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Utilizing Geographic Information Systems to Zone Landslide-Prone Areas for Urban Development in the Kandy Municipal Region, Sri Lanka

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Abstract: This investigation aims to delineate areas susceptible to landslides based on the current state of development in the Kandy Municipal Council Areas. Unplanned urbanization is taking place in many areas of Kandy city including landslide-vulnerable areas. Landslide vulnerability constraints the sustainable development of the city because city planning and management authorities do not have spatial information to guide the development. This inquiry employs the sophisticated Geographic Information System methodology, leveraging the formidable capabilities of Geospatial Information Technology. To accomplish this objective, various parameters including terrain, soil composition, drainage patterns, precipitation distribution, road infrastructure, and building locations have been meticulously analysed and integrated through a process of superimposition using weighted overlay techniques in GIS. Consequently, by overlaying the socio-economic development data with the identified zones of landslide susceptibility, a comprehensive depiction of areas prone to landslides, and the associated risks faced by roads and structures, has been developed. The findings of this study indicate that approximately 35% of the areas are classified as high-hazard zones, while approximately half fall under the medium-hazard category. The remaining areas are identified as low-hazard zones. The outcomes of this investigation are expected to provide invaluable support to urban planners and policymakers, facilitating informed decision-making in the domain of urban development.

Keywords: Kandy, Landslides, Zonation, Development, Disasters

1.0 Introduction

The frequency and severity of natural disasters have been on the rise globally, prompting many nations to prioritise mitigating their impacts (Manawadu & Wijeratne, 2021). However, some countries are struggling to manage the consequences within their borders due to unexpected and high frequencies of catastrophes. Advanced nations are likewise grappling with the difficulties of managing disasters, particularly in the form of frequent and severe landslides. These events have resulted in significant loss of life and property damage in various countries (Necmioglu et al., 2023). Despite the efforts of developing nations to mitigate the impact of landslides, they have not been entirely successful in this endeavour (Necmioglu et al., 2023).

A landslide is a natural phenomenon of surface rock erosion in mountainous regions. Currently, due to population growth, there is a shortage of flat land suitable for constructing residences in hilly areas (Dananjaya & Edirisooriya, 2019). Consequently, settlements and human activities in slope areas and landslide-prone regions have various impacts caused by landslides. The impact of landslides in Kandy, Sri Lanka, can be significant and devastating. Here are some of the key impacts: (1) Loss of lives: Landslides can result in the loss of human lives. People living in areas prone to landslides are at risk of being buried under the debris, leading to fatalities; (2) Displacement of people: Landslides can force people to evacuate their homes and move to safer areas. This displacement can disrupt their lives, livelihoods, and social networks; (3) Damage to infrastructure: Landslides can damage or destroy roads, bridges, buildings, and other infrastructure. This can hinder transportation, communication, and access to essential services like healthcare and education; (4) Economic losses: The destruction of infrastructure, agricultural land, and property can result in significant economic losses for individuals, communities, and the country as a whole. It may take years to recover from these losses; (5) Environmental degradation: Landslides can cause severe environmental damage, including deforestation, soil erosion, and the loss of biodiversity. The debris and sediment carried by landslides can also contaminate water sources, affecting both human and ecological health; (6) Disruption of services: Landslides can disrupt essential services such as electricity, water supply, and sanitation. This can further exacerbate the challenges faced by affected communities; (7) Psychological impact: The trauma and stress caused by landslides can have long-lasting psychological effects on individuals and communities. It can lead to anxiety, depression, and post-traumatic stress disorder (PTSD). To mitigate the impact of landslides, it is crucial to implement effective early warning systems, land-use planning, and infrastructure development practices that consider the vulnerability of the area (Rawat et al., 2015). Additionally, raising awareness among the local population about the risks and promoting sustainable land management practices can help reduce the impact of landslides in the future (Ranasinghe et al., 2016).

GIS (Geographic Information System) is a powerful tool that can be used to analyse and manage various types of spatial data, including data related to landslides (Ranasinghe et al., 2016). Landslides are geological events that involve the movement of rock, soil, and debris down a slope. They can cause significant damage to infrastructure, property, and human lives. GIS can be used in several ways to study and understand landslides (Chinthaka et al., 2023). GIS can be used to create detailed maps of landslide-prone areas. By analysing various factors such as slope gradient, soil type, land cover, and rainfall patterns, GIS can help identify areas that are more susceptible to landslides. These maps can be used for land-use planning, infrastructure development, and emergency response. GIS can be used to assess the risk of landslides in a particular area (Dananjaya & Edirisooriya, 2019). By combining data on slope stability, vegetation cover, land use, and historical landslide occurrences, GIS can help identify areas that are at high risk of landslides (Ranasinghe et al., 2016). This information can be used to prioritize mitigation efforts and develop early warning systems. GIS can be used to monitor and track changes in landslide-prone areas over time. By integrating data from remote sensing technologies such as satellite imagery and LiDAR (Light Detection and Ranging (Jullian et al., 2021)), GIS can help detect changes in slope stability, vegetation cover, and land use that may increase the risk of landslides. This information can be used to implement timely mitigation measures. GIS can be used to support emergency response efforts during and after a landslide event (Chinthaka et al., 2023). By integrating real-time data on weather conditions, road networks, population density, and infrastructure locations, GIS can help emergency responders identify affected areas, plan evacuation routes, and allocate resources more effectively (Senouci et al., 2021). Overall, GIS plays a crucial role in understanding, managing, and mitigating the risks associated with landslides. By integrating various types of spatial data, GIS can provide valuable insights and support decision-making processes related to landslide prevention and response (Jayasekara et al., 2019).

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Despite the abundance of resources in Kandy City, it is vulnerable to the consequences of landslides, one of the disasters it faces (Perera et al., 2018). Buildings and human endeavours over the past two years have altered the structure and nature of landslides, resulting in increased destruction. In response to this devastation, the Sri Lankan government commissioned a study in 1986 to mitigate the risk of landslides in the central highlands. The National Building Research Organisation (NBRO) conducted this study with financial support from the Government of Rwanda (Carrión-Mero et al., 2021). Moreover, a study mapping the landslide hazard area in certain parts of Kandy has been conducted by the National Building Research Organization (NBRO) (Wanninayake & Rajapakshe, 2018). Nevertheless, these studies do not fully identify all landslide hazard areas. Consequently, the study report also highlights the incomplete identification of disaster zones. Thus, this study is aimed at establishing a landslide hazard zoning plan specifically for the city of Kandy (Karunanayake & Wijayanayake, 2019). Given its significance, Kandy is undergoing rapid development activities, and it is imperative to establish emergency zones consistently and securely (Jayasekara et al., 2019).

The Kandy Municipal Area is situated at an elevation of 400-650 metres above sea level, where various development projects are underway (Perera et al., 2018). Kandy serves as the central city of the Central Province, and since gaining city status, it has witnessed various developments. Unfortunately, these development initiatives are also taking place in landslide-prone areas within the Kandy Municipal Region (Katupotha, 2015). In other words, numerous developments are occurring in the city that encroach upon designated landslide hazard zones. Moreover, houses and buildings are being constructed within these areas at risk of landslides. Thus, there is a potential for property damage and loss of life due to construction and other activities in these identified landslide risk areas (Rathnaweera et al., 2012). It can be concluded that carrying out multiple projects without considering the hazards of landslides poses a significant problem. Additionally, although development activities are taking place in some areas, these activities may eventually extend into landslide-risk areas as the city expands. Therefore, the issue of landslide-prone regions remains a concern as we consider the future. This study, which utilises geographic information technology, aims to accomplish the following objectives: (1) to identify landslide-prone areas within the Kandy Municipal region; (2) to identify activities taking place within the landslide hazard zone; (3) to identify areas suitable for urban development within the Kandy Municipal area; and (4) to conduct landslide hazard assessment and mapping.

