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The Identification of Landslide Risk-Prone Areas in the Imbulpe Divisional Secretariat in Sri Lanka: A GIS-Based Multi-Criteria Decision Analysis

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Abstract

Landslides can be identified as a prominent natural hazard that causes significant loss of life and property damage in many parts of the world and Sri Lanka. Planning experts, local governments, and decision-makers can benefit greatly from the identification of landslides and the creation of landslide susceptibility maps. Accurate landslide susceptibility maps are essential to minimize the loss of life and property. The landslide risk zones in any area can be plotted using GIS-based MCDA techniques that integrate the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) functions in ArcMap. This study attempted to develop a multi-criteria decision analysis for the appraisal of landslide risk zones in the Imbulpe DSD in Rathnapura District. To analyze the danger of landslides, MCDA was used in conjunction with GIS as a spatial decision-making tool. Slope, drainage pattern, soil type, geology, land use, and rainfall pattern were the six factors used in the study. Landslide risk maps were produced based on weighted techniques such as Analytic Hierarchy Process and Weighted Linear Combination. The slope area significantly affects the likelihood of a landslide. Results revealed that landslides were spreading in a manner that extended toward the eastern section of the study area. Because there are no good locations to build houses in the study area, a huge number of individuals tend to live in unprotected areas. The majority of the landslides in the area occurred during May, October, and November because those months received heavy rainfall. As remedial actions, it can be proposed to displace people living under landslide risk in the northeast and northwest slope areas to suitable protected areas.

Keywords: AHP, GIS, Landslide risk, MCDA, Vulnerability

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INTRODUCTION

A landslide is mostly a result of nature. It is believed that landslides started to happen practically as soon as the earth started to receive rain. Although landslides occur frequently as natural disasters, they can also be caused by human activities. Clearing of forests on slopes, clearing land for farming without using soil conservation techniques, shaking of slopes owing to continual heavy rains, destabilization due to gravelling, removal of loose soil binding, and logging are some human activities that can cause landslides. In high-terrain places where heavy rainfall is frequent, landslides are a severe hazard. Sri Lanka experienced heavy rain and severe gusts during the southwest monsoon. Due to rainfall from the southwest monsoon, the Rathnapura District in Sri Lanka's Sabaragamuwa Province is prone to landslides (Kumara, 2021). Sri Lanka has a total land area of 65,610 km², of which 20,000 km² is at risk of landslides. The area occupies around 30% of Sri Lanka's total land area and has expanded to several districts (Bandara, 2005). It was reported that the heaviest landslide that occurred in the Ratnapura District in May 2003 highlighted the community's extreme susceptibility. Ratnapura experienced 347.2 mm of unusually heavy rainfall in 24 hours on May 17, 2003. There have been numerous landslide incidents in the Ratnapura district, which surrounds the municipality area (Kumara, 2021). Sliding of Palawela, Panapola Kanda, and Muwagama Kanda take priority. Landslides are the most common natural disaster in Sri Lanka, usually posing a threat to the country's central highlands, ranking first overall (Pussealla et al., 2016). Of those, 30.7 per cent of over 20,000 km² of the terrain is highly vulnerable to landslides (Bhandari et al., 1994). The districts in Sri Lanka that are most likely to experience landslides include those in the central highlands, including Badulla, Nuwara Eliya, Ratnapura, Kegalle, Kandy, Matale, and Kalutara, and the southern hills, including Matara, Galle, and Hambanthota.

Landslides occur in several districts depending on the geological location of the central highlands and the spatial pattern of human settlements. The most recent statistics show that 30% of Sri Lanka's population resides in mountainous areas, which make up 20% of the country's overall land area (National Building Research Organization - NBRO, 2018). According to the NBRO (2018), 12 districts in Sri Lanka are vulnerable to landslides. As a tropical country, Sri Lanka has been experiencing extreme disaster events as a result of climate change. Thus, the massive loss of life and property is reported every year as a result of frequent landslide events. Even though natural disasters cannot be prevented, their harm can be lessened by–making people aware of these natural hazards before it occurs. Hence, various steps are being taken by

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the government sector as well as the non-government sector, both local as well as international, to lessen the impact of this circumstance. Geographic information systems (GIS) may be utilized as a useful tool, among the techniques employed in managing natural hazards. These techniques are still searching for effective solutions to control the issue by recognizing the risks involved. Identifying landslide-prone areas and managing them to reduce potential property damage and human casualties is a crucial step in reducing the risk of landslides and determining the size and spatial distribution of the landslide risk as well as evaluating the risk of landslides (Pardeshi et al., 2013). The process of determining the danger to people's safety and health from hazards is known as risk assessment. The risk assessment formula (Kevin, 2012) is as follows.

Risk = Hazard × Exposure × Vulnerability

To study landslide hazards using modern methods, GIS-integrated multi-criteria analyses are currently being carried out all over the world, including in Sri Lanka. The study conducted by Ranagalage (2013) attempted to identify landslide risk zones in the Walapane divisional secretariat division in the Nuwara Eliya district using a GIS-based method. By analyzing the temporal and spatial patterns of landslides that occurred in the study area, high-risk, moderate-risk, and risk-free areas have been identified and plotted. The study found that 36 out of 125 Grama Niladhari divisions in the Walapane Divisional Secretariat have reported landslides, indicating 28.8 per cent of the total. It has been determined that the rainfall of more than 250 mm in January had an impact on the number of landslides that were reported in the year 2007, which accounted for 31 per cent of all landslides. Hemasinghe et al. (2017) used a logistic regression model to investigate Landslide Susceptibility Mapping in the Badulla District of Sri Lanka. The main objective of their study was to use a logistic regression model to locate landslide risk areas in the Badulla district. Specific objectives included creating landslide risk maps, creating a database for assessing future landslides using a geographic information system, and giving hazard managers improved data. Results revealed that 76.0 per cent of landslide sites are in extremely high-risk locations while 39.3 per cent of the whole land area is in a moderate-risk zone, and 40.2 per cent of the total land area is in a low-risk zone.

Chau (2003) performed a study in the hilly region of Lantaui in Hong Kong to map the landslide risk zones and update the land use map of the region. To examine the relationship between landslides and spatial features, the locations of landslides have been correlated with rainfall, slope distribution, slope height, and geology data. The fact that human activities should be controlled in the

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mountainous area can be focused through the preparation of a landslide vulnerability map. Additionally, based on the study landslides in the vicinity have been predicted. It has been discovered that the places where landslides have occurred are more prone to landslides in the future. Landslide hazard mapping and evaluation using GIS based on a grid-cell-based quantitative technique were conducted by Dhakal et al. (2000) in the Kuleshani river basin, which is a part of the Himalayan Mountain range in central Nepal. Dananjaya et al. (2009) conducted a study in the Kiriketi Oya and Belihul Oya watersheds to establish landside vulnerability and risk assessment. The study focused on the location of landslide-prone areas between the Kirikati oya and Belihul oya catchments. The objectives were to investigate the relationship between geological conditions and landslide events. Dhakal's research used Landsat 8 OLI-TIRS (30m resolution) satellite imagery to determine the vegetation index and examine land use patterns. About 60% of the land area of the research area has been observed to have a moderate or high risk of landslides. Data analysis and interpretation have been performed Using ArcMap 10.3 software. The most vulnerable areas in the region have been determined to be Namperial, Nagaraka, and Kuburuthaniwala.

