of infrastructure networks. Zones with high road densities may consequently be more vulnerable since it is logical to anticipate that high infrastructure development density may be correlated with road density.

Risk = Hazard × Vulnerability, hazard (landslide susceptibility) and vulnerability (building density and road density) are overlaid to calculate landslide risk.

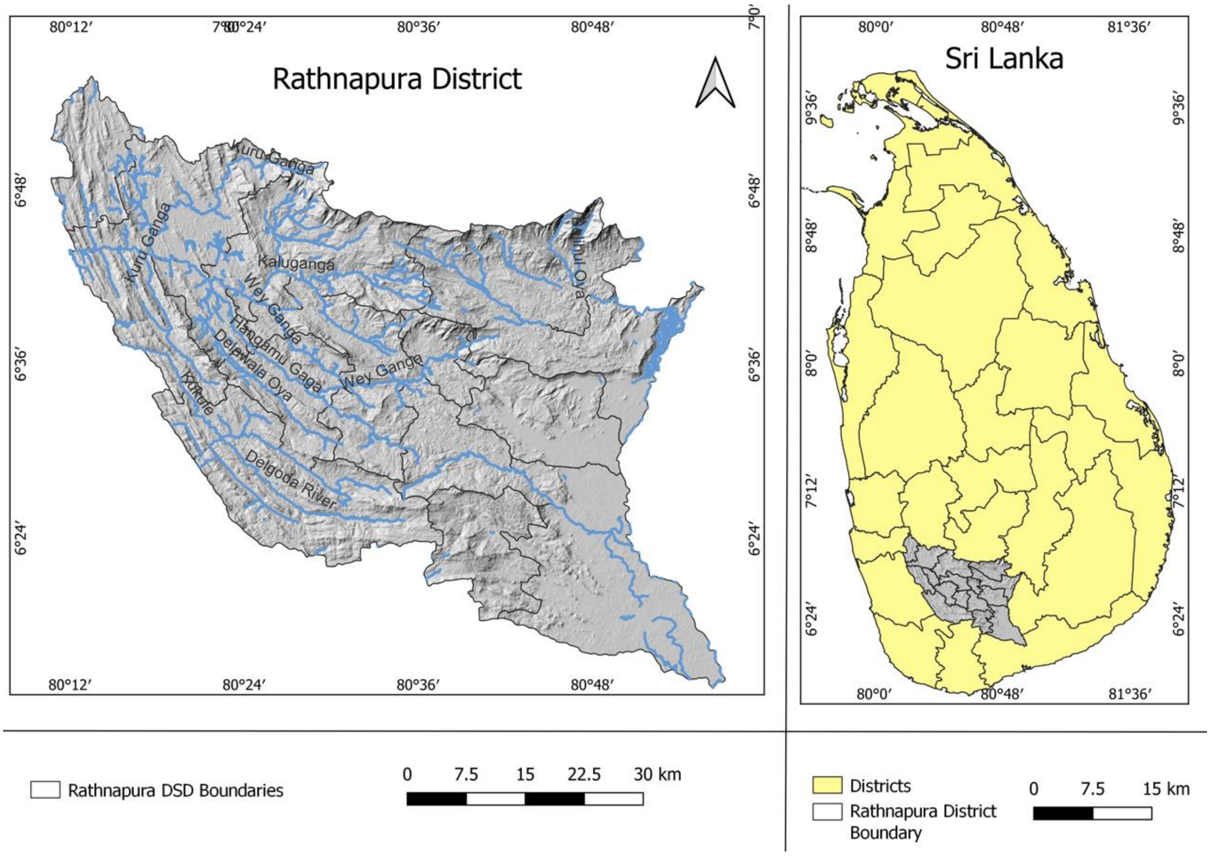
According to the research article, integration of vulnerability and Hazard Factors for Landslide Risk Assessment of State of Guerrero (México) which has done the risk assessment with the aggregation of susceptibility and vulnerability maps, it is found that there is a low risk in coastal areas, which belong to high vulnerability, and low susceptibility in State of Guerrero Mexico. The reasons are that low susceptibility areas are centered in geo-lithology prone to slides, with gentle 23 slope values, the ecological values are modest, low values from the marginalization index due to being the zones with the highest percentage of employment based on the third economic sector trade, and tourism indicates the low vulnerability of the landslides. This study again noticed that there is a high risk in mountainous regions of the West of the state of Guerrero, which belong to high vulnerability and high susceptibility. This article explains that the reasons of risk of landslide occurrence is high because of the high accumulation of precipitation and density of lineaments on lithology susceptible to landslide.

Geo-spatial approaches, with the integration of GIS, remote sensing, and advanced modeling techniques, have significantly enhanced landslide susceptibility, vulnerability, and risk analysis. Globally, especially in Sri Lanka, GIS-integrated multi-criteria assessments are presently being conducted to investigate landslide hazards utilizing contemporary techniques. Using a GIS-based approach, Ranagalage's (2013) study sought to identify landslide risk zones in the Walapane divisional secretariat division in the Nuwara Eliya district. Geo-Spatial approaches are an ideal tool for landslide modeling and handling a large set of data, providing an efficient environment for analysis and display of results with its powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world. Geo-spatial approaches are helpful since it considers data which has reference systems for analysis, Open Sourced Geo-Spatial Approach and Remote sensing analysis can be used for spatial data collecting, analysis and presenting for the utilization of dynamic maps. Open-source software like QGIS (Quantum Geographic Information System) has become a valuable tool for developing countries to conduct geographic analysis, offering significant advantages over commercial software like ArcGIS in terms of cost, accessibility, flexibility, and community support. QGIS is totally free, it is a desirable choice for governments, educational establishments, and nonprofits in developing nations with tight budgets and it supports a wide range of open geospatial data formats making it more flexible and interoperable with various data sources. In comparison, ArcGIS necessitates expensive licenses, particularly for sophisticated features and add-ons

Methodology

Evidently, the Rathnapura District is more prone to landslides compared to other regions, highlighting the pressing need for effective mitigation strategies. To address this issue, the researcher aims to identify landslide-susceptible zones, assess their vulnerability, and evaluate the associated risks within the Rathnapura District using open-source geospatial technology. QGIS facilitates the integration of various open data sources, such as OpenStreetMap and satellite imagery, enabling developing countries to utilize free data for landslide disaster management. The following sections outline the methods, data sources, and methodologies employed to delineate the boundaries of Rathnapura District and its Divisional Secretariat Divisions.

