NASA SpaceApps 2021 - Team Cifra

Project Siren

IDENTIFYING RISK WITH SCIENCE + COMMUNITIES

Siren: GIS-based landslide susceptibility mapping, risk prediction & community awareness application using statistical methods in Badulla area, Sri Lanka

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1. Introduction

Landslides are not a threat that only occurs in Sri Lanka. These are some of the recurrent natural problems which are widespread throughout the globe, especially in mountainous areas. These scenarios cost immeasurable values by causing a significant injury and loss of human life, damage in properties and infrastructures, etc. Landslide is defined as the movement of a mass of rock, debris, or earth down a slope under the influence of gravity(WP/ WLI - International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory 1990). They are caused by various factors such as heavy or prolonged precipitation, earthquakes, rapid snow melting, and a variety of land use activities. Landslides can involve flowing, sliding, toppling, or falling movements and lots of landslides exhibit a mixture of two or more sorts of movements.

Landslides are among the most frequently experienced natural disasters in many districts in Sri Lanka; Badulla, Nuwara Eliya, Ratnapura, Kegalle, Kandy, Matale, Kalutara Districts which are located within the central hills, and Matara, Galle, and Hambanthota Districts in the southern hills. These districts can be identified as the landslide-prone areas in Sri Lanka. According to National Symposium on Landslides in Sri Lanka, among those, approximately 20,000 km^2 (30.7%) of the acreage is highly at risk of landslides. With the increase of development and expansion of human settlements, landslides became a serious concern within the mountainous regions of the country which leads them to suffer from significant loss of life and property. In Sri Lanka, landslides have become a major threat to the social, economic, and environmental aspects of Sri Lanka. Therefore, identification of landslide susceptible areas associated with the terrain and making the community aware of the threat level is important for ensuring the sustainability of developments while minimizing the possible disasters due to landslides. Badulla District often falls in a landslide in Sri Lanka. Meantime, many places in this district expect the landslide. The spatial probability of landslide event itself can be identified through landslide susceptibility mapping which is used in our mobile application.

2. Objectives

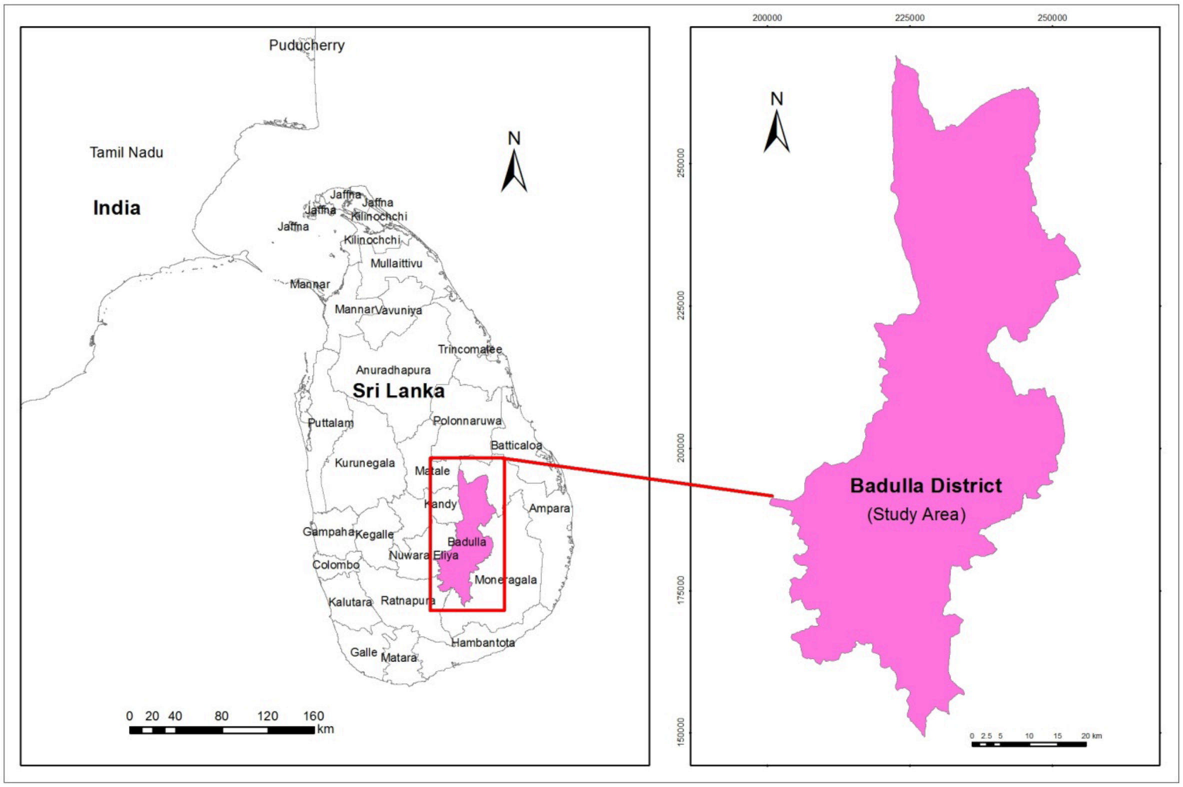
The main objectives of this project were,