2.0 Study Area

This study has been carried out in the city of Kandy. Kandy City is situated within the Kandy district in the Central Province of Sri Lanka. The Kandy Municipal Council area is characterised by the presence of the Mahavali River, the principal river in the Kandy district, which curves and forms a natural border around the city. Located at the geographic centre, Kandy serves the entire country as a pivotal point in the heart of Sri Lanka, providing convenient connections to other prominent cities (Jayawardene et al., 2005). Functioning as the administrative centre of the Kandy district, it adjoins the regions of Matala, Badhulai, Kegala, Nuwara Eliya, and Kurunegala as its boundaries. Figure 1 show the study area and its respective Divisional Secretariat divisions. The study area spans an expansive landscape of 27.01 km^2 (2701 hectares).

It is also the administrative hub of the central province. The city boasts a populace of 110,000 individuals, with a density of 4100 inhabitants per square kilometer. Situated at a distance of 26 km from Matale town, 128 km to the city of Badula, 38 km to the city of Kegalle, 77 km to the city of Nuwara Elia, and 147 km to the city of Ratnapura, it stands as the most populous municipality in Sri Lanka.

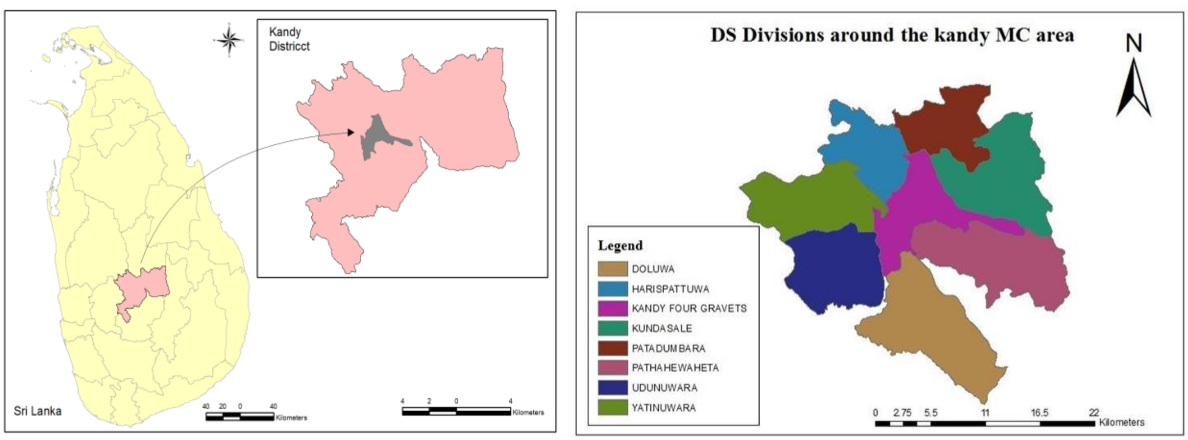

Figure 1: Sub Administrative boundaries of Kandy District

3.0 Materials and Methodology

3.1 Materials

A multitude of data has been gathered utilizing diverse methodologies for this aforementioned study concerning the classification and depiction of regions prone to landslides within the Kandy Municipal Area. Data concerning landslides and associated factors have been comprehensively examined. For this purpose, information has been procured from various reputable institutions. Each distinct type of information has been acquired as secondary data from credible sources, employing appropriate methods of collection. These data have been amassed to ascertain the underlying causative factors of landslides.

In this context, the determinants contributing to landslides include geological formations, gradients, land utilisation, soil composition, historical incidences of landslides, drainage patterns, precipitation levels, and texture, among others. As the key objective is to identify and delineate landslide-prone regions, primary data encompassing slope images, as well as land utilisation imagery, have been acquired, while first-hand empirical insights about landslides within the area have been derived from residents and entrepreneurs. Furthermore, the collected data relevant to this investigation, including its sources, formatting, and nature, are listed in Table 1.

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Table 1: Data types and data sources

Data	Data sources	Type of data	Data format
Elevation map/slope	Survey Department	Secondary data	Digital/ shape file
Drainagemap- natural	Kandy MC / UDA	Secondary data	Digital/ shape file
Land use map	Survey Department/ UDA	Secondary data	Digital/ shape file
Soil map	GSMB/ UDA	Secondary data	Digital/ shape file
Geological map	GSMB	Secondary data	Digital/ shape file
Existing development map	Satellite image	Secondary data	Digital/ shape file
Landslide map (past occurrence)	NBRO	Secondary data	Digital/ shape file
Rainfall	Meteorology Department	Secondary data	Tabular format
Road network	Survey Department	Secondary data	Digital/ shape file
Impacts	community	Primary data	Interview/Reports

Data was acquired for this study through interviews conducted with individuals possessing expert knowledge in the field of landslides. In this manner, insights were gathered from esteemed individuals such as the Chairman and members of the Kandy National Building Research Organization, as well as the Chairman and members of the Urban Development Authority. These data were acquired through the formulation of pertinent inquiries encompassing landslide factors, frequency, timing, and geographical locations. These insights proved instrumental in advancing the course of this study.

The fundamental information for identifying the hazardous landslide areas within the Kandy Municipal Area, available on a topographic map scaled at 1:10000, was obtained from the Survey Department. Variations in elevation indicated by contour lines spaced 5 m apart, provide a comprehensive depiction of the natural terrain of the area. Figure 2. shows the topography of the research area.

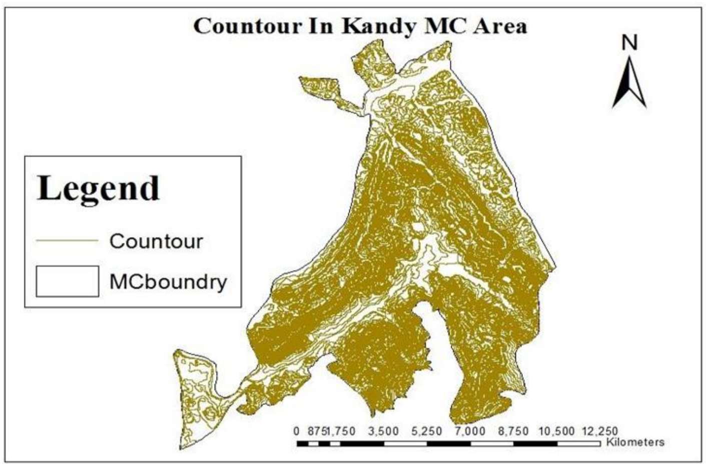

Figure 2: Contour variations in the Kandy Municipal Area

The availability of a proper drainage network plays a vital role in the prevention of landslides. Drainage, be it natural or man-made, facilitates excess water to drain, thus reducing the possibility of land sliding. The drainage network as well as the spatial distribution of rivers within the area have been employed to analyse the effectiveness of the present drainage system. These data were also obtained from a topographical map scaled to 1:10000. Figure 3. visually shows the drainage network in the study area. Natural and man-made drainage in many parts of the city have been encroached upon, and they are not functioning properly.

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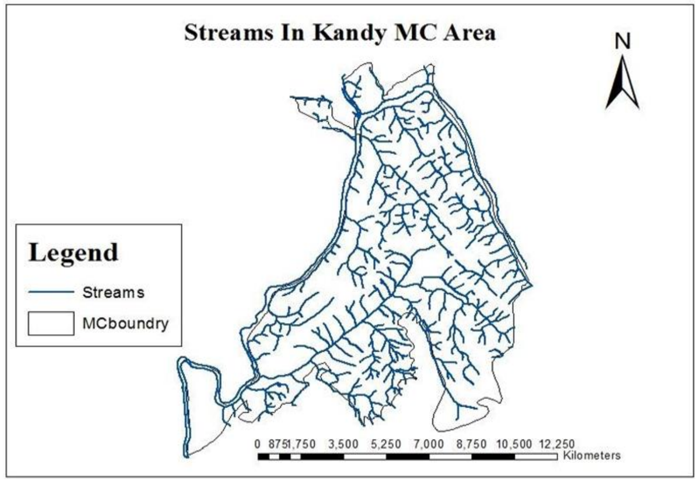

Figure 3: Drainage pattern in the Kandy Municipal area

The arrangement of roadways throughout the city are major predisposing factor to landslide susceptibility. This particular map, Data on road network obtained from the Land Survey Department on a scale of 1:10000, delves into the representation of critical road sections such as A9, A5E, and A1, as well as minor roads and railway lines. Figure 4. elucidates this pertinent information.