Study Area



Source: Created by Author 2024

Figure 2: Rathnapura District Map

Figure 2 illustrates the study area, Rathnapura District, which belongs to Province Sabaragamuwa Province Sri Lanka. District is located between 6° 15'N - 6°55'N latitude and 80°10'E. - 80°57'E longitude. The central part of the Ratnapura district is highly dissected by the tributaries of the Kalu Ganga and the Walawe Ganga. The Kalu Ganga is the second largest river in Sri Lanka. According to the climate classification, the "A" climate can be identified in the Ratnapura district. "A" denotes Rainy climates - temperature of coldest month over 18°C; no winters, cold or cold season. Red-Yellow Podzolic soil is the main soil category. Two main vegetation types occur in the Ratnapura district. They are tropical rain forest and the mountain forest. According to the population density data of 2021, it is 363.4 km² in Rathnapura of district

Data and Methods

Table 2: Data Type Used in the Study

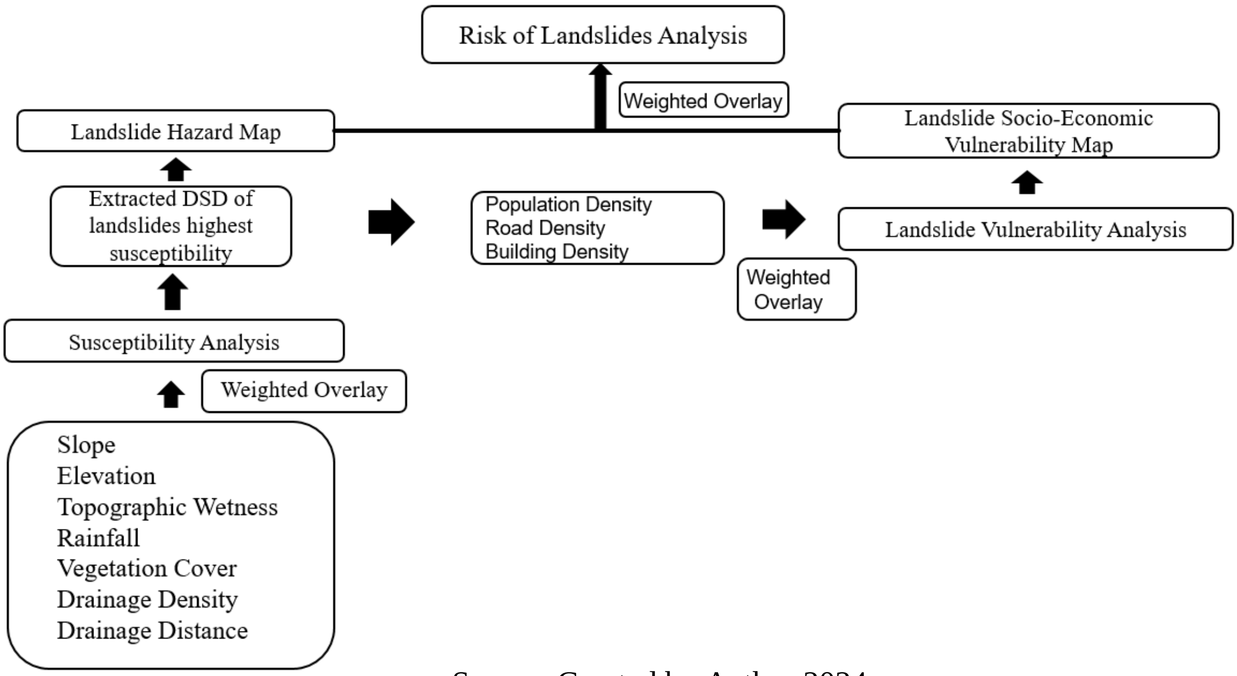
Data	Year	Data Source
Slope		30m Shuttle Radar Topography Mission (SRTM) data downloarder – Digital Elevation Model
Elevation		30m Shuttle Radar Topography Mission (SRTM) data downloarder – Digital Elevation Model
Rainfall	2010 - 2021	NASA Power open data portal
Vegitation	2022	United States Geological Survey (USGS) Earth Exporer data downloarder
Topographic Wetness Index		30m Shuttle Radar Topography Mission (SRTM) data downloarder – Digital Elevation Model
Drainage Density	River Network	OpenStreatMap
Drainage Distance	River Network	OpenStreatMap
Population	2022 estimated population density	2011 population censes data

Built-up Areas		OpenStreatMap
Road Network		OpenStreatMap

Table 3: Indicators and Measures of Variables

Assessment	Variables	Indicator	Measures
Landslide Susceptibility	Slope	Angle of the slope	Ranking variables based on researches and recognized Sri Lankan classifications and weighted overlay variables to find landslide susceptibility.
	Elevation	Distance above the Mean Sea Level (DEM)	
	Rainfall	Average of 12 years annual rainfall of 2010 - 2021	
	Vegetation	Area of the different vegetation canopy coverage (NDVI) of 2022	
	Topographic Wetness	Topographic Wetness Index	
	Drainage Density	Streams density	
	Drainage Network	Streams distance	
Socio - Economic Vulnerability	Population	Population density 2022	Find the nature of vulnerability to landslides for all low to high susceptible areas of landslides.
	Built-up areas	Building density	
	Transport Network	Road Density Calculation	
	High susceptible and high vulnerable areas of landslide	High susceptible and high vulnerable locations	
Risk of Landslide			Find the highest and lowest risk areas of landslides based on landslide susceptibility and vulnerability

Utilizing the diagram below, the methodologies of indicators and measures for data analysis are discussed.