Furthermore, there have been sporadic reports of landslides and property damage in the Imbulpe Divisional Secretariat Division in the Ratnapura District. Every year, there is a significant loss of life and property due to landslides, and the government spends a lot of money on reimbursing victims, relocating them, and rebuilding their homes. The fundamental issue is the loss of life and property as a result of inadequate knowledge of the study area's landslide-prone zones. So it is possible to lessen the area's potential landslide risk by being aware of them. Therefore, this particular study defines the landslide risk zones and identifies the safest places for resettling people by evaluating the factors that influence the incidence of landslides. To pinpoint potential landslide risk areas in the Imbulpe divisional secretariat, this study is crucial from an experimental standpoint. The risk of a disaster can be determined using the information obtained from this empirical research, and the resulting loss of life and property can then be subtracted.

The main objective

The main objective of this study was to prepare a risk area map to identify landslide risk areas using Geographical Information Systems based on the factors affecting landslides.

Specific objectives

To examine how Geographic Information Systems can be used to identify and manage landslide areas. To identify potential landslide risk

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areas in the Imbulpe DSD and guide its mitigation.

MATERIALS AND METHODS

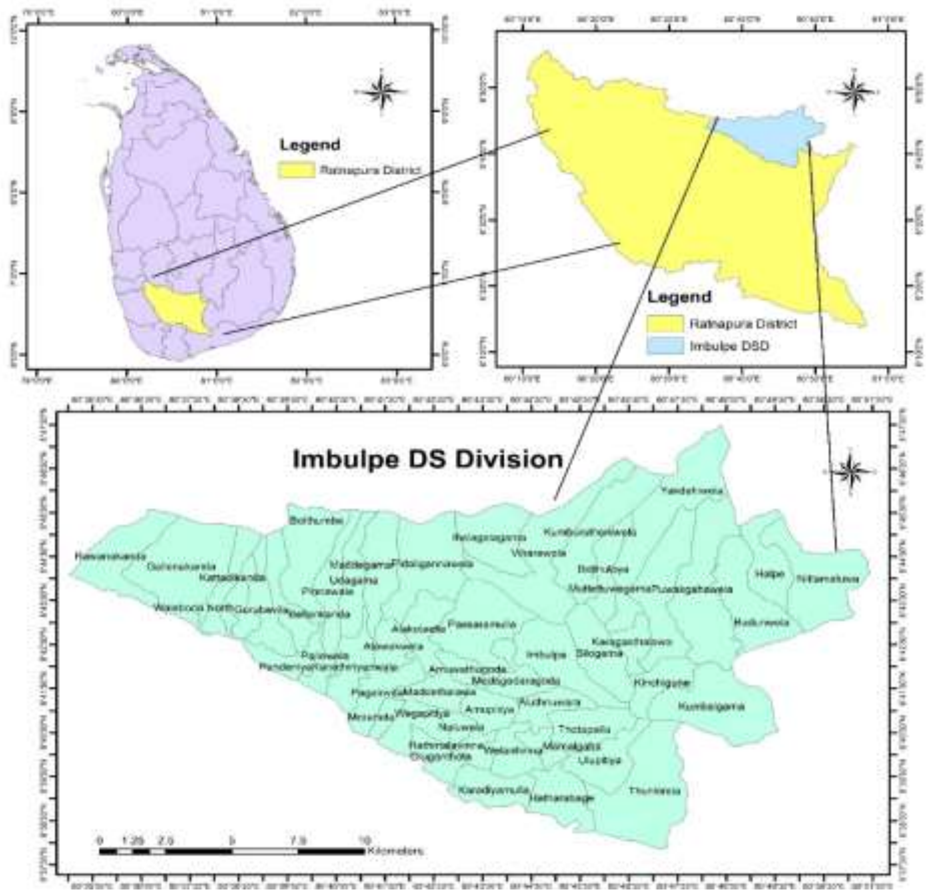
Study Area

The location of the Imbulpe Divisional Secretariat, which is located in the southernmost region of the Ratnapura District, lies between latitudes 6°55" and 6°78" north and longitudes 80°-71" 80° east. The Nuwara Eliya District in the north, the Walawe River and the Balangoda Divisional Secretariat in the south, the Badulla District in the east, and the Balangoda and Ratnapura Divisional Secretariat in the west are the boundaries of the Divisional Secretariat. The Imbulpe area is situated in the intermediate zone next to the Sabaragamu mountain range, according to the topography. According to geographical features, the majority of the settlements in the area have been located on steep slopes and high heights ranging from 320 to 2180 m. It can be classified as dry, wet, or intermediate depending on the climate, and the region's average annual rainfall ranges from 2000mm to 4500mm (Imbulpe DSD, 2020). Rainfall is mostly brought on by the Southwest Monsoon, but it is also brought on by the Northeast Monsoon and the Inter-Monsoon. Landslides and falls happen during the rainy months from April to July because the soil layers on the mountain slopes are wet. It is composed of rocks from the Precambrian highland series, according to geology. The research area's southern border is where the Walawe River, a significant river in Sri Lanka, runs. Dendritic drainage patterns extend from the high mountain peaks to feed the river.

Data Used

To achieve the objectives of the research, both secondary and primary sources of data were used. Secondary sources are institutional data and data collected through the internet. To fulfil the objectives of the study, books, manuals, journals, research articles, and other information such as several reports of landslides and their effects were collected under secondary data. Data from the Survey Department, Land Use Planning Department, National Building and Research organization, Meteorological Department, and Geological & Mines department served as the basis for gathering the study's pertinent information. Table 01 illustrates the types of those information, sources, and scales. Ten of the 50 Grama Niladhari Divisions (GNDs) with the highest risk of landslides were chosen for the study out of the Divisional Secretariat of Imbulpe, which was designated as the study region. The slope angle, elevation and rainfall intensity were the main consideration while selecting 10 of the villages. Several methods were followed in collecting the primary data related to the research, and methods such as questionnaire survey, in-person interviews, field observation, and photographs were used. It was feasible to get information about the community's experiences and issues by exchanging views with those who live in the study area. The Imbulpe Divisional Secretariat's disaster affairs officer and land planning officer were also discussed with the *Grama Niladhari* of the relevant GNDs. Landslide risk zones in the area were defined using the researcher's experience as well as other natural and anthropogenic factors. The characteristics of the landslides that had occurred in certain locations were also made known there.