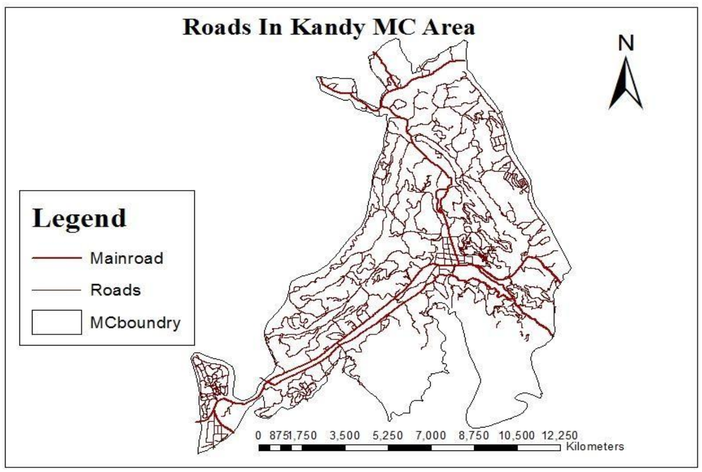

Figure 4: Roads network in the Kandy Municipal area.

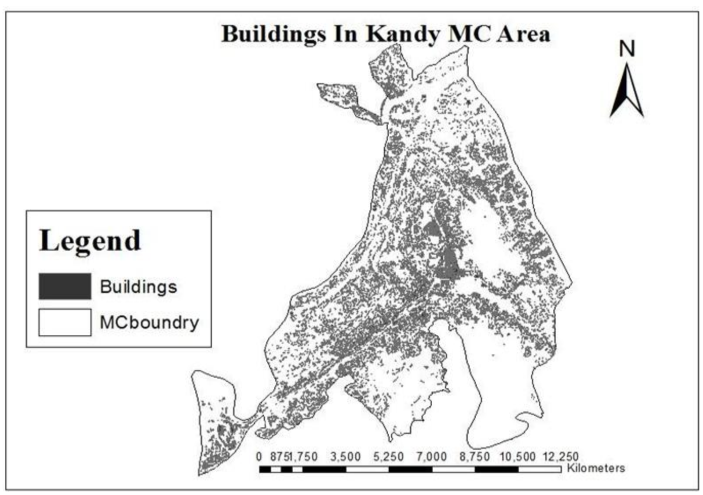

Figure 5: Building distribution in the Kandy Municipal area

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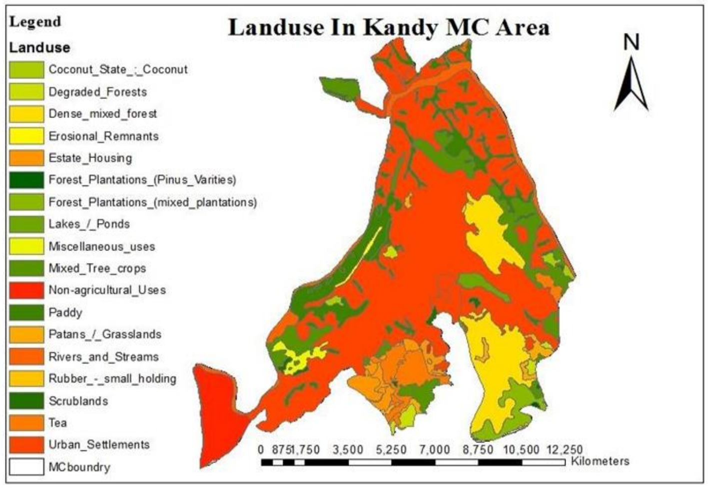

Figure 6: Land use pattern

Further, data on structures and buildings within the study area that could be considered for landslide vulnerability analysis has also been duly compiled. This dataset is invaluable in identifying regions prone to landslides, encompassing all structures and residential areas. Figure 5. visually encapsulates the distribution of the structures.

Furthermore, the acquisition of land use land cover data becomes vital as the occurrence and severity of landslides are inextricably linked to land utilization. As urban development precipitates various changes in land usage, an assessment of this data, acquired from the National Building and Research Organization (NBRO), is indispensable in understanding the landslide phenomenon. Figure 6 illustrates the pattern of land use and land cover in the study area.

Furthermore, an understanding of past landslides is essential in the delineation of the current landslide hazard area, as well as comprehending the necessity for additional data about landslide causative factors. Consequently, this data was procured from the National Building Research Institute. Figure 7. portrays these crucial insights.

Lastly, an exploration into the physical characteristics of the terrain and the composition of the soil and geology are imperative in determining landslide occurrences. A comprehensive comprehension of the soil and geology serves as a pivotal factor in landslide analysis. This is vividly portrayed in Figure 8 and Figure 9.

Rainfall also contributes to the occurrence of landslides. In this region, approximately 2000-2500 mm/year of rainfall are received. Rainfall data for the city is available from 1994 to 2004. For this study, data from 1998 to 2008 has been utilized. This data has been obtained from the Meteorological Department.

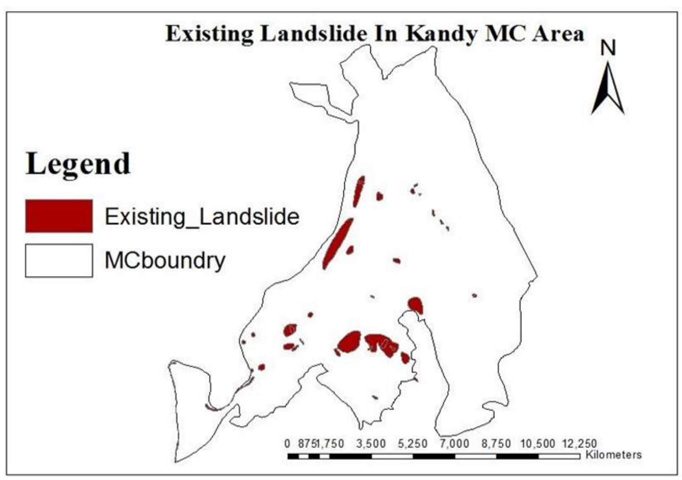

Figure 7: Existing Landslides area

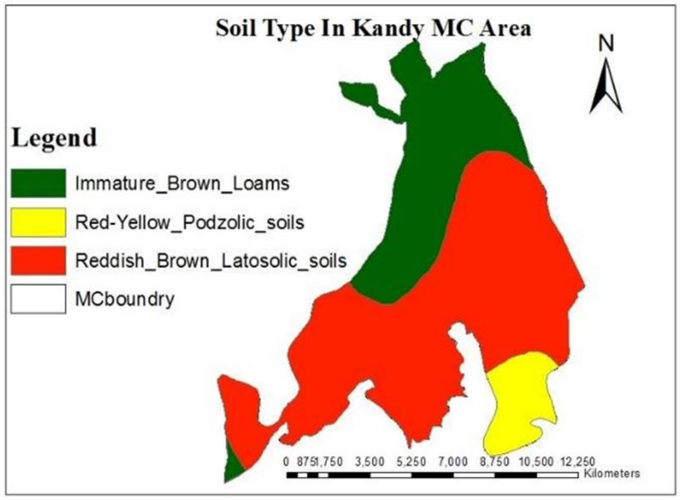

Figure 8: Soil Pattern

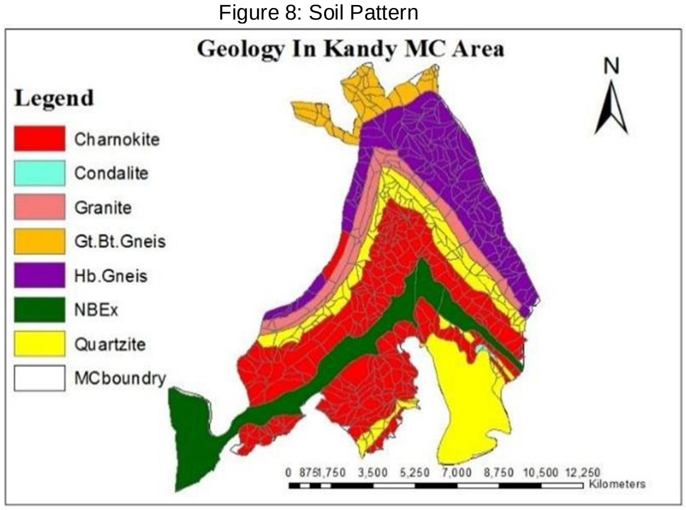

Figure 9: Geological variations in the Kandy Municipal area

3.2 Methodology

3.2.1. Factors contributing to landslides

These data were collected in primary and secondary forms to identify and categorize landslides. Primary data was collected through field surveys and interviews with residents and stakeholders. Additionally, secondary data regarding drainage systems, elevation, soil and geology existing buildings and structures rainfall, and existing landslide locations, have been as spatial data.