Source: Created by Author 2024

Figure 3: Method of Data Analysis

The digital elevation model is used to measure the slope angle, elevation, and Topographic Wetness Index. The rainfall pattern of the Rathnapura district was determined by employing an inverse distance weighted (IDW) method by interpolating a raster surface from 15 locational rainfall data. The analysis of the vegetation canopy is done using the Normalized Vegetation Index. Using the river network, drainage density and drainage distance are determined. Next, by examining the density of buildings, roads which are extracted from updated OpenStreatMap and population, socio-economic vulnerability is identified. Ultimately, the susceptibility and vulnerability study is used to identify variations of the risk areas. Weighted overlay approach is applied to complete this analysis overall.

Results and Discussion

The existing literature has identified several key factors that contribute to landslide occurrences. These factors include slope gradient, elevation, topographic wetness index (TWI), rainfall intensity, vegetation cover, drainage density, and proximity to drainage channels. To assess the overall landslide susceptibility in a given region, these factors are systematically ranked from low to high based on their influence. Following this ranking, the variables are weighted and overlaid using spatial analysis techniques, such as Geographic Information Systems (GIS). This multi-criteria evaluation approach allows for the creation of a comprehensive landslide susceptibility map which can guide decision-making processes in hazard management, land-use planning, and risk mitigation efforts.

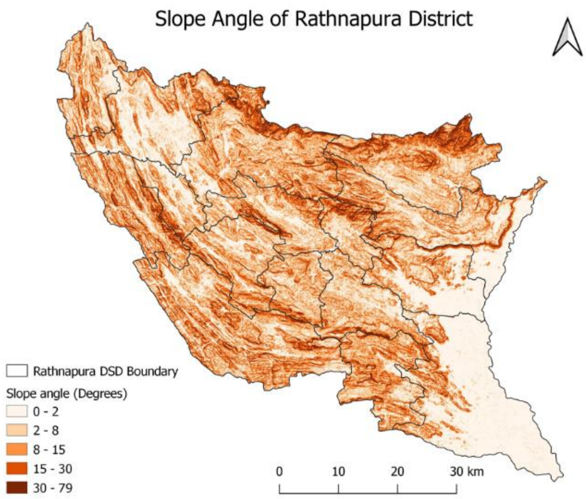


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Figure 4: Slope of Rathnapura District

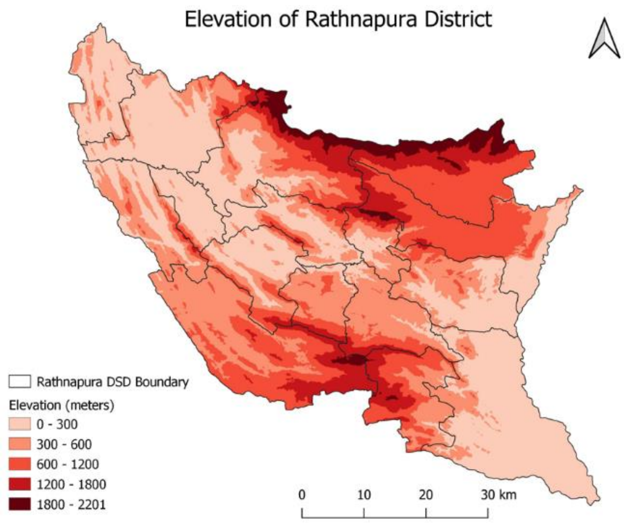

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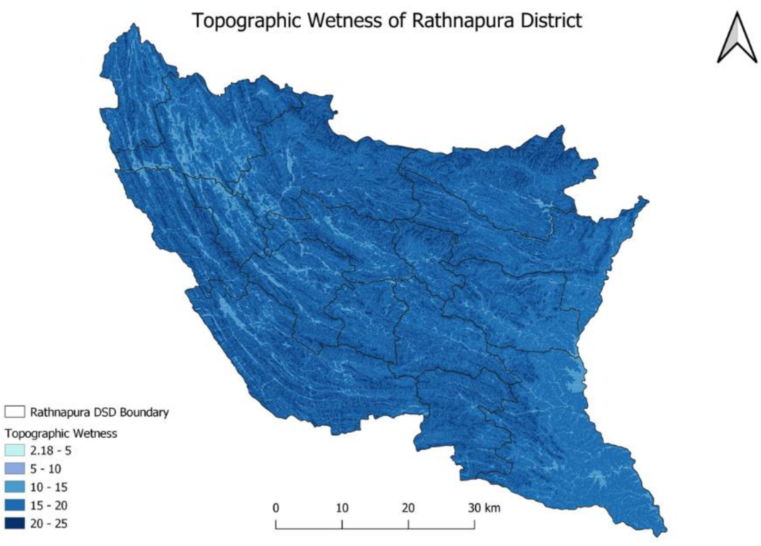
Figure 5: Elevation of Rathnapura District



Source: Created by Author 2024

Figure 6: Topographic Wetness of Rathnapura District

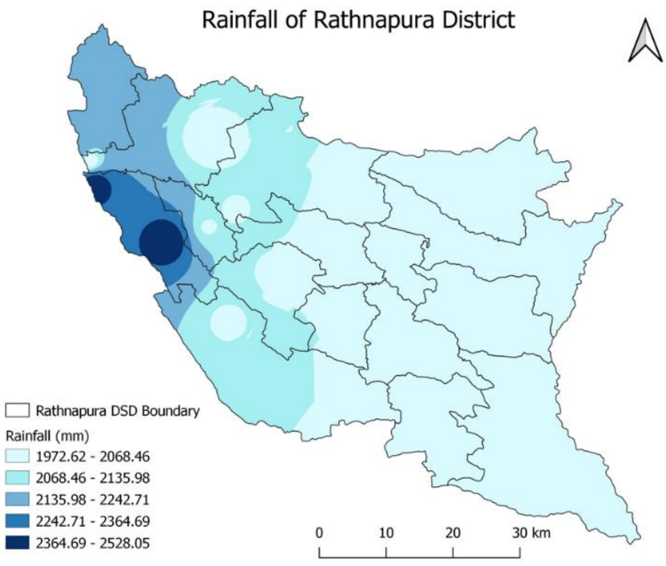


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Figure 7: Rainfall of Rathnapura District