Figure 01: Geographical location of the Study Area



Source: Compiled by Authors, 2022

Table 1: Summary of the Secondary Data Sources and scale

Data Types	Source	Scale
Contours	Survey Dep. Digital Data Layers, 2020	1:10,000
Soil type	Land use Planning Dep, 2020	1:10,000
Geology	Geological & Mines bureau Dep, 2020	1:10,000
Rainfall	Metrological Dep, 2020	1:10,000
Water Bodies	Survey Dep. Digital Data Layers, 2020	1:10,000
Land use	Survey Dep. Digital Data Layers, 2020	1:10,000
Road Network	Survey Dep. Digital Data Layers, 2020	1:10,000
Landslide Data	National Building Research	

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(Damages, Reports..etc)	Organization (NBRO), 2020
Others	*Resource Profile*, Imbulpe DSD, 2020

Source: Compiled by Authors, 2022

Data Processing

Data Analysis

The data were analyzed using two different approaches: Qualitative and quantitative. Geospatial applications such as ArcMap 10.5 and Google Earth were used to assess the accuracy of the confirmed data after the data relevant to the research was quantitatively verified. In this study, the region's landslide risk zones were identified, categorized, and mapped. The potential risk was divided into three categories using the Geographic Information System (GIS) as high, moderate, and low and those risk areas were identified. Six major factors affecting landslides were considered using MCDA and AHP methods. The relationship between the approaches was determined using several criteria in the MCDA-based AHP model approach, which is the most effective and widely accepted method in the world. As a preliminary step, these criteria were converted into raster data for analysis. The slope map and the rainfall map were in raster data form and other criteria were converted to raster data. The value of risk was determined when converting to raster data.

GIS-Based Multi-Criteria Decision Analysis

A process called GIS-based MCDA integrates and transforms geographic data with value judgments to produce information for decision-making (Malczewski, 1999). Identifying the size and geographic distribution of the landslide risk is the definition of a multi-criteria risk assessment. The result of the GIS-based multi-criteria risk analysis is a produced map that allows for the ranking of risk zones. Through the logical, well-organized procedure of MCDA, numerous elements can be recognized and given priority. MCDA, a spatial and relatively novel concept utilized for assessing landslide risk, can be used in conjunction with GIS. GIS-based MCDA can be considered as the process of transforming and integrating geographic data and value judgments in decision-making and information retrieval. Although there are several methods for estimating and analyzing the decision criteria in MCDA, the AHP methodology provides a comprehensive contribution. Various techniques were used in landslide risk assessment using this methodology. All criteria were converted into vector-to-raster and raster-to-vector data under the GIS approach (Figure 03). Slope and elevation maps were generated from a 30m resolution DEM which was derived from the 1:10000 digital data layers. As a next step, the Euclidian distance method was used to determine

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the distance between the criteria in examining the relationship between them. The criteria were reclassified respectively and then weighting was done for all the criteria based on the opinions of experts in the field. It was done through the weighted overlay method and the risk areas were quantitatively calculated using the Dissolve and Calculate geometry tools. The impact of each variable's relationship to the outcome of landslide risk can be evaluated using the MCDA method. The landslide risk area maps can be made by using the Analytic Hierarchy Process approach to assess both quantitative and qualitative data.

Analytic Hierarchy Process (AHP) developed by Thomas L. Saaty (1980) as one of the most popular methods is currently used in research related to multi-criteria decision analysis. AHP is a flexible but structured methodology. The main stage of this methodology is to structure all the criteria used into a hierarchical framework. Also, it is used to rank a set of alternatives or to select the best of a set of alternatives. The criteria are ranked concerning the main goal of the study and are divided into various categories. Determining the weights of the criteria and analyzing the relative importance has been done using AHP. AHP methodology involves decomposing the decision problem into a hierarchy of the most important elements of the decision problem. In the study, the relationship of the criteria used to determine the main problem in the identification of landslide risk zones was established. A GIS data system has illustrated how spatial decision problems have influenced landslide risk identification. A pairwise comparison of decisions and determinants takes place in this process and a GIS database is created. The eigenvalues and eigenvectors of all criteria were calculated in the form of a pairwise comparison matrix or as a ratio matrix. In this way, Saaty has introduced a range of values from 1 to 9 in determining the relative weights for the Criteria and comparing them in pairs (Table 02). This scale was used when experts compared criteria for identifying landslide risk through semi-structured questionnaires. In creating the landslide risk map, each map is represented by a raster map and classified based on the values of the maps. Under the process of standardization, the values and classes of the maps were converted to a common scale. Further, the resulting weights of the criterion maps were processed into individual scores using a weighted linear combination (WLC). The WLC procedure is used to standardize the maps and confirm that the sum of the weights of the calculated criteria is equal to 1. Based on this approach, criteria such as slope, Drainage, and rainfall with high standardized values are most suitable for achieving the study objective, while determinants with low values are determined based on risk areas. In this way, based on the scores calculated for all the criteria, the determinants with high scores such as rainfall and slope have been selected as having a high potential for landslide risk. This GIS-MCDA method is built on the idea of a weighted average, where continuous criteria are standardized to a common numeric range and then integrated using a weighted average (Drobne and Lisec 2009). The criterion with the highest score is chosen after all the scores for the criteria have been calculated. The major criteria were slope, drainage pattern, soil type, geology, land use, and rainfall pattern. There are numerous issues with integrating six distinct factors to construct the hazard zone map in this manner. As a result, many sources were used to categorize each variable, including information from the National Building Research Organization, viewpoints from landslide experts, and viewpoints from knowledgeable individuals.

Table 2: Saaty's Scale

Scale	Degrees
Extremely Preferred	1/9
Very Strong to Extremely	1/8
Very Strongly Preferred	1/7
Strong to Very Strongly	1/6
Strongly Preferred	1/5
Moderately to Strongly	1/4
Moderately Preferred	1/3
Equally to Moderately	1/2
Equally to Moderately	1/2

Source: Saaty, 1980

Criterion Maps

Landslides are a major identifiable natural hazard in Sri Lanka. Landslides occur mainly in the Central Highlands and Sabaragamu Mountains of Sri Lanka and its impact is on both human and environmental aspects. Landslides are mainly determined by the factors of slope angle, elevation, rainfall pattern, soil and drainage. When identifying a landslide risk zone, primary attention should be paid to these criteria.

Slope

One of the key elements influencing the occurrence of landslides in the region is slopes. The area's slope was divided into five groups. It can be seen that the slope value is more than 15.09 degrees in the direction of the region's northern boundary. The villages of Yakdehiwala, Belihul oya, and Viharawela are situated in the slope angle range of 36.02 to 67.54.

Geology

The region includes twelve major geological groups and is a member of the highland series. The locations of prior landslides in the area are shown on the geological map, along with the geological category to which those areas belong. Major geological kinds including granite, marble, quartzite, and chanokite are present in the area.