3.2.2. Identification of Factors Triggering Landslides

After collecting the data, each factor that contributes to landslides is mapped within a framework. Factors such as slopes exceeding 15%, areas with poor drainage, human activity zones, regions with sandy soil, areas undergoing unplanned development, areas already identified as landslide-prone and high rainfall zones have been categorised in this process.

3.2.3. Rasterization of data

Through this process, the identification of landslide-causing factors and the organization of collected data into a suitable format has been conducted. Thus, slope maps, drainage maps, landslide maps, soil type maps, topographic maps, existing development maps, and rainfall data have been prepared. Furthermore, the maps in vector format have been converted into raster form to facilitate the overlay.

3.2.4. Reclassification

Once the data has been prepared in raster format for the landslide analysis, it undergoes a reclassification process, wherein specific values are assigned within the respective landslide classes. For instance, slopes ranging from 0 to 5% are grouped as one class, while slopes ranging from 5 to 15% belong to another class, and the probability of landslides in the 0 to 5% slope class is designated as "0". Similarly, other data variables are also reclassified based on their susceptibility to landslides. Elevation, soil, geology, land use and land cover, existing development, drainage system, and map of occurrence of the landslides have been reclassified.

3.2.5. Derivation of Map

Following the reclassification of the data, the images are standardized individually. Each data variable is assigned a value based on its relevance to landslides, considering its contribution and impact on landslide occurrence. For instance, geographical factors are given priority concerning landslides.

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3.2.6. Overlay

Various factors that determine the landslide occurrences converted into raster format were overlaid with weight to each factor depending on the influence to trigger a landslide.

3.2.7. Hazard Map

Once the landslide hazard areas have been identified and categorized, a hazard map corresponding to those zones is created. This gridded image is comprised of a landslide zone map overlaid with a map, of human activity. By correlating this information with the designated zones and hazard zones were determined.

3.2.8. Field Verification

The outcome of the analysis, landslide vulnerability map, and hazard map were verified in the field with the existing development and conditions on the ground. To facilitate this, direct visits to the study area were undertaken based on the landslide assessment map.

3.2.9. Assessing Resilience Development

Through the aforementioned criteria, landslide hazard areas within the Kandy Municipal Area have been identified. Among these areas, resilience development has been evaluated, specifically identifying and assessing areas suitable for further development. Thus, comprehensive analysis was conducted on an individual basis, and the results were utilized within the geographic information system.

3.2.10. Data Preparation and Analysis

Numerous datasets have been acquired for investigation. Even within these datasets, there exist variations in the determination of landslides. Distinct categories have been observed within each dataset, thus attributing specific categories to the occurrence of landslides. Such classifications aim to be categorized on a broader scale. If the incline exceeds 15 degrees, landslides are prone to transpire, and certain factors such as non-drained areas, regions with human activities, sandy soil, unplanned development areas, development within landslide-prone regions, and heavy rainfall are isolated within each dataset. This implies that even the gradient contributes to the escalation of land subsidence. Accordingly, it has been deduced that areas with a slope greater than 15m present a higher susceptibility to landslides. Furthermore, areas equipped with effective drainage systems facilitate the dissipation of water. Otherwise, rainwater gathers in the soil, leading to both floods and landslides.

Moreover, when specific areas exhibit heightened human activities and the alteration of land surface by human intervention, the stability of the land is compromised, thereby culminating in landslides. Additionally, landslides occur with swiftness in regions featuring sandy loam. Furthermore, when developments are undertaken without proper planning, structures may be erected in unsuitable locations, rendering landslides possible. It is also postulated that landslides are prone to transpire in regions already susceptible to such occurrences and under conditions of heavy rainfall. In such scenarios, the threshold for triggering a landslide is a continuous rainfall exceeding 2500 A. As a consequence, certain principles have been formulated.

3.2.11. Transformation of data to facilitate analysis

In this study, the data has been prepared in a format suitable for comprehensive analysis. Some of the data has been digitized and changed into the shape file format. Additionally, the pertinent data has been rasterized to facilitate subsequent methodologies. The major analysis method of this study is a multi-criteria overlay, then all data collected for this study changed into the raster format (Figure 10).

To acquire the land slope data of the study area, the topographical map is first converted into TIN format and subsequently transformed into DEM format, from which the land slope data is extracted. The maximum incline within this region reaches up to 73%. Figure 11 illustrates this phenomenon.

A cartographic representation of the major and minor rivers in the study area has been compiled. This map delineates the distance between the surrounding lands and the riverbanks, providing valuable insight into the relationship between drainage patterns and landslide occurrences. Please refer to Figure 12. for visual reference.

To investigate the contribution of land use in the study area to landslides, the aforementioned data has been transformed into a self-reported format. Various classifications have been identified within the land use data, which have been consolidated into six distinct categories, as depicted by different types. These categorizations do not apply to the current study and have thus been condensed accordingly (Figure 13).

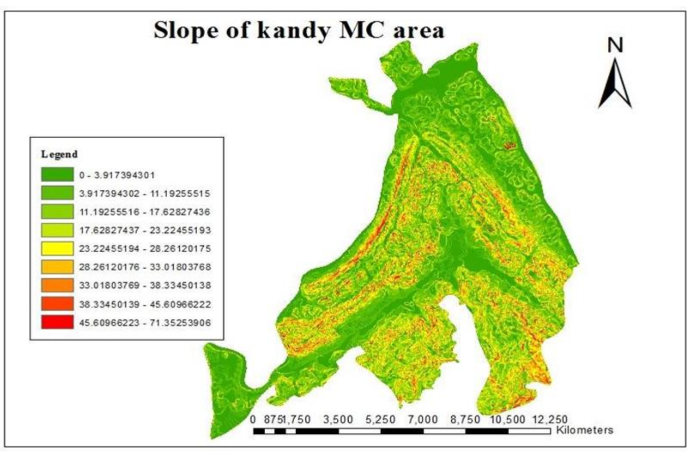

Figure 10: Razterzied Slope pattern of the study area

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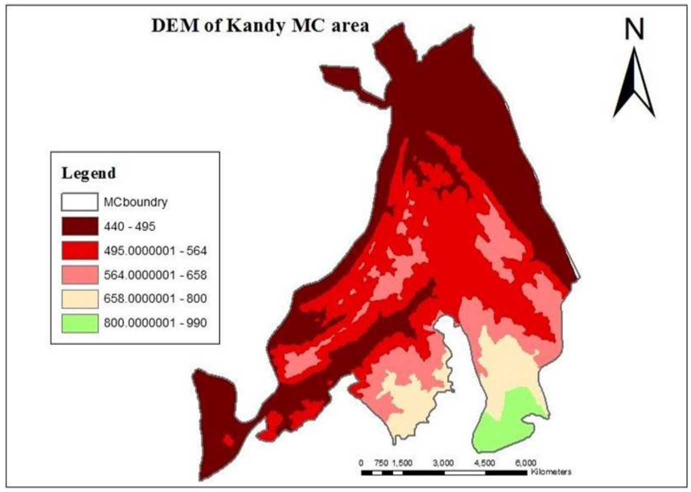