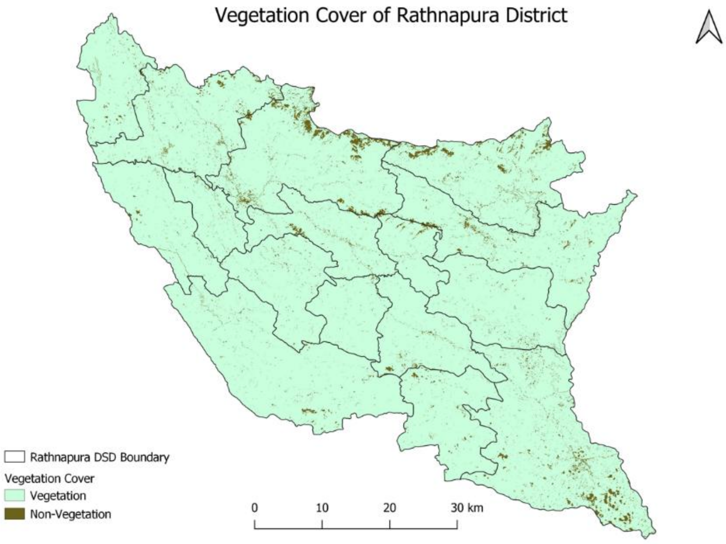

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Figure 8: Vegetation Cover of Rathnapura District

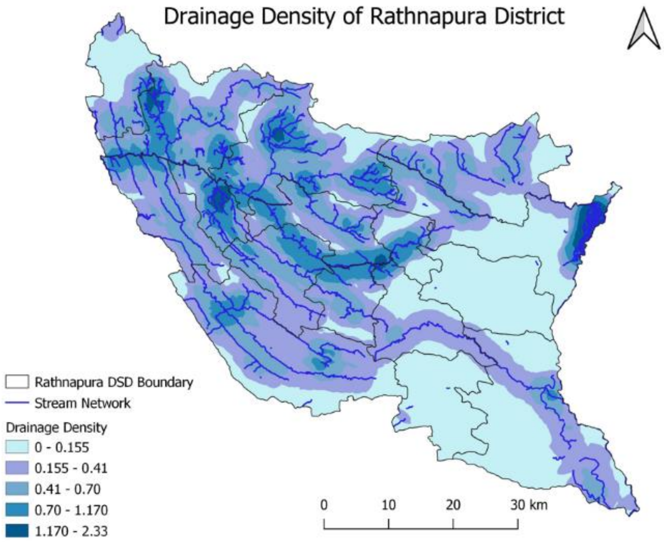

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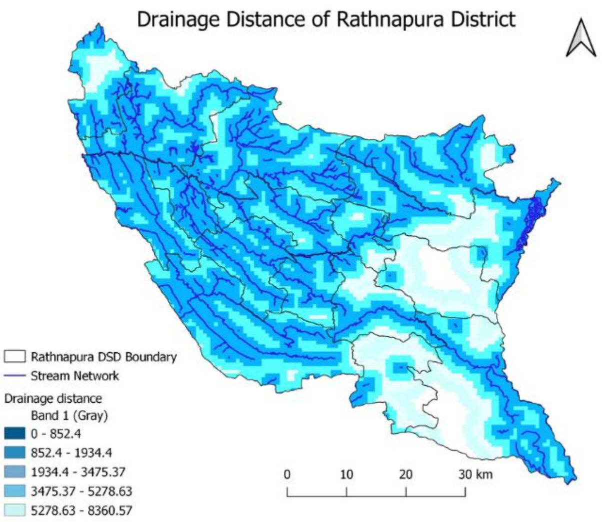
Figure 9: Drainage Density of Rathnapura District



Source: Created by Author 2024

Figure 10: Drainage Density of Rathnapura District

High slope values between 30 m to 80m very steep areas in Rathnapura, Imbulpe, Ayagama and Balangoda DSDs. Steep slopes are more prone to erosion (Figure 4) . Areas at higher elevations are associated with steeper slopes. High elevation values of 1800 m to 2201m highlands in Imbulpe, Rathnapura, Balangoda, Kalawana and Kolonna Korale DSDs are having high susceptibility of the landslides due to greater gravitational forces (Figure 5).

According to the topography wetness index value range of 2 – 10 areas are higher in Rathnapura District (Figure 6). Those areas belong to 15 – 80 slope range in degrees. According to the standard measurements in the slope angle, this mentioned rate considers very strong slope to very steep slope. This means, there is no enough wetness capacity in the hydrological process on the topography since there is less rapid water infiltration rate while runoff water on the slope. Then the soil erosion becomes high in these areas. Topographic Wetness Index value range of 15 -20 areas play second fields to TWI value range of 2 - 10 areas in Rathnapura District. Those areas belong to 0 – 14 slope degree category that the rate considers as level flat to moderate slope (Figure 4). The majority values of TWI is represented in this category which means that indicates wet areas of the topography because lower slope areas has rapidly water infiltration rate. Then the ground water capacity becomes high. There is soil moisture, which means higher cell values in TWI represents areas with increased accumulated run off in area.