Soil

The study area contains a variety of soil types, with more than 70.0 per cent of it being red-yellow podzolic soil. Tea is often grown in locations where the soil layers are common because of the dark hue and good drainage of these soils. Low-lying locations typically have alluvial soil, and paddy agriculture is done there. Around Belihul Oya, Galagama, and Kubalwela, you can find bog soil and half-bog soil. In the areas with greater elevations, lithosols soils are common.

Land Use

The area has been occupied by 14 different land use classes, with 38.4 per cent of the total land area being set aside for forests, 17.1 per cent for homesteads, 15.0 per cent for tea plantations, and 12.7 per cent for scrubs. Forests are protected on the majority of the land, and they are common in the higher elevation zone. Due to the area's use for agricultural activities without effective land management for tea plantations and other crops along the mountain slopes, landslides are severely impacted for the raea. Deforestation increases the likelihood of landslides in regions with bare ground and shrubs.

Drainage

The Strahler method was used to grade the drainage map, and a drainage network with grades from 01 to 05 was produced. There is a drainage pattern that permeates the whole research region when the river network in the area is classified using the Strahler method. The study was undertaken by choosing the tributaries from 01 to 04 grade mostly by building buffer zones to investigate the impact of the river network on landslides. The river network from 1 to 4 was chosen because most rivers are found within the boundaries of groups 1 to 4, and because landslides typically happen in areas with steeper slopes.

Rainfall

The data gathered from the Meteorology Department was used to determine how often it rained there. For this, the monthly rainfall information for 2019 was gathered from the Detanagalla, Belihul Oya, and upper Belihul Oya stations. The following maps display estimated rainfall for the three months of October, November, and January. Inverse Distance Weighting (IDW) is used to interpolate rainfall data and provide continuous raster rainfall data within and around the DSD area.

Criterion Maps Re-classification

The study applied six criteria to identify landslide risk areas of Imbulpe DSD. These six requirements are also unique. In other words, the buffer zones made for the canal map are in meters and the slope zone is measured in degrees. Each criterion was reclassified using information from a variety of sources, including information from the National Building Research Organization, assessments by landslide specialists, and firsthand experience. The slope angle ranges from 0 to 67.54 degrees, and the slope zones are distinguishable. The reclassification places zones 0–15 as low risk, 15–30 as intermediate risk, and zones 30–70 as high risk.

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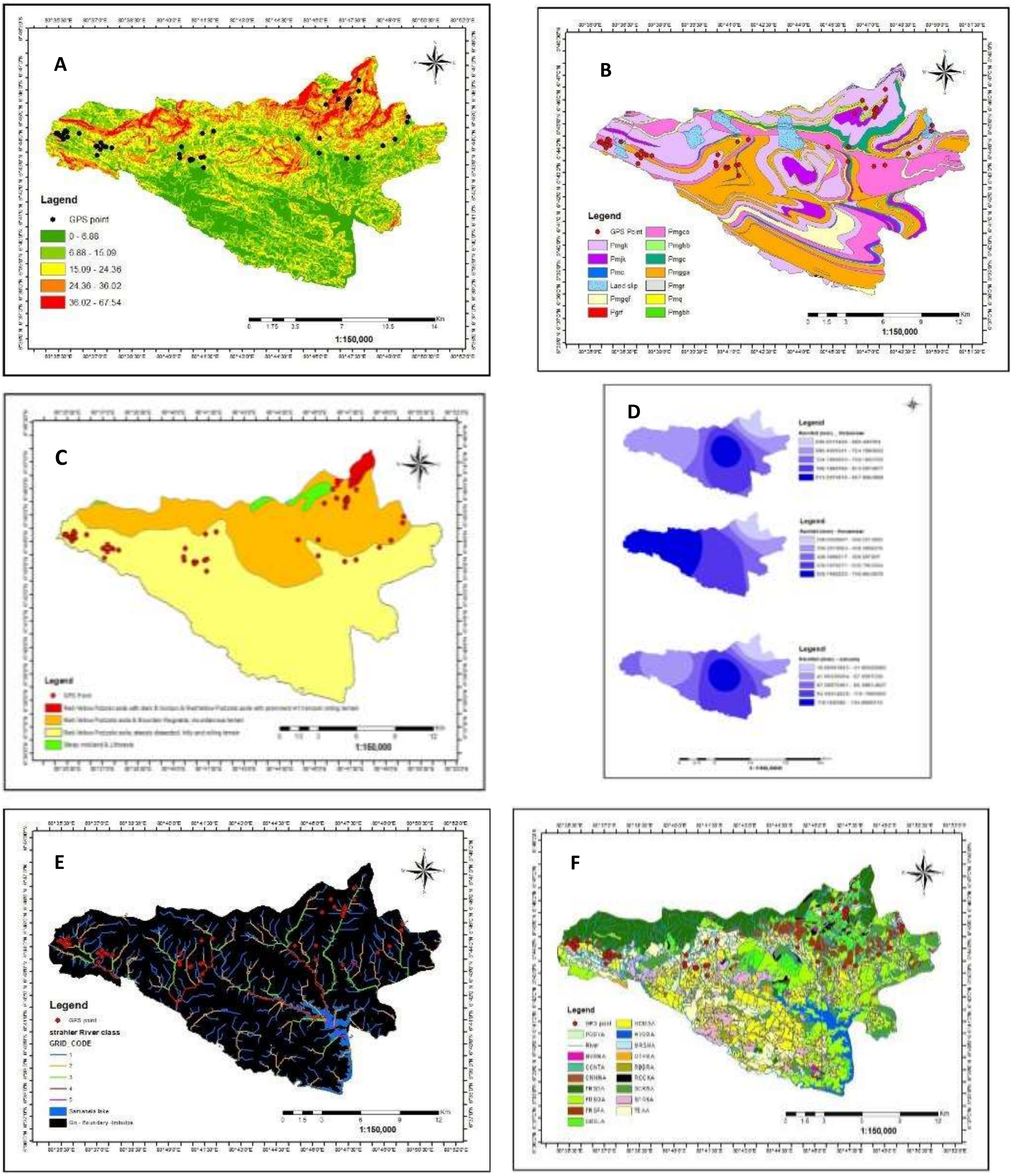
Figure 02: Criterion Maps



A – Slope, B – Geology, C – Soil, D – Rainfall, E – Water Bodies, F – Land use
Source: Compiled by Authors, 2022