Figure 11: DEM pattern of the study area

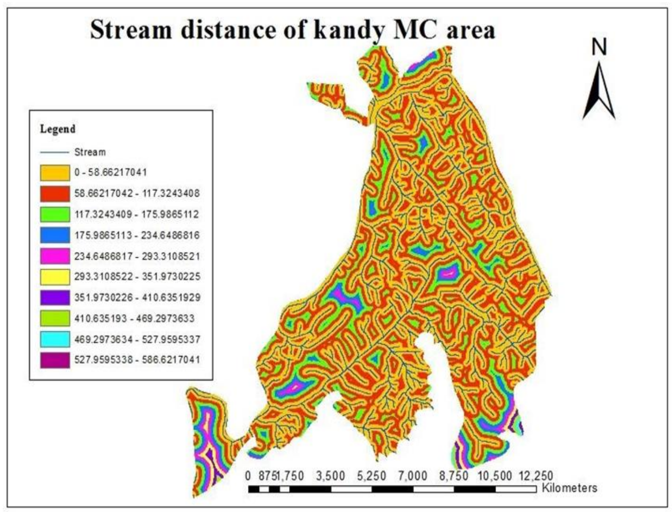

Figure 12: Rasterized Drainage stream pattern of the study area

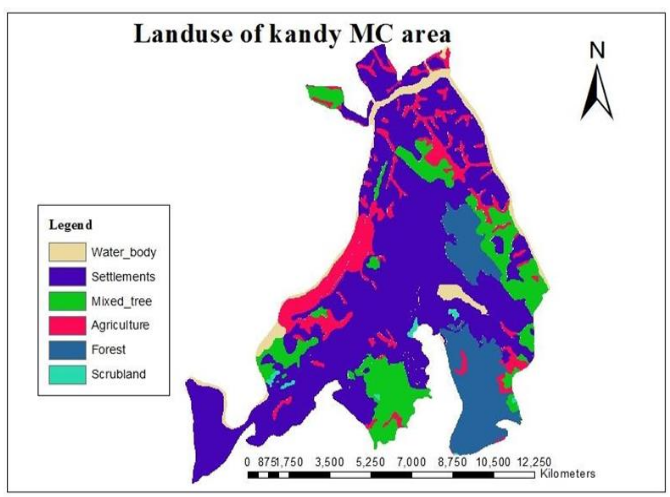

Figure 13. Rasterized Landuse pattern of the Kandy municipal area

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Geology and soil type, denoting the nature of the soil present in the study area, has been converted using the conversion tool Arc tool and changed into a raster format. There are three soil types documented, exemplified in Figure 14. Geological data, crucial for the overlay analysis of the survey, has also transformed into a self-contained format employing the Correspondence method. This enables the analysis of seven distinct rock types, as illustrated in Figure 15.

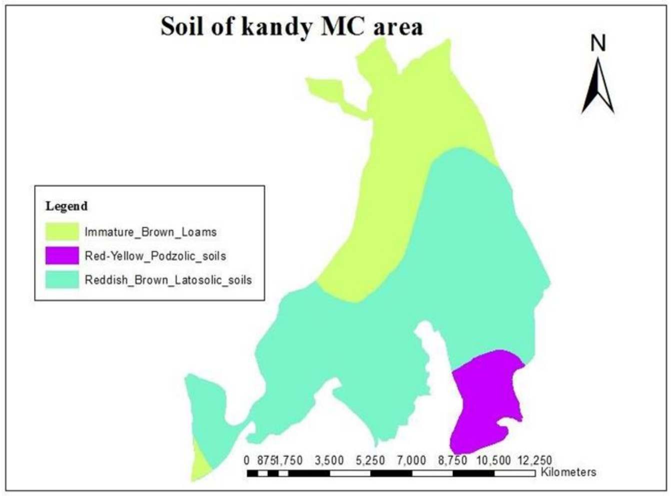

Figure 14. Rasterized Soil pattern

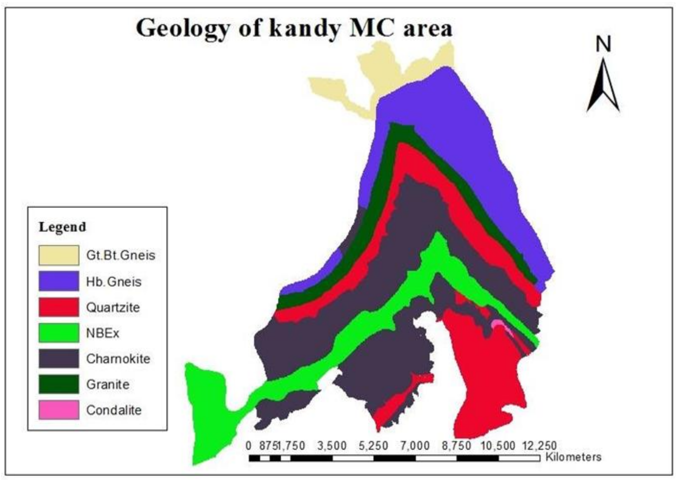

Figure 15. Rasterized geological map of the Kandy Municipal area

To construct a hazard map after overlay analysis, road network data has been procured for the study. Specifically, the region encompassing Kandy city has been isolated. Drawing from the aforementioned data, the current state of development in the study area has been mapped, including rainfall data for a specific year. Rainfall data for the final year of the study, 2008, has been disaggregated to showcase its correlation with landslides every month. Please refer to Table 2. for the 2008 rainfall data.

Table 2: Monthly average temperaure of the Kandy District

Month	Rainfall (mm)
January	108.6
February	84.4
March	383.7
April	303.5
May	72.8
June	54.5
July	115.1
August	75.8
September	55.1
October	298.3
November	273.1
December	94.5

Source: Department of Meteorology, 2023

3.2.12. Reclassification of Raster Data

Upon gathering and transforming diverse data for this study, reclassification has been conducted. This involves the conversion of data into an arbitrary form, and subsequent reclassification based on the correlation between each classification and its corresponding landslide occurrences. Consequently, data regarding landslides, drainage, erosion, soil types, and geography have been reclassified and extrapolated. During this reclassification process, the highest value has been assigned to the landslide hazard class or factor, while the lowest value corresponds to the low landslide hazard class or factor, which is represented on a scale of 1 - 10. These reclassifications are outlined in Table 3, complemented by visual representations obtained during data processing. Thus, the process of reclassification is conducted based on the scores attributed to each of the aforementioned factors. Consequently, a reclassification map is obtained. To designate these areas as susceptible to landslides, a continuous mapping process is executed.

Table 3: Reclassified data.

S. N	**Factor class**	**Weight values of the Factor class (1-10)**
Slope Factor (^{0})		
1	0-5	0
2	5-15	2
3	15-30	7
4	30-45	9
5	45-60	10
6	60-80	10
Geology Factor		
1	Charnokite	10
2	Granite	9
3	Quartzite	8
4	NBEx	3
5	HB.Genesis	1
6	Gt.Bt.Genesis	1
7	Condalite	0
Soil Factor		
1	Immature Brown Loams	10
2	Reddish Brown Latosolic soil	8
3	Red-Yellow podzolic soil	2
Stream Factor (m)		
1	0-25	2
2	25-50	3
3	50-75	4
4	75-100	6
5	100-125	8
6	>125	10
Land cover Factor		
1	Waterbody	6
2	Settlements	10
3	Agriculture	8
4	Mixed terr	7
5	Forest	0
6	Scrubland	1

3.2.13. Weighting for the factors

Extensive data has been collected in this study for the identification and zoning of landslide-prone areas. Subsequently, this data is subjected to various procedures. Based on this, the relevant dataset chosen for analysis is subjected to overlay analysis to identify the landslide-prone areas in the reclassified data. The factors considered are land slope, drainage, erosion, soil type, and topographical data. These factors have been assigned based on their significant contribution to landslide occurrences, as supported by reputable research papers. The outcomes are depicted in Table 4.