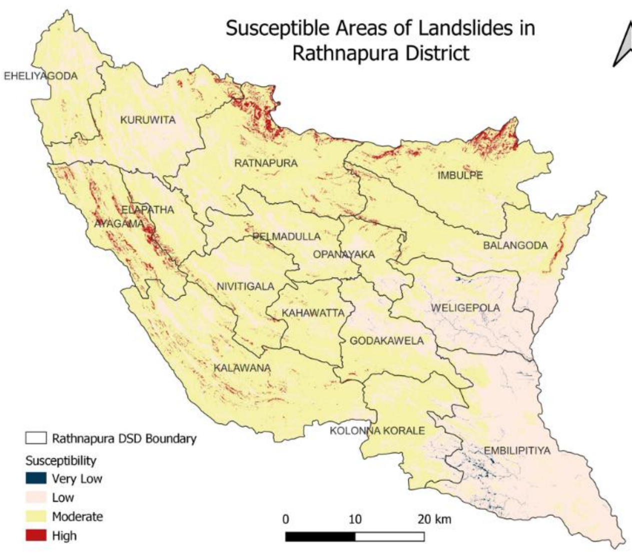
According to the gathered twelve years (2010-2021) rainfall data, all the average annual rainfall values are appeared as 1973.62 mm to 2528.05 mm which means there is higher rainfall due to the wet zone area of the Ratnnapura district with the main contribution over 40 percent of the total being derived from the southwest monsoon. The rest of the fall is received equally from both the northwest monsoon and convectional activity. According to this value, majority area has received 1973 mm to 2135 mm rainfall. Ehaliyagoda, Kuruwita, Ayagama and Elapatha areas have received 2136 mm – 2242 mm rainfall and some of the areas of Ayagama DSDs have received 2243 mm – 2528mm in Rathnapura Distrct (Figure 7). Excess rainfall leads to surface runoff, which can erode slopes and undercut their bases, increasing landslide susceptibility and intense rainfall can trigger fast-moving, shallow landslides or debris flows.

At a glance, most of the areas are covering vegetation in Rathnapura district (Figure 8). The vegetation canopy consists with rain forests, mountain forests and shrubs while non-vegetation category is represented barren lands and built-up areas which means that those areas are can be predicted of landslide susceptibility up to some extent.

Drainage density is defined as the total length of streams and rivers per unit area of a watershed. It is an indicator of how well or poorly an area drains water. When considering drainage density Kuruwita, Elapatha, Rathnapura, Balangoda and Opernayake DSDs are covering high drainage density (Figure 9) which means that higher surface runoff can lead to more rapid saturation of soils, which weakens their structural integrity and increases the likelihood of slope failure or landslides and increased erosion from numerous channels may destabilize hillsides, contributing to landslide initiation.

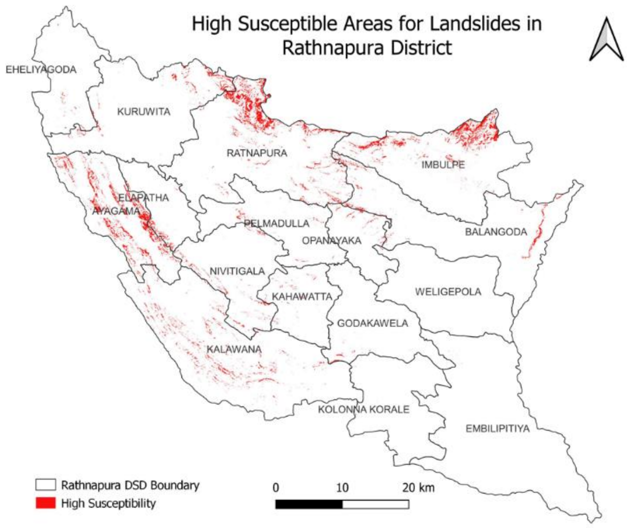
Drainage distance refers to the distance from any point on the land to the nearest drainage channel. It influences the way water accumulates and moves across the landscape. The areas with short drainage distances such as Embilipitiya, Kolonna Korale, Balangoda, Ehaliyagoda, Rathnapura and Klawana DSDs. concentrated runoff can erode slopes, increasing the risk of landslides (Figure 10).

Steep Slopes with high elevation, especially where vegetation cover is sparse, are highly prone to landslides, particularly during periods of intense or prolonged rainfall. These slopes experience rapid water infiltration and surface runoff, which weakens soil structure. Areas with high drainage density and short drainage distances on steep terrain are subject to intense erosion during heavy rain, further destabilizing slopes and increasing the likelihood of landslides. Topographic wetness plays a significant role in landslide susceptibility, as areas with high TWI values tend to accumulate water, leading to prolonged soil saturation and weakening slope stability, especially in combination with steep slopes and intense rainfall. While vegetation cover mitigates some of the negative effects of rainfall, deforestation and vegetation clearance can greatly increase the risk of landslides. By considering the above landslide triggering off factors the landslides susceptibility areas of Rathnapura district can be identified as following map.



Source: Created by Author 2024

Figure 11: Susceptible Areas of Landslide in Rathnapura District



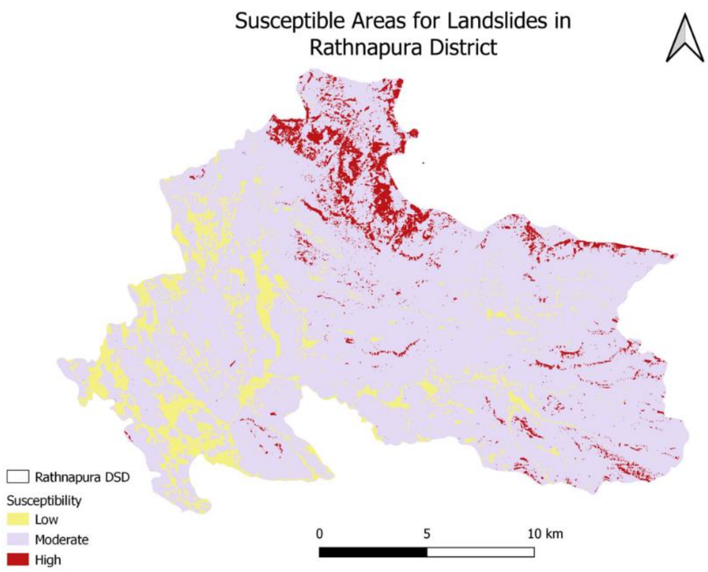
Source: Created by Author 2024

Figure 12: High Susceptibility areas for Landslides in Rathnapura District

Table 4: High Susceptibility Areas for Landslides in each DSDs of Rathnapura District

Divisional Secretariat Divisions	Area of DSD SqKm	Area of Susceptibility SqKm
Rathnapura	326.93	18.41
Ayagama	165.66	15.40
Imbulpe	255.33	14.15
Kalawana	381.57	7.65
Kuruwita	260.20	3.76
Balangoda	277.53	3.72
Nivithigala	157.55	2.12
Elapatha	80.44	1.63
Pelmadulla	145.95	0.90
Opanayake	74.86	0.89
Kahawatta	101.43	0.67
Godakawela	156.53	0.46
Ehaliyagoda	136.52	0.42
Kolonna Koral	171.37	0.06
Weligepola	201.38	0.042
Embilipitiya	396.86	0.016

According to above grid, Rathnapura DSD has very high susceptibility areas of landslides than the other DSDs of Rathnapura Distric and it covers 18.41 km^2 area out of 326.93 km^2 of Rathnapura DSD boundary. Following map shows very high susceptibility of landslides in Rathnapura District.