- To develop an awareness of the community about the threat level they are in
- To develop a Landslide Susceptibility Map using WoE models
- To provide an improved decision support tool for hazard managers and planners to incorporate Earth observations (as satellite data) with local open data provided by national entities and scientific institutes.
- the general public can contribute by capturing data in their territories to improve the precision of the analysis.

3. Study Area

The study was focused on landslide susceptibility mapping in Badulla District, which is situated in the Uva province between 6º 59' 05" of North latitude and 81º 03' 23" of the East longitude of Sri Lanka, using causative factors and application of FR and WoE models. The district covers about 2871 sq. km of land area with altitudes varying from 50 to 2530 m above sea level.

Most of the land area is mountainous, with the growth of population, there is an increasing demand for the lands and utilization of land. Most of the landslide incidents occur due to heavy rainfall. The area can be classified into two main geographic regions. These are the upper region and the lower region. In this area, the slopes are ranging from flat slopes on the top to steep slopes in mountainous areas. Slopes in these areas which are close to the streams are steep to vertical and susceptible to erosion and landslide phenomena. The presence of steep scarps, rugged slope faces, and steep ridges showed that this area is prone to active surface processes and landslide incidences. Based on elevation, the climatic zones of the study area can be identified as such. There is great variation in the rainfall amounts with maximum rainfall occurring during the fall of the year with the heaviest rainfall occurring during the months of October and November.



4. Methodology

To achieve the above-mentioned objectives of this project, data collection and organization, preparation of landslide inventory datasets, database construction of landslide causative factors, and application of WoE models were carried out to prepare the landslide susceptibility maps. After that those models were s]used for the validation process.

Here we focused on two main sectors.