Table 4: Factors for the landslides and their weightage values.

No	**Landslide Factors**	**The weight value of the Factors**
1	Geology	21
2	Landcover	23
3	Soil type	19
4	Streams	15
5	Slope	22

Consequently, as the methodology employed in this study is ‘Received Overlay’, a receipt is provided for the aforementioned considerations. These are regarded as 100ms, and a yield rate is assigned to each factor or dataset. These results are subsequently utilized for the overlay process.

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3.2.14. Overlay Process

Numerous techniques for landslide hazard analysis are available. Some notable approaches include the Statistical approach, Inventory approach, and Deterministic approach among others. Moreover, the weighted overlay method, derived from the Overlay method, is utilized. An integral element of this study involves the application of the given overlay method's structural analysis. To execute this overlay process, the previously classified data - land slope, drainage, erosion, soil type, and topography - are employed. Overlapping procedures are implemented for these factors, based on the receipt rate provided in the Preference map process (Figures 16 to 19).

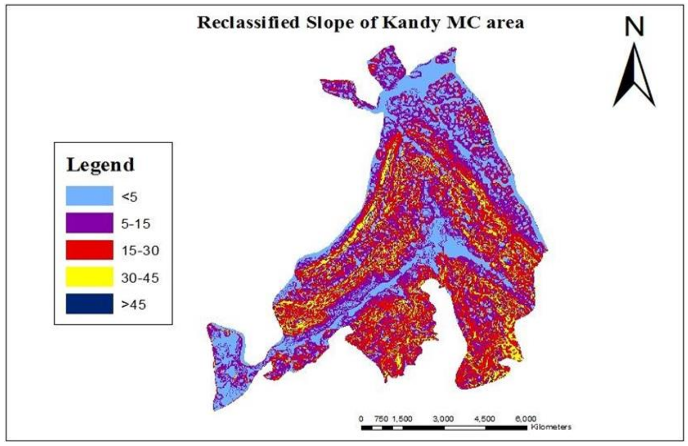

Figure 16: Reclassified slope of the Kandy Municipal area

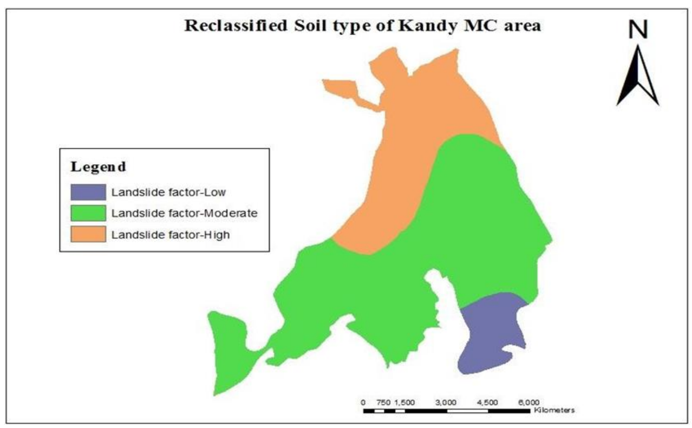

Figure17: Reclassified Soil map

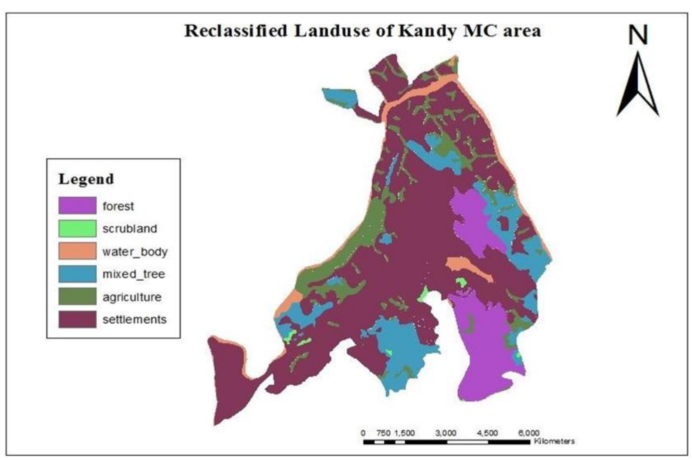

Figure 18: Reclassified Landuse pattern of Kandy Municipal area

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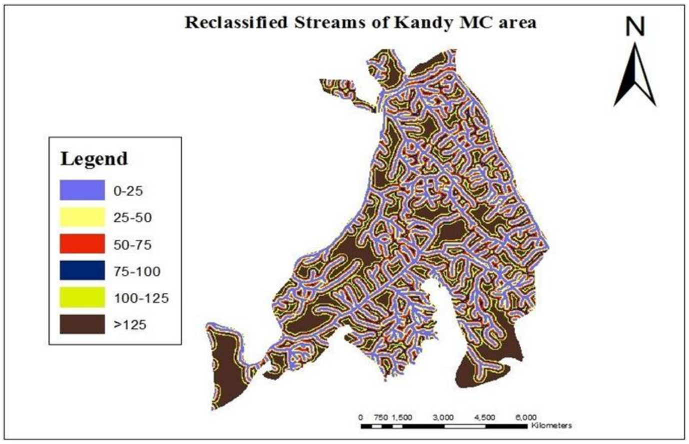

Figure19: Reclassified Drainage map of study area

Based on these considerations, an overlay analysis is performed. As a result, landslide hazard zones are obtained in the form of rasters. In other words, the five factors encompassing landslide drainage, landslides, soil type, and topography are superimposed, taking into account the values established in the overlay process, as well as the values assigned in the reclassification process for each factor. Since this process is carried out in raster form, the outcome is also acquired in raster form. A map illustrating these landslide hazard zones is created in raster format.

Subsequently, the Razter-formatted map undergoes reclassification. In this process, it is classified into three classes. Specifically, class 1-3 represents low danger, class 4-6 signifies medium danger, and class 7-8 denotes medium-high danger. The separation of classes is based on historical landslide data. The image obtained from the reclassification process, along with the reclassified graph, is depicted in Figure 20 & 21.

Furthermore, the hazard zoning map generated through the overlay process is transformed into a grid format as it needs to be amalgamated with other data to construct a hazard map. Consequently, the landslide hazard zones are delineated through the overlay method.

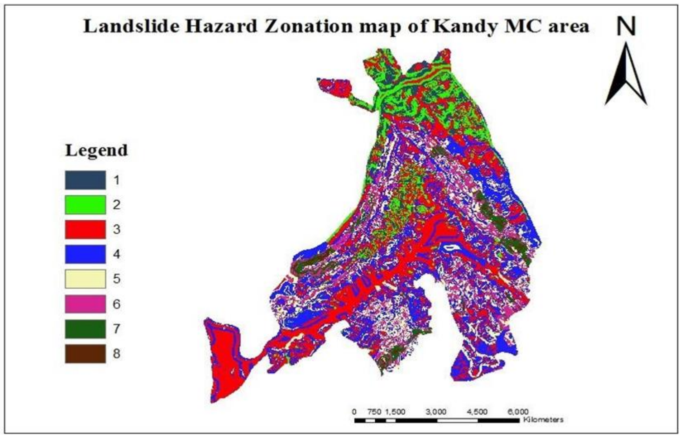

Figure 20: Raster format Landslides disaster zones in Kandy Municipal Areas

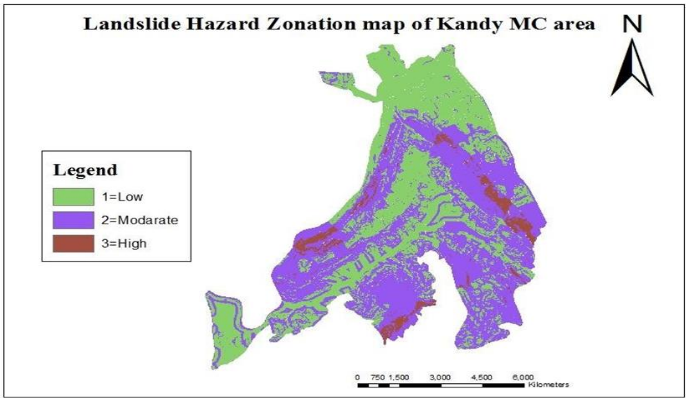

Figure 21: Reclassified Landslides disaster zones in Kandy municipal areas

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4.0 Results

4.1 Evaluation of Landslide Hazard Zone (LHZ) of Kandy City

Kandy city falls victim to the perils of landslides. The severity of this calamity is escalating due to numerous construction undertakings. Consequently, this analysis of landslide hazards strives to glean the distinguishing features of these dangers resulting from the superimposition process. Kandy City is partitioned into three distinct disaster zones: the high-hazard zone, the medium-hazard zone, and the low-hazard zone. These areas span an area of 4 %, 52% square meters, and 44%, respectively, within the confines of Kandy city. These ranking outcomes are deduced for each disaster category employing the subsequent calculation.