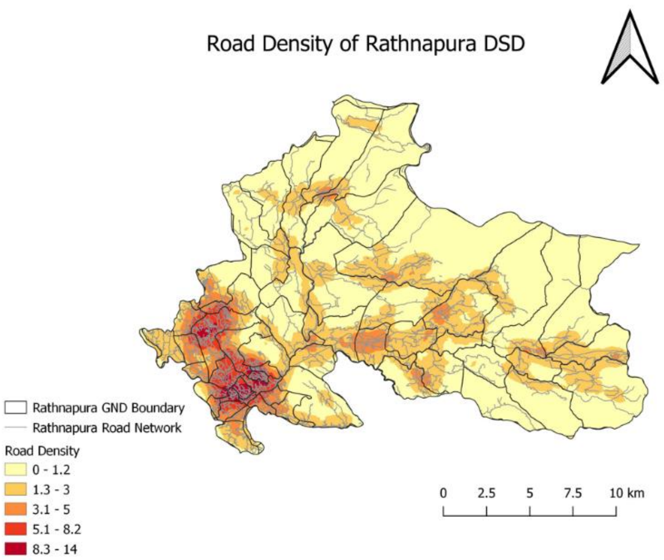


Source: Created by Author 2024

Figure 13: Susceptible Areas for Landslide in Rathnapura DSD

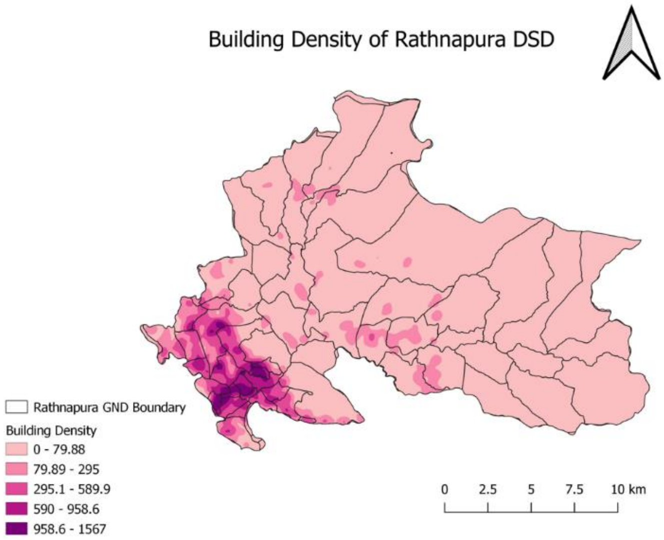
This map illustrates the distribution of the 18.41 km^2 landslide-prone area among the Rathnapura DSD boundary in terms of low, moderate, and high susceptibility. The majority of the places are classified as moderately susceptibility to landslides. High susceptible areas to landslides spread among 45 GND boundaries.

Population density of year 2022, Road density and building density utilized for the vulnerability Analysis of landslides. Below maps demonstrate how socio and economic vulnerability influences for susceptible landslides areas of Rathnapura DSD.