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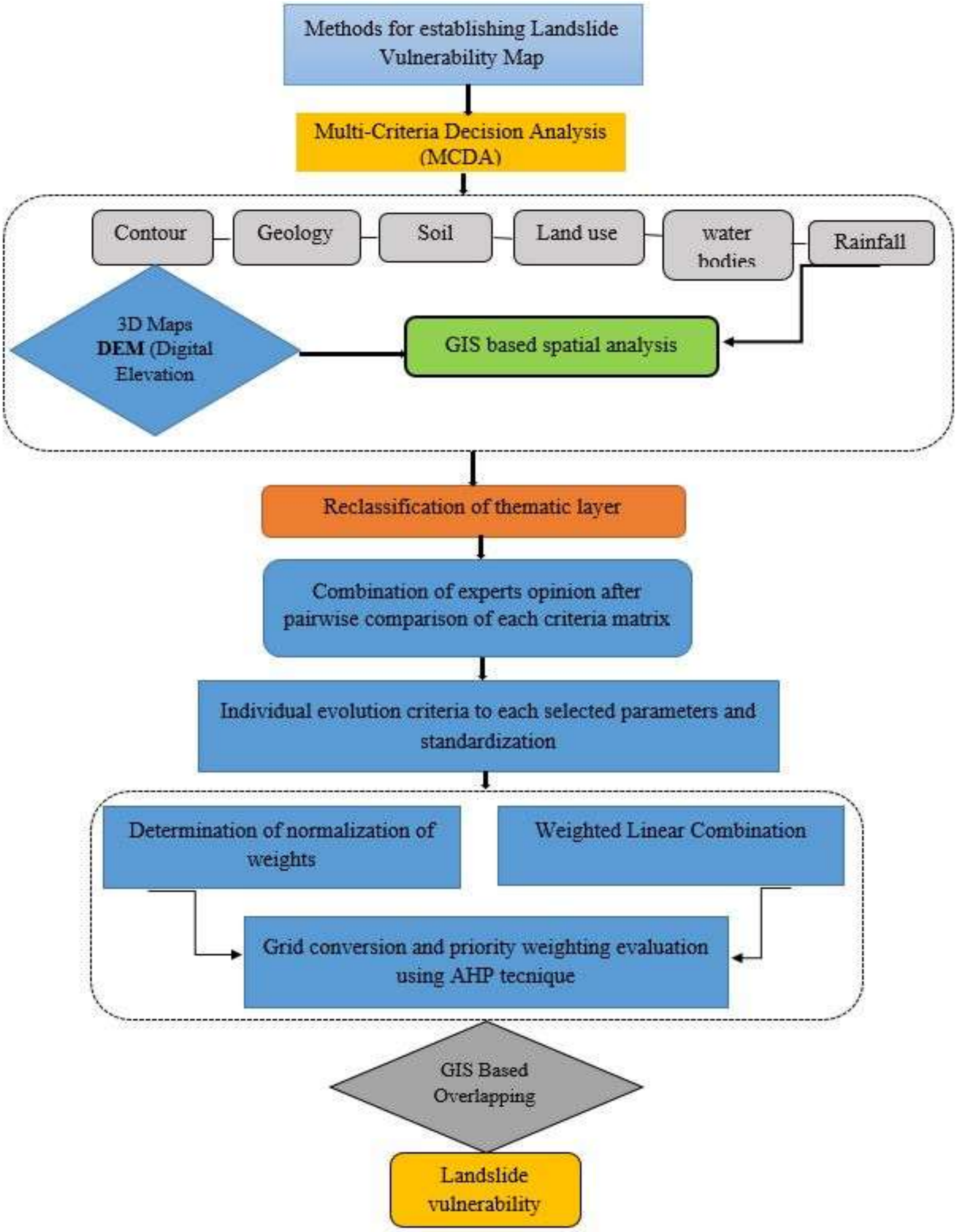
Figure 03: Methodological flow chart of the study



The slope area map reveals a high-risk area in the northeastern portion of the region, whereas the southwest and centre regions have a lower risk. Within the study region, there are twelve different geological zone classifications. Marble is a type of geological zone that is often dolomitic and coarse-grained. Zones such as Chanockit gneisses and Cordiente gneiss were recognized as high-hazard locations, whereas gneisses and

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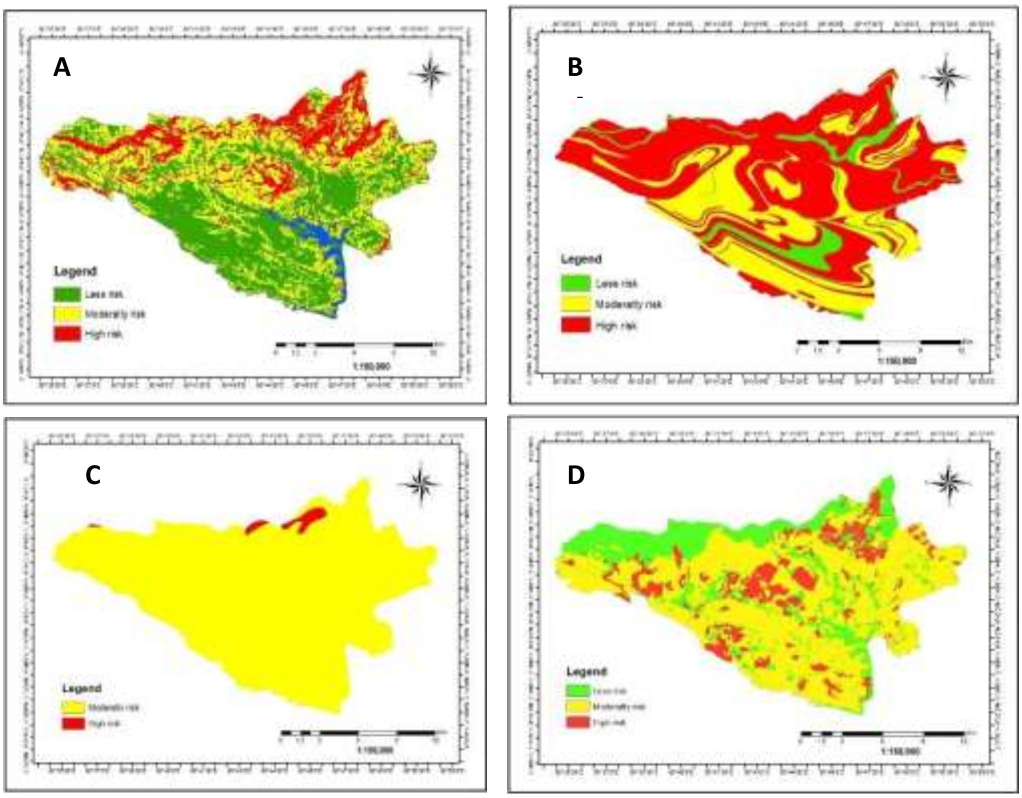
granulites were classified as lower-risk areas. Because it is in a moist zone, the soil profile is frequently damp. The region is categorized as having moderate risk and high risk, and four soil zones can be found there. The high-risk area includes mountain regosols and red-yellow podzolic soil. It can be found in the area's northern section. There are 16 different types of land use patterns which are specific to each location.