$$\text{Percentage Landslide Occurrence} = \frac{\text{Area that have been affected by landslides in the relevent hazard class}}{\text{Total are in the relevent hazard class}} \times 100$$

4.2. Identification of Landslide Prone Areas

The creation of the landslide hazard zone map for the study area is accomplished through the process of overlaying. These perilous zones are categorized into zones of high, medium, and lower hazards. Table 5 provides a visual depiction of these classifications. The hazardous locales and treacherous activities within the study area are effectively identified based on these zones. The purpose of this study, namely, "to identify and cartographically represent the activities occurring within the landslide hazard area," is achieved using the subsequent procedure. In this manner, a hazard map is meticulously formulated through a meticulous juxtaposition of buildings, land usage, and road networks with the corresponding hazard zones. This concept is elucidated in Figure 22.

Table 5: Extents of different types of landslide area

Type of hazard	Area (ha)
Low Hazard	1161.14
Moderate Hazard	1374.35
High Hazard	112.41

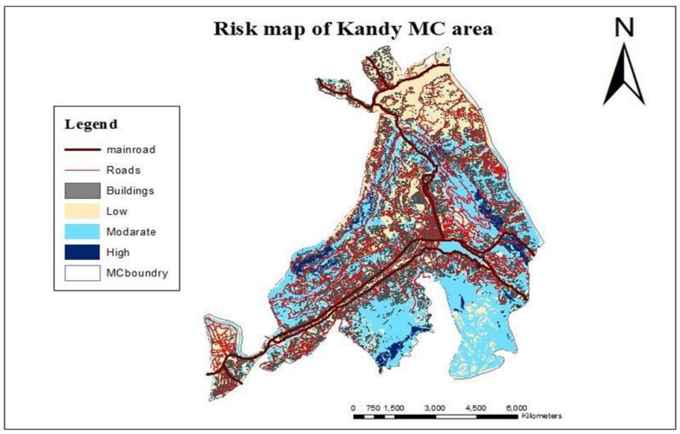

Figure 22: Building and Roads Risk map of the Kandy municipal areas

To expound further, the pernicious land uses, the count of buildings, and the extent of road networks encompassed by each disaster zone are identified as precarious structures and thoroughfares. On this basis, the road network map is superimposed onto the disaster zone map, thereby effectively identifying the roads situated within the specific disaster area.

Enlisted below are selected streets positioned within the high-hazard zone. Only certain sections of these streets fall within the ambit of the hazard zone.

- Bodhiraya Mawatha
- Green gallop road
- Ailapperuma mawatha road
- Srimath kudarathwatta Mawatha
- Riverdale road
- Wattarantenna Mawatha
- Pitakand road
- Nittawela road

4.2 Different landslide zone

Furthermore, a map adorned with edifices is superimposed with the cartographic representation of the disaster-stricken areas, and specific calamitous regions are discerned. This spectacle is presented in Figure 23, accompanied by delineations of landslide-prone zones, as well as buildings and roads. The overlays and identification of hazardous activities are vividly depicted in Figure 24. As a means of evaluating the perilous conditions of landslides in the city of Kandy, the zones of jeopardy concerning buildings and roads are ascertained through the

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meticulous process of overlaying. The delineation of landslide hazard zones is performed to facilitate the ongoing assessment of the associated risks and the roads, buildings, and land uses located within each zone are meticulously identified. This is amalgamated with the individual extraction of each zone, thus acknowledging the intricacies of the terrain.

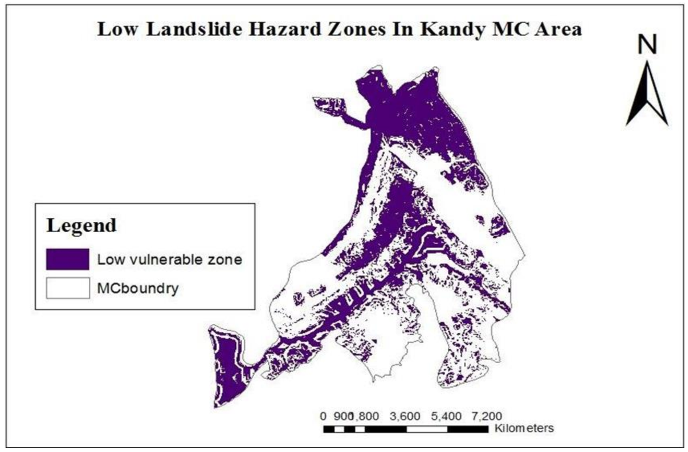

Figure 23: Low risk of Landslide zone in Kandy Municipal Area

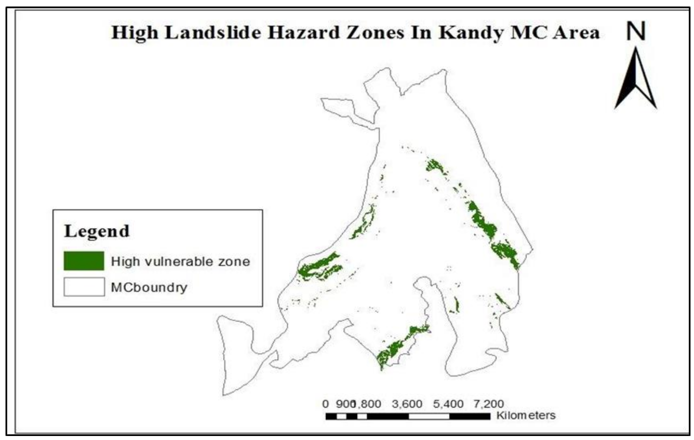

Figure 24: High risk of Landslide zone in Kandy municipal area

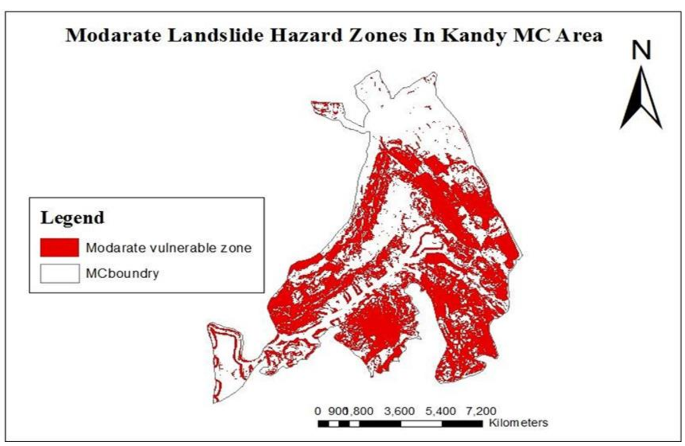

Figure 25: Moderate landslides risk zone in Kandy municipal area

Each distinct disaster zone has been systematically separated to ascertain the characteristics of the buildings located within these zones. By amalgamating the high, medium, and low disaster zones in this manner with the building map, estimates have been made regarding the number of buildings present in each zone and the corresponding ratios between them. An illustrative diagram (**Figure 25**) depicting the integration process is also provided as an example.