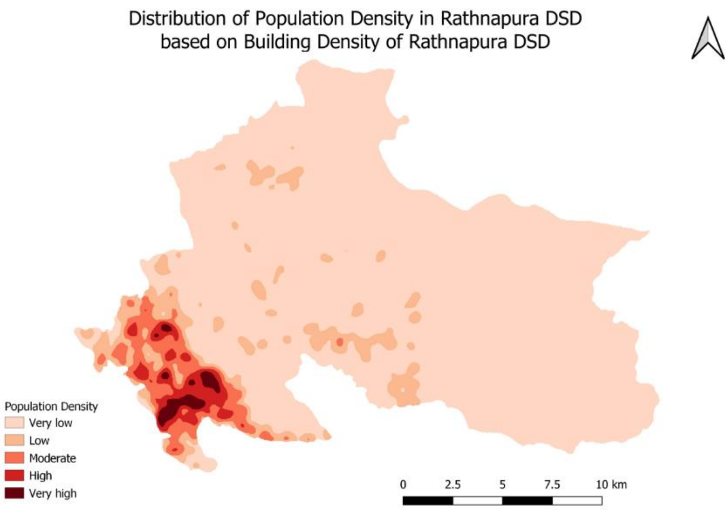
Source: Created by Author 2024

Figure 14: Road Density of Rathnapura DSD



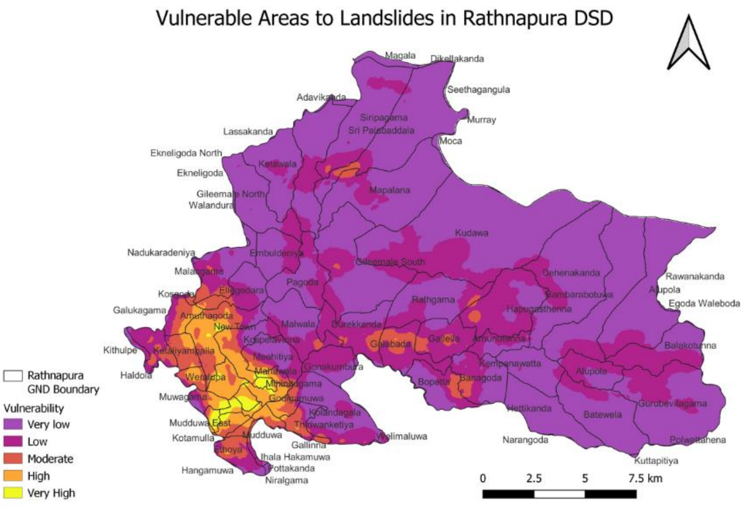
Source: Created by Author 2024

Figure 15: Building Density of Rathnapura DSD



Source: Created by Author 2024

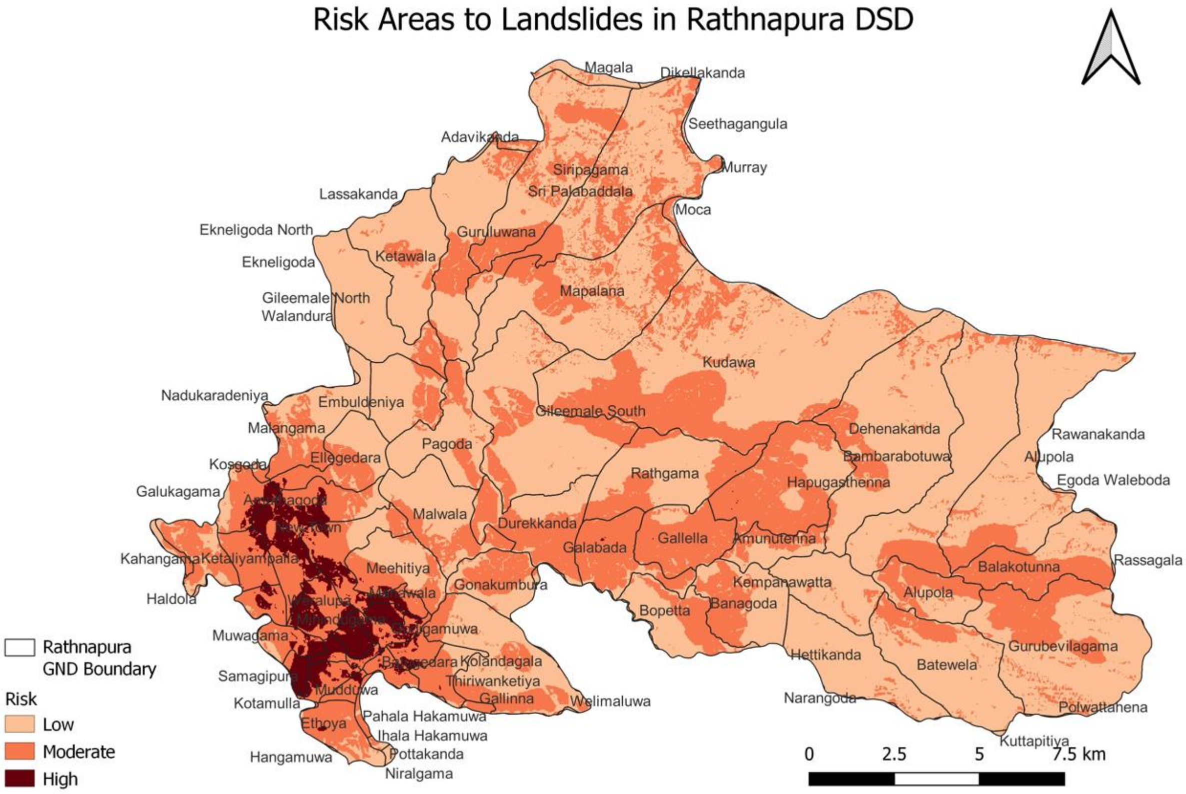
Figure 16: Population Density of Rathnapura DSD



Source: Created by Author 2024

Figure 17: Vulnerable Areas of Landslides in Rathnapura DSD

These maps show that the Rathnapura DSD's South-West region has a high population, road, and building density. It is demonstrated that South-West region is more vulnerable to landslides in Rathnapura DSD. Areas classified as having very high and high socio-economic vulnerability to landslides are concentrated within 27 GND boundaries (Figure 17). In contrast, both very low and low socio-economic vulnerability areas are distributed across 81 GND boundaries, out of a total of 90 GNDs. This disparity suggests that a smaller portion of the population is at greater risk due to the concentration of socio-economic vulnerabilities in a limited number of divisions, while the majority of GNDs experience lower levels of vulnerability. Understanding this distribution is crucial for targeted disaster risk reduction strategies and the equitable allocation of resources to mitigate landslide impacts on the most vulnerable communities



Source: Created by Author 2024

Figure 18: Risk Areas of Landslides in Rathnapura

An assessment of landslide risk across Grama Niladhari Divisions (GNDs) indicates a notable variation in risk levels (Figure 18). High-risk areas are concentrated within 30 GND boundaries, suggesting that these regions face a significantly elevated threat of landslides. In contrast, low-risk areas are more widely dispersed, covering 80 GND boundaries. This distribution highlights a geographic imbalance, where a smaller number of GNDs are disproportionately exposed to landslide hazards, while the majority of GNDs experience lower levels of risk. Understanding the spatial distribution of landslide risk is essential for prioritizing mitigation efforts, resource allocation, and implementing effective risk reduction strategies in the most vulnerable regions.

Conclusion and Recommendation

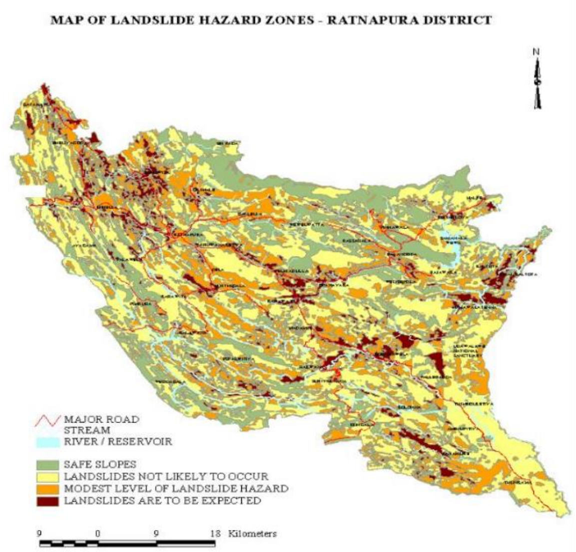
Effective landslide mitigation requires the identification of high-susceptibility areas and the factors that trigger landslides. Understanding these factors is crucial for developing recommendations to minimize both the vulnerability and overall risk of landslides in susceptible regions. Mitigation, defined as the reduction or limitation of the adverse impacts of hazards and disasters, plays a key role in reducing landslide risks.