1. Rainfall at the moment

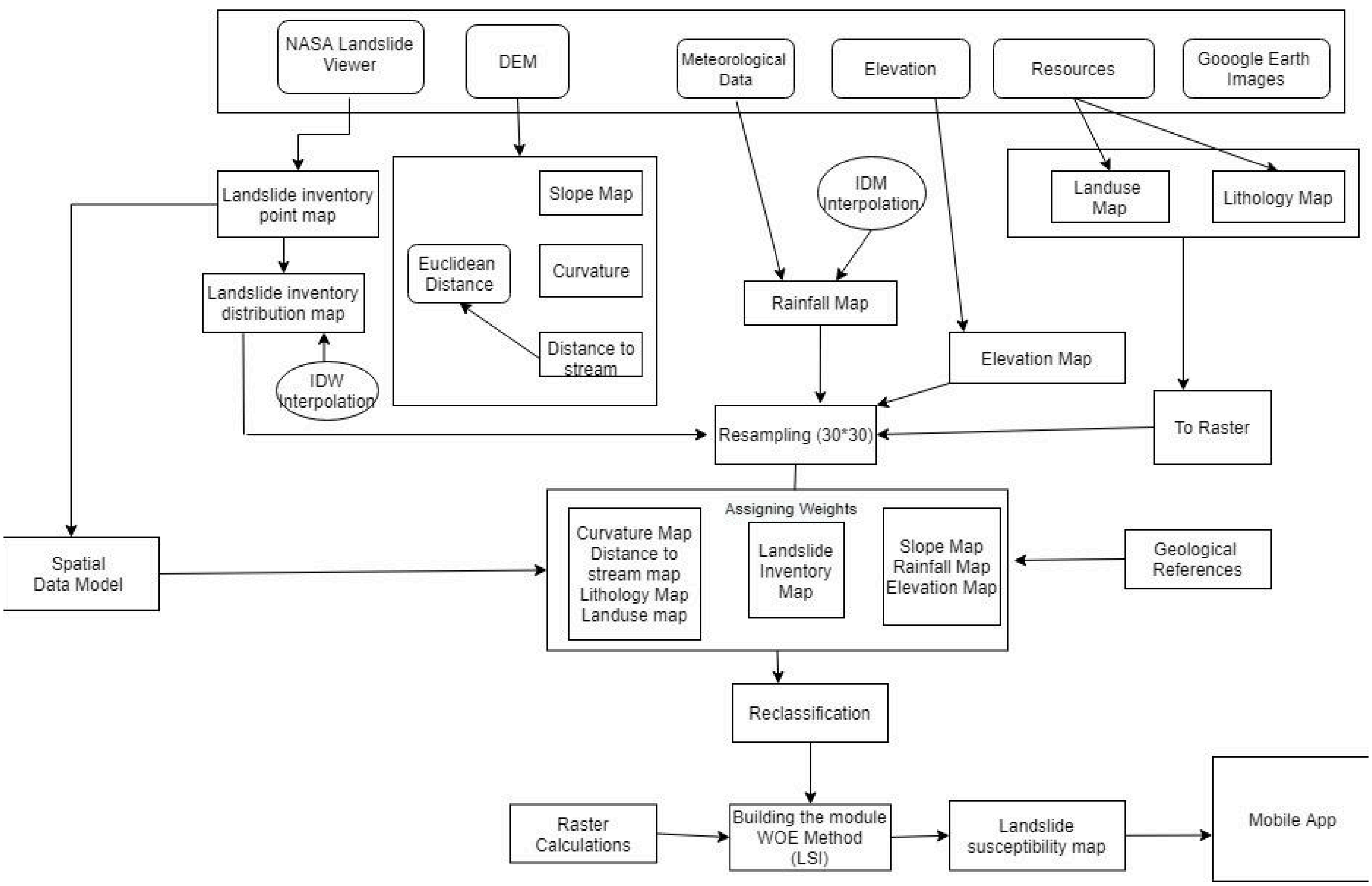
Here, the current rainfall condition and the duration of rainfall. Then, calculate the occurrence probability of landslides because of rainfall(Using a machine learning model).

2. Conditions of the land

Here, we considered whether the landslide causative factors related to the surface met the relevant condition to cause a landslide by the use of a susceptibility map (WoE model).

Using the conditional probability of the above sectors, the threat level was predicted.

4.1Landslide Susceptibility Map



First, coordinates of locations where landslides happened in the Badulla area were collected. This was done using NASA landslide viewer. Next, the inventory point map was created. After that, a landslide distribution map was created using the IDW method because it was difficult to find a polygon map of the relevant area.

By the use of digital elevation model, distance to stream, slope & curvature maps were created. Meteorological data were used to create the rainfall map. Google earth images were used to create the land use map. A lithology map was created by referring to data of ORR associates. Using elevation data elevation map was created. Land use & lithology maps were converted to raster. All the maps were resampled for 30m spatial resolution. Weights were assigned accordingly. In curvature, land use, lithology, distance to stream maps weights assigned using spatial data module. Geological data were used to assign weights of slope, rainfall, elevation maps. The reclassification was done using those weights. Finally, a landslide subspeciality map was created using LSI. Then it was converted to Jason & used in the mobile app.