Henceforth, to identify areas devoid of landslides and continue implementing development projects in such locales, the pivotal result of this study is the categorization of landslide-prone areas based on the current scenario, culminating in the creation of a comprehensive map. Moreover, the extent of each landslide hazard zone and their corresponding rates are meticulously calculated. As an integral aspect of the landslide hazard zones within the Municipal area, the roads, buildings, and land uses in the high-hazard zones have been identified and their sizes and rates have been ascertained. Similarly, other disaster zones have been meticulously planned and coordinated in conjunction with the aforementioned activities.

Consequently, activities undertaken within the medium hazard zones are likewise subject to hazard warnings during specific times of the year. Undeniably, rainfall emerges as the predominant causative factor precipitating the occurrence of landslide disasters. The identified disaster zones within the Municipal regions of Kandy are divided into three distinct categories, aptly elucidated. The high hazard zones encompass the 112h region, which accounts for three-quarters of the overall area, while the middle danger zone is encompassed within the 1374h region.

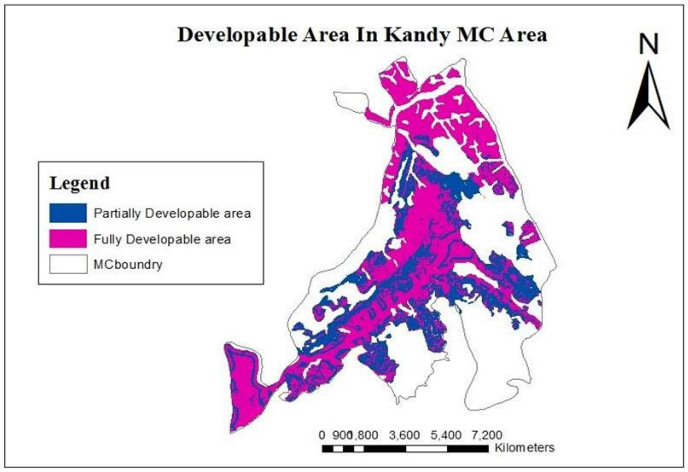

Figure 26: Landslides free and developable zones in the Kandy municipal area

Kandy's current landslide hazard status is a chronic problem for a developing city; It is arranged in such a way that it can give characteristics. In addition, various recommendations have been made as safe development in Kandy city is necessary following the increasing population (Figure 26). In that way, the data such as the artificial drainage system of landslides in Kandy city should be revised. Also, technical approaches are needed to assess the risk associated with landslides. For example, remote sensing data may refer to information technology usage and information data. Also, the wrong data about Kandy City needs to be removed. Based on the hazard levels obtained through this study, some recommendations have been made.

5.0 Discussion

The Kandy District in Sri Lanka is prone to landslides due to its hilly terrain and heavy rainfall. The district is located in the central part of the country and is known for its tea plantations and scenic landscapes. Landslides in the Kandy District are often triggered by heavy monsoon rains, which can saturate the soil and destabilize slopes. The district receives a significant amount of rainfall during the southwest monsoon season, which usually occurs from May to September. The most vulnerable areas in the Kandy District are those located on steep slopes and near rivers or streams. These areas are at a higher risk of landslides due to the combination of loose soil, heavy rainfall, and erosion. In recent years, the Kandy District has experienced several devastating landslides. One of the most notable incidents occurred in 2017 when heavy rains caused a massive landslide in the village of Aranayake, resulting in the loss of lives and destruction of homes and infrastructure.To mitigate the risk of landslides, the Sri Lankan government and local authorities have implemented various measures. These include the construction of retaining walls, slope stabilization, and early warning systems. Additionally, awareness campaigns and educational programs are conducted to inform residents about the dangers of landslides and the necessary precautions to take. Despite these efforts, landslides remain a significant threat in the Kandy District. Climate change and deforestation are also contributing factors that increase the vulnerability of the area to landslides. It is crucial for ongoing monitoring, preparedness, and response measures to be in place to minimize the impact of landslides in the district.

The Kandy District in Sri Lanka is known for its hilly terrain and is prone to landslides, especially during the monsoon season. The spatial pattern of landslides in the district can be analysed using various techniques, including remote sensing and GIS. Remote sensing data such as satellite imagery can be used to identify areas that are susceptible to landslides. The use of digital elevation models (DEMs) can also help in identifying areas with steep slopes and areas that are prone to erosion. GIS can be used to analyze the spatial distribution of landslides in the district. The use of spatial analysis tools such as kernel density estimation can help in identifying areas with high landslide density. This can be further analyzed by overlaying other spatial data such as land use, soil type, and rainfall patterns to identify the factors that contribute to landslides in the district.The spatial pattern of landslides in the Kandy District is influenced by various factors such as topography, geology, land use, and rainfall patterns. The district is characterized by steep slopes and a complex geological structure, which makes it highly susceptible to landslides. The areas with the highest landslide density are typically located in the central and eastern parts of the district, where the terrain is steeper and the rainfall is higher.The spatial pattern of landslides in the Kandy District highlights the need for effective landslide risk management strategies. This includes the implementation of early warning systems, land use planning, and the development of appropriate infrastructure to mitigate the impact of landslides on the local communities.

5.1 High Hazard Zone

Provide advance notices and warnings to the residents of the area about landslide hazards and make agreements with them(Necmioglu et al., 2023). To construct buildings in this area, only engineers in the field of engineering who have the experience and knowledge to design buildings according to the landslide area should be allowed to carry out construction activities in this area(Allstadt et al., 2022). Also planning for the construction of buildings should be done knowing the land use regulations and its limitations. The surface and drainage network of this particular area should be created and maintained as a uniform pipe for wastewater treatment. Opportunity should be given to use new technologies to better understand the risk levels of the region. Maintenance systems and predictive systems should be designed through technology. Legal action should be taken against the builders of these flats (Déleg et al., 2021).

5.2 Medium disaster zone

People living in this area should also be sensitized on precautions and clarity about landslides(Kanta Kafle, 2017). To carry out new building activities, increase or modify buildings, complete inquiries with the construction companies, and construct the building with their permission. Uniform land use regulations should be introduced. Also, engineers should have experience and knowledge of land use hazards. Laws should be made known to the people about how and where activities should be done in disaster zones and laws should be updated according to the specific area. Low Hazard Zones. The people living in this area should be made aware of the danger of landslides. Landslides should be protected by not carrying out activities. Examples include protecting forests from destruction and carrying out safe farming practices.

6.0 Conclusions

The cartographic representation of the landslide hazard zones serves as a significant outcome of this study, aptly referred to as the zoning of landslide hazard areas in the city of Kandy. Since the identification of areas prone to landslides by the National Building Research Organization in 1986, no subsequent studies about landslide hazards have been conducted in the region. Nevertheless, the Urban Development Authority formulated a development plan for the city of Kandy in 2001, intended to span until 2016. Following this plan, various development initiatives have been undertaken. Consequently, the occurrence of landslide disasters has observed a marked increase within the Kandy Municipal area, which has undergone significant changes.

The primary activities in the city of Kandy are predominantly concentrated within the areas classified as low-hazard zones among these disaster zones. Notably, most of the main thoroughfares and the city center itself fall within this region. However, with the ongoing implementation of development initiatives in these locales, there exists a distinct possibility that this zone may transition into a medium or high-hazard zone. Moreover, the areas designated as the city area, namely the commercial zone and public facilities, as outlined in the plan devised by the Urban Development Authority for Kandy City, are also encompassed within the medium hazard zones. Similarly, a significant portion of the areas designated as residential zones are also located within the medium and high-hazard zones. This situation is perceived as a factor that augments the risk of landslides. Furthermore, rapid developments are currently underway along the main road, yet these areas are also encompassed within the low and medium-hazard zones. In other words, while there exists a disparity in the level of disaster management between the aforementioned high and medium-hazard zones, it remains a salient fact that landslide disasters are more commonly observed in the medium-hazard zones during July and August.

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