Tea, waterbodies, woods, homesteads, rubber, and cinnamon are examples of common land use classifications. High-risk zones include grasslands, streams, and undeveloped land; moderate-risk areas include homesteads and brush; and low-risk areas include paddy fields, coconut plantations, and cinnamon plantations. The Strahler approach was used to reclassify the drainage system based on graded river grades. This led to the designation of 4-5 streams as low-risk zones, 2-4 tributaries as moderate-risk areas, and 1-2 tributaries as high-risk areas. The buffer zone or elevation was crucial in calculating the risk according to the tributary zones. The rainfall map was reclassified using rainfall for the three months of October, November, and January. As a result, it appears that the area saw rainfall ranging from 16.0 mm to 857.6 mm. It was determined during the investigation that rainfall is a significant component causing landslides. Even when all other landslide-affecting elements are present in full force, rainfall has a direct impact on the activation of landslides.

Figure 04: Re-classified criterion maps



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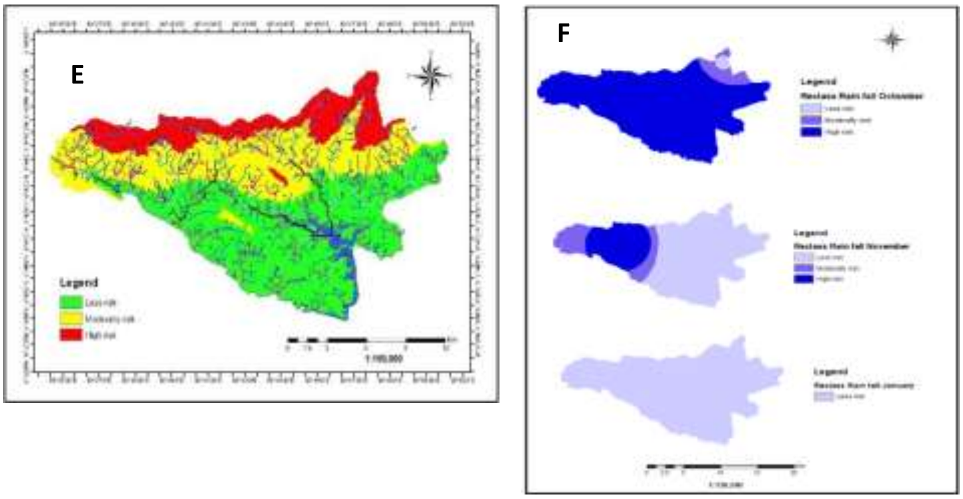

A – Slope, **B** – Geology, **C** – Soil, **D** – Land Use, **E** – Water Bodies, **F** – Rainfall
Source: Compiled by Authors, 2022

RESULTS

The research aimed to create landslide vulnerability maps of Imbulpe using a simple methodology involving geo-informatics. To fulfil the aim, the following analysis was carried out. The results of vulnerability levels and area calculation for major criteria such as slope, geology, soil, land use, water bodies, and rainfall parameters differed from each other based on their criterion values which were assigned based on the results of expert opinions.

Analysis of Landslide Risk

Separate risk maps have been created for October, November, and January based on rainfall. Landslide risk can be classified as high risk, moderate risk and low risk. Compared to November and January, October indicates an increase in the high-risk area. High-risk locations are 3.61 per cent in November, compared to 10.26 % in October. On the other hand, it dropped to 2.19 per cent by January. 25.72 km^2 of the whole area is in the high-risk area in October. The average limit of landslide hazard, which is also examined, is 59.49 per cent in November and steadily rose to 89.0 % in October. By January, it had dropped to 54.20 per cent. As a result, October has a propensity for having more dangers because of the impact of rain. The areas with less landslide risk was 0.72 per cent in October and the amount increased to 36.89 per cent by November. In January, it rose to 43.60 per cent. (Figure 05 & 06). As a result, it appears that overall landslides are more likely to occur in October. The geological profile revealed a 59.03 per cent influence on landslides in the area, while rainfall in October revealed a high percentage of 93.73 per cent when examining the contribution of the parameters used to produce the risk regions map of the region. In general, the moderate-risk locations have proportionally greater criteria for land

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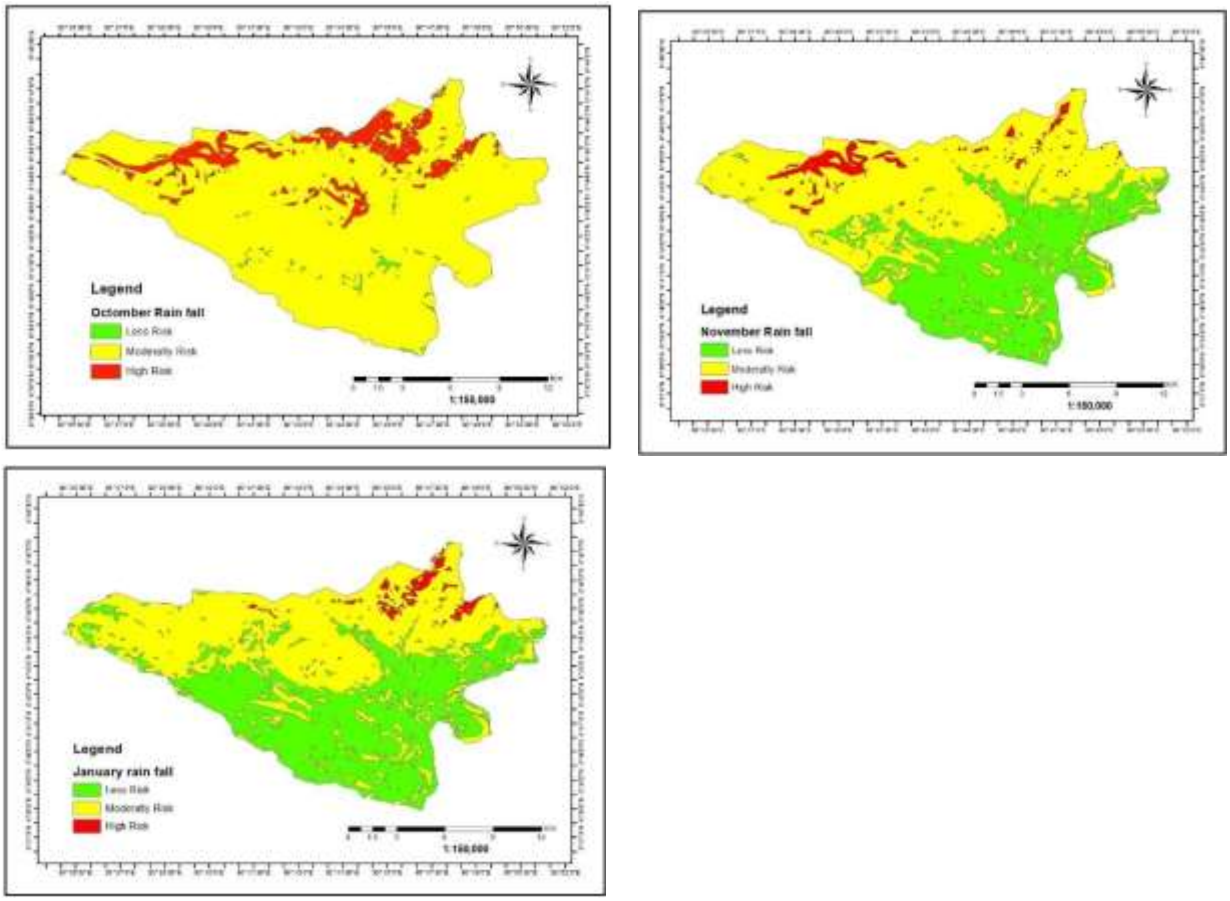
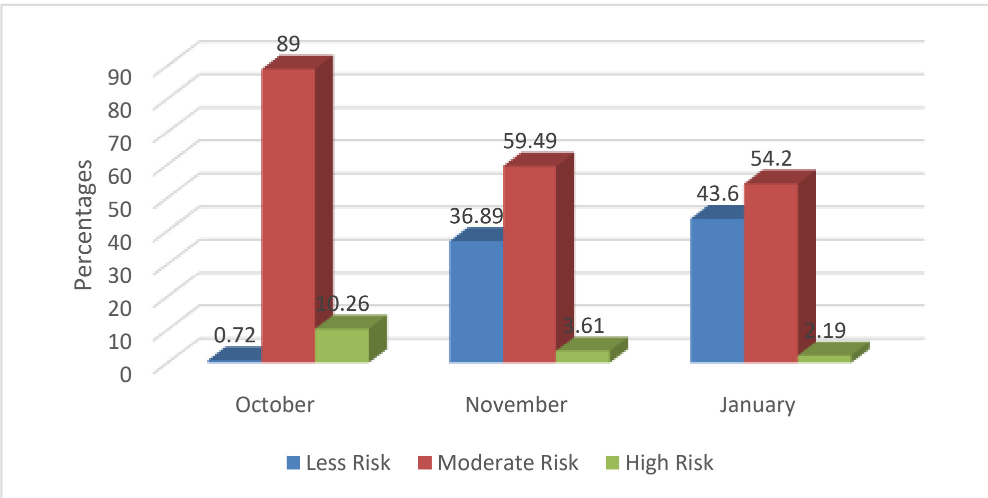
use, slope area, soil type, and river network than the lower-risk areas.