- GIS primary data & analysed data(factor maps, final risk map, screenshots):-

  https://github.com/ishancoderr/Landslide_-Identifier

4.2 Mobile Application

Machine Learning model

Data got by following links:

Resourse_1

Resourse_2

Resourse_3

Data preprocessing: Preprocessing_Link

Make Logistic regression and make model and get it as tflite file :ML model and covert to tflite file Link

Mobile application developed by using flutter.

This machine learning model and Geojson file are included in the app for calculation purposes.

Positional data ,Rain hours and condition of the rain(ex: heavy rain,lite rain) got as user inputs.then calculate rainfall how enough for landslides occurring (probability using machine learning model). Check user in which risk area (ex : Low risk ,High Risk).After that previous probability modified with land Risk probability.

Then It shows the user.

Further modification : App will suggest safe area directions to users.

Mobile app github link: Siren mobile app

5. Procedure

5.1 Data collection and organization

The necessary data for this project were collected from various sources. The methodology was proposed after referring to some collected relevant literature from published and unpublished papers. Landslide-related factors include three aspects such as topographic factors, water-related factors, and human being activity factors. From those following; slope range, aspect, distance from rivers, distance from roads, land use, lithology were selected as the landslide causative factors in the present study.

DEM data from Google Earth Engine, rainfall data from climate-data.org, lithology data from ORR & Associates, and Google Earth image from Google Earth for land use. Through lithology maps, data collection was carried out on different rock types & their characteristics. The relative degree of weathering, slope steepness, location of springs and swamps were collected. Landslide inventory mapping on both active landslide and scarp areas by measuring their dimensions with accumulation zone, land use and land cover, land user activities including farming & construction.

A prior investigation was done by gathering data through a questionnaire among the community in the Badulla area to have an idea about current land conditions & difficulties they have to undergo due to landslides. The data has been systematically processed and analyzed first in ArcGIS followed by Microsoft Excel and then finally in ArcGIS. Lithology data were converted through Geo Mapper before that.

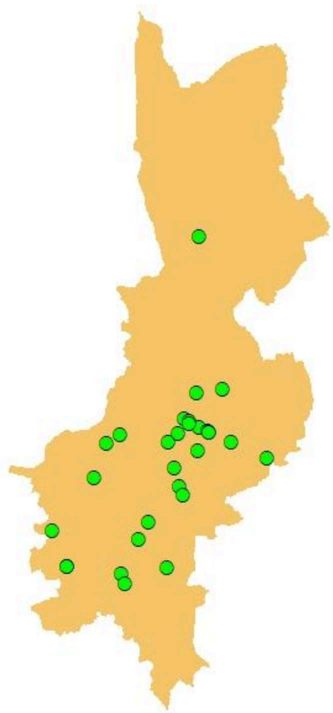
5.2 Preparation of landslide inventory dataset

The following factors concern the quality of the landslide inventories; the accuracy, type, and certainty of the information shown in the maps. With advanced mapping methods in satellite, aerial and terrestrial remote sensing technologies, we can have desired updates of landslide maps.

The dataset used in the landslide inventory dataset in this project was which were identified from NASA Map App Gallery after necessary image interpretation was done and questionnaire was shared among citizens around the Badulla area. For landslide susceptibility mapping landslide polygons can be divided into training and validation datasets.