An analysis of landslide-prone areas reveals that many are characterized by low to moderate Topographic Wetness Index (TWI) values, high elevation, steep slopes, and excessive annual rainfall. Furthermore, these areas often include barren lands, illegal construction projects, and regions dominated by shrubs and grasslands. These factors increase the susceptibility to landslides and highlight the need for targeted recommendations to address the root causes of landslide triggers.

Mitigation strategies must address both structural and non-structural aspects to effectively reduce susceptibility, vulnerability, and risk. Structural measures may include the construction of retaining walls, slope stabilization, and improved drainage systems. Non-structural measures may involve proper land-use planning, regulation of illegal construction, and public awareness campaigns to enhance disaster preparedness. A comprehensive approach, addressing both the physical and socio-environmental factors that contribute to landslide risks, is essential for successful mitigation efforts.

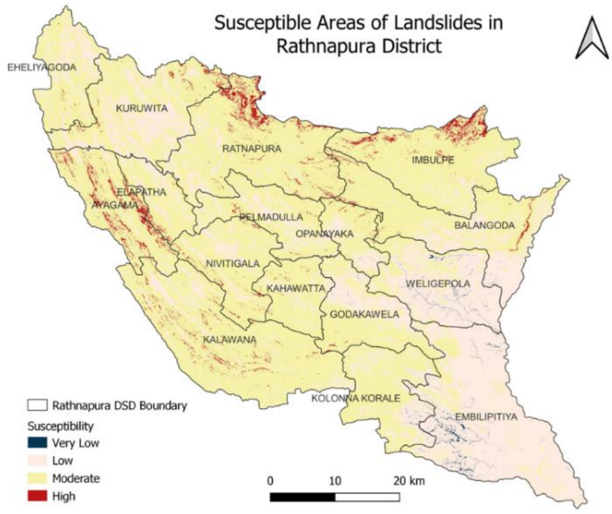
As the non-structural methods (intangible measurements), identifying the hazards zones by using geo-spatial technologies are necessary to take actions immediately before it becomes a disaster. Therefore, this open sourced geo-spatial technologies based research study can be taken as non-structural measurement for the landslide analysis of susceptibility zones, vulnerable locations and risk zones in a cost effective way. Flowing maps depict the effectiveness of utilization of open source geospatial techniques as the initial step of the disaster risk reduction . The landslide hazard map produced by the National Building Research

Organization (NBRO) was analyzed in conjunction with landslide susceptibility maps generated through open-source geo-spatial technologies.



Source: NBRO

Figure 19: Map of Landslides Hazards Zones in Rathnapura District



Source: Created by Author 2024

Figure 20: Susceptible Areas of Landslide in Rathnapura District

The analysis reveals notable discrepancies, with certain areas identified as highly susceptible to landslides in the open-source map (Figure 20) being marked as safe slopes in the NBRO hazard map (Figure 19). This divergence highlights the importance of field validation and further refinement in hazard zonation processes. Despite these differences, the majority of the landslide hazard zones demarcated in the NBRO map align closely with the open-source generated map, as demonstrated. This consistency underscores the reliability of open-source geo-spatial tools as a cost-effective method for initial landslide susceptibility assessments. However, the need for integrating institutional knowledge and field-based data remains crucial to enhance the accuracy and effectiveness of hazard mapping for risk mitigation and disaster preparedness.

One of the key advantages of these open-source tools, such as QGIS, is their cost-effectiveness and ability to provide an initial understanding of hazard zones. Government officials can use these technologies for preliminary disaster risk reduction analysis, helping to prioritize fieldwork. After initial identification, field data can be collected and integrated into QGIS using tools such as QField and Merging Maps plugins. This combination of field data with geo-spatial analysis improves the accuracy of risk assessments, enabling early warning systems to be effectively disseminated by relevant authorities. In addition to geo-spatial technologies, other non-structural measures such as spatial planning, land-use zoning, enforcement of building regulations, identification of safe evacuation routes, and public awareness programs on disaster preparedness are essential components of comprehensive disaster risk reduction strategies. These approaches contribute to enhancing community resilience and ensuring sustainable development in landslide-prone areas.

Structural measures, as tangible methods of disaster prevention, involve physical constructions or the application of engineering techniques aimed at reducing or eliminating the impacts of hazards. These measures are critical for enhancing the resilience and hazard resistance of structures and systems in vulnerable areas. In the context of landslide mitigation, after assessing identified landslide-susceptible areas, several preventive strategies can be employed. These include the construction of retaining walls, soil nailing, reshaping surface and subsurface drainage systems, and introducing hydro-shedding techniques. These methods are designed to mitigate the vulnerability of landslides by providing structural reinforcement.

It is equally important to recognize early warning signs of potential landslides, particularly in regions experiencing heavy rainfall. Pre-landslide indicators, such as the development of ground cracks, ground subsidence, slanting of trees, utility poles, or fences, as well as the appearance of cracks in the floors or walls of buildings on slopes, and the sudden emergence of springs or muddy water, can signal impending slope failure. Monitoring these signs can aid in implementing timely disaster prevention measures.

In Sri Lanka, engineering solutions have been adopted to mitigate landslide hazards, including the installation of physical barriers, retaining walls, slope stabilization techniques, and drainage improvements. These solutions aim to reduce immediate physical risks by stabilizing hillsides through the use of concrete structures, protective nets, and drainage pipes. Additionally, geotechnical structural interventions such as soil reinforcement, soil nailing, surface protection, slope modification, and soil removal are essential in landslide-susceptible areas. These measures, when applied correctly, contribute significantly to reducing the risk of landslides and protecting communities living in vulnerable regions.

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