Figure 05: Risk areas based on the three months Rainfall pattern



Source: Compiled by Authors, 2022

Figure 06: Distribution of risk areas by rainfall



Source: Compiled by Authors based on Risk Map, 2022

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The estimated weights indicate that slope areas contribute 33 per cent, rainfall contributes 21 per cent, and drainage pattern contributes 18.0 per cent to the occurrence of landslides in the area. In terms of the terrain of the region, the northern part of the division has a fairly complex topography. There is a land area with a slope of more than 45 degrees. The 5525 hectares make up more than 60.0 per cent of the total area. It makes up around 21.0 per cent of the study area's overall area. The final risk area map indicates that 14.13 per cent of the entire land area is in high danger of landslides. 64.53 per cent of the area is considered to be somewhat prone to landslides. This region spans 16162 hectares. 5343 hectares or 21.33 per cent of the land are considered to be lowrisk. As a result, there is a high danger of landslides throughout the entire area, and 78.66 per cent of it is at moderate risk. We can infer that landslides pose a threat to more than half of the study area's land area. Figure 07 depicts the locations and distribution of several high landslide-risk zones that can be found in the research area.

As mentioned earlier, AHP and Pairwise comparison methods were used in the assessment of landslide risk zones, and the opinions of 10 experts in the relevant field were consulted while comparing the criteria. Disaster management officials, National Building Research organization officials, and experts in GIS research were selected for the study. The risk areas were evaluated using the AHP and Pair-wise Comparison Matrix (PCM) methodologies to create the final landslide risk area map, based on the input from the subject-matter experts and the fundamental standards. The judgment of the decision maker determines the standard and efficacy of decisions. Based on the experiences of the general public and industry professionals all determinants were compared to each other to determine their relative weight. Each criterion is given a weight once each determinant is separated into various classes. Each criterion has a maximum and lowest weight allocated to each class, ranging from 1 to 10. In this process, the factors affecting landslides are compared and a matrix is built according to the values of 1 to 9, the contribution of each factor with the other factors.

Since six criteria were used in the study, the matrix can be considered as 36 cells. Accordingly, one side is built into a matrix, and the other side is divided by the corresponding value, and the resulting value is indicated. The weights allocated to the various classes and their averaging were calculated to determine landslide risks. The soil profile had a maximum value of 0.33 and a minimum value of 0.06. The slope area significantly affects the likelihood of a landslide. Calculations show that 0.10 for land use, 0.12 for geology, 0.18 for drainage, and 0.21 for rainfall have been derived, respectively, for the other factors (Table 3). It is feasible to determine how the hazard is distributed along each slope

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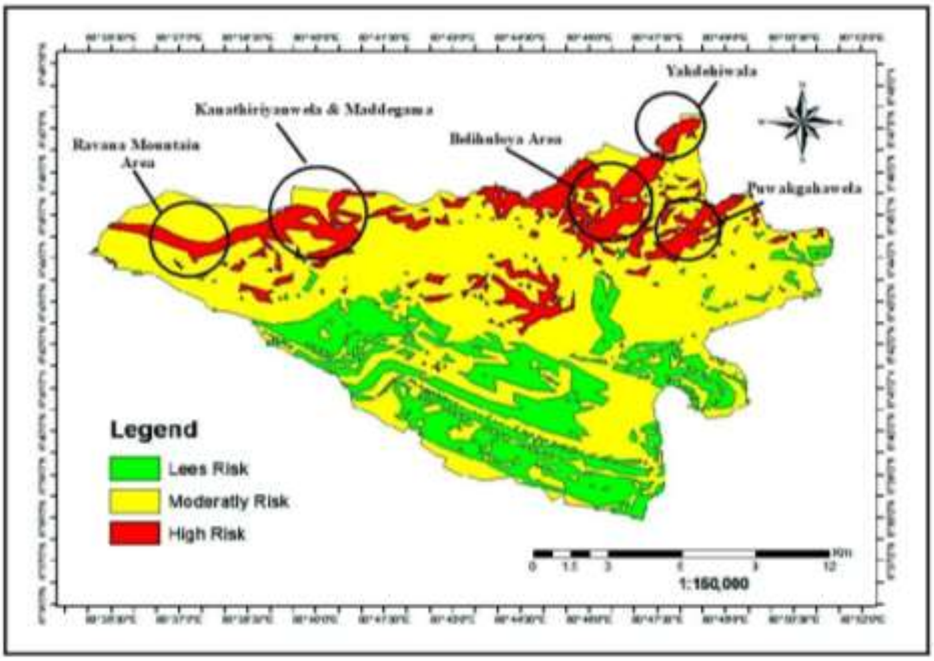
direction by combining the risk area map and the slope area. As a result, the direction of the landslides in the area has extended towards the eastern section of the research area. Every direction has an aspect, and the slope direction can be used to determine the direction of landslides.

Table 3: Pair-wise comparison matrix and final weights for Landslide risk criteria

Criteria	Land Use	Geology	Slope Area	Drainage	Soil Types	Rainfall	Total	Weight
Land Use	0.10	0.12	0.12	0.05	0.12	0.09	0.59	0.10
Geology	0.10	0.12	0.17	0.08	0.18	0.09	0.73	0.12
Slope Area	0.29	0.24	0.35	0.32	0.29	0.52	2.01	0.33
Drainage	0.29	0.24	0.17	0.16	0.12	0.09	1.06	0.18
Soil Types	0.05	0.04	0.07	0.08	0.06	0.04	0.34	0.06
Rainfall	0.19	0.24	0.12	0.32	0.24	0.17	1.27	0.21

Source: Based on AHP Calculation, 2021

Figure 07: Potential Landslide risk areas in the Imbulpe DSD



DISCUSSION

Pre-Landslide characteristics in the Area

Through field verification, the pre-landslide features that were noted in the region, irregular human activity and construction, the nature of landslides, and the actual locations of dwellings and buildings were discovered. Subsidence is another one of landslides' predecessors. Some houses have a 05 to 10-degree tilt. In the Kanthirianwala area, there has been subsidence. In some spots, it has ranged from a few trenches to about a foot (Picture 01). Although the soil has been fortified by the placement of rocks and the cultivation of tea, it is still possible to identify the places that are

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susceptible to sinking. According to the geological position, which is in the Garnet sillimanite biotite gneiss + graphite zone, the slope angle is between 24-36, and it can be established based on the pertinent institutional data that some physical change within the ground is what is causing this issue. Explosions in the walls of nearby homes and structures have been noted before landslides, and they are a forerunner to the risk of landslides. Thus, a change in the terrain on which homes or other structures are built causes cracks in houses. The research area's villages of Yakdehiwala and Kanathirianwala have several of these characteristics, and the following photo gallery depicts such homes with damaged walls (Picture 02). This area has been recognized as one where landslides can occur due to the high slope of the area and informal human activities. These pre-landslide features increase during the rainy season. It is important to assess the risks involved in constructing homes and other structures, particularly in mountainous terrain. The building work has been done in the research region by cutting the slope areas sporadically, according to field studies that have been done there. In the villages of *Kanathirianwala*, *Ravanakanda*, and *Gallena Kanda*, irregularly cut slopes and constructions can be observed along the slopes of the mountains (Picture 03).

Picture 01: Subsidence in the Kanathiryanwela Area

Picture 02: Yakdehiwala & Kanathiryanwela

Picture 03: Irregular Land uses

Source: Field Survey, 2022

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Nature of Landslides in the study area

The location of the place, the type of rocks present, and the distribution and location of the soil profile all affect these sorts of landslides. As a result, based on in-person observations in the field and the judgments of experts, the types of landslides that have happened in the area might be suggested. According to the landslide trend in the area, 55.0 per cent of fractures have occurred. Following that, 20.0 per cent of rock falls happened. Then, landslides, debris flows, and subsidence happened in that order. The settlements of Yakdehiwala and Ravana Kanda are home to the majority of the residences close to the mountain summits. It is crucial for individuals who live close to mountain tops, in the midst of mountains, or on mountain slopes to maintain a constant state of alertness since the damage caused by landslides may be determined based on the physical location of the houses.

Table 04: Nature of the landslide

Nature of the Landslide	value	%
Fracture	33	55
Rock Fall	12	20
landslide	05	8.33
Debris Flow	03	5
Subsidence	07	11.66
Total	60	100 %

Source: Field Survey, 2022

Physical position of houses and buildings

According to the questionnaire survey conducted among the households in the area, the distribution or location of houses and buildings could be identified in four ways. The nature of the location determines the vulnerability and the potential damage can also be considered. According to the data obtained, 51% of the houses, that is, most of the houses are located in the hillside areas, and 25% of the houses are located in the middle of the mountains. The area has 13 houses located near the high peaks, which is a percentage of 22 (Table 05). In Yakdehiwala and Ravana Kanda some villages, most of the houses are located near the hilltops.

Table 05: Physical position of houses and buildings in the study area

Physical Position	Size	Percentages (%)
Located on the hilltop	13	21.66
Located on the hillside	31	51.66
Located in the middle of the mountain	15	25
Located on the plain area	01	1.66
Total	60	100

Source: Field Survey, 2022

CONCLUSIONS AND RECOMMENDATIONS

The most advanced and widely accepted method, the GIS-based MCDA-AHP method, was used to conduct the Imbulpe DSD landslide risk analysis. The southwest monsoon and the second inter-monsoon are responsible for receiving the majority of the rainfall, according to a study of nearly 25 years' worth of rainfall data in the research area. Heavy rainfall occurs during May, October, and November.

Most of the landslides that have occurred in the study area occurred during this period. One of the main points found in the updating of the land use map is that there are still more forests and scrubs in the study area. This is because the forests in the area have been preserved as protected areas. Landslides can be caused by Chena cultivation, bare land, and grasslands that have a strong impact on landslides. With the gradual increase in population, the need for housing and agricultural land in the area has intensified. A large number of people tend to live in unprotected areas because there are no suitable areas for building houses in the study area. Accordingly, insecurity in those areas leads to increased risk. After grading the drainage pattern spread over the study area according to the Strahler method, a river network with grades 1-5 can be identified. Therefore, it is constantly saturated with water. Before preparing the potential landslide risk map, weighting was done for the six criteria used for it, and the slope areas and rainfall were more important. Studying the risk area created for October, November, and January, it appeared that the highest risk of October. Areas with risk of hazard can be identified in the North, North-West, and East directions. The thing to be concerned about is that a moderate population density is centred in this area. There is one village with a high population density, and the damage could be huge in future landslides. In connection with the river basin, it appears that the *Belihull Oya* and *Hirikatu Oya* are high-risk areas. The slopes extending towards the south to east show a higher risk of landslides. Apart from that, this condition is mostly seen in North-West, South to West, and West direction slopes. The worst landslide in the area occurred in 2003 and due to the heavy rainfall, the landslide spread over a large area. Future calamities can be prevented by identifying irregular construction, cultivation, forest destruction, and landslide risk areas in the area and controlling human activities in those places, educating people on how to recognize the early signs of landslides. The people in the northeast and north-west slope areas with landslide risk in the area should be displaced from those areas and given houses in protected areas. There is a need to establish a systematic process so that researchers, decision-makers, and planners can get the data available from institutions working on future landslide management. A data system should be created in such a way that everyone can access it by creating a data system that can be used on the Internet, which is controlled by the Disaster Management Center and is constantly updated. To mitigate future landslide risks, the responsible officials must be involved in proving the ability to conduct research through such Geo-spatial techniques and approaches as MCDA-AHP.

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