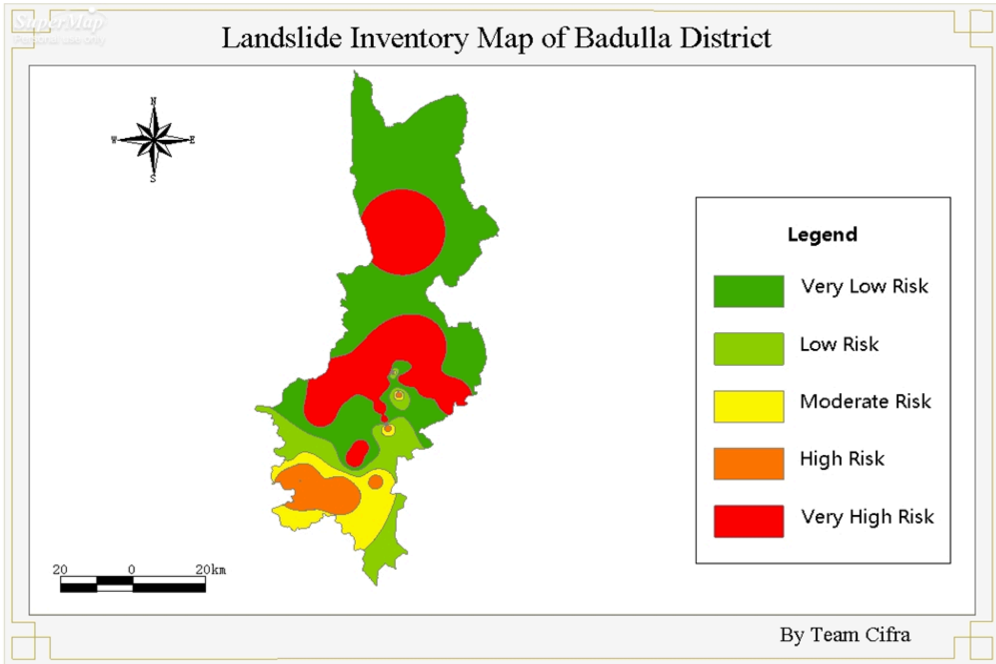
- Training dataset is used for constructing the predictive model
- Validation dataset is used for validating the model

validation by taking their spatial distribution into consideration. Here, landslide polygons were randomly split into two classes with 80% for training and 20% for validation by taking their spatial distribution into consideration.



Inventory Data - Point: NASA Map Gallery

Inventory Map



IDW Interpolated Inventory Map

5.3 Database for landslide causative factors

When it comes to landslide susceptibility analysis in the Badulla area, a spatial database was first constructed for the causative factors mentioned before, within the spatial analysis tools of ArcGIS 10.8 software. The database consists of the landslide training and validation inventory datasets and the landslide causative factors:

- Slope
- Curvature
- Land use
- Elevation
- Lithology
- Rainfall
- Distance from the stream

By calculating the weights of these factors, the evaluation was done. Instead of strict rules regarding the triggering factors for landslide susceptibility mapping, the chosen factors should be operative and measurable depending on a particular area's characteristics. In most cases, a combination of landslide causative factors may be effective in addition to the triggering factor for landslide occurrence instead of considering only one factor.

Here, heavy and prolonged rainfall is the triggering factor. Landslide locations were identified with reference data and community survey, land use types around the landslide scar, spring locations, lithology, and human activities were investigated for purpose of preparing the landslide susceptibility maps.

Selection of landslide causative factors was done considering the nature of the study area and the availability of data. Seven parameters were selected including slope, aspect, curvature, lithology, rainfall, land use, and distance to stream. All causative factor maps were converted into raster maps with the same coordinate system (WGS 1984 UTM) and the same pixel size(30mx30m).

To extract the information from maps the rasterized training (80%) landslide map and all the causative factor maps have been overlaid using the spatial analyst tool of ArcGIS. By using that calculation the ratings or weights of all factor classes for WoE models were done. The summation of these ratings or weights of each landslide factor will help to evaluate the spatial relationship between them. The probability of landslide occurrence in the study area can be measured using them.

Parameters related to topography like slope, aspect, curvature and distance to stream maps were derived from DEM with a cell size of 30 m by 30 m. Lithology and land use maps were prepared from intensive fieldwork and Google Earth image interpretations. The rainfall map was generated using the IDW interpolation technique of the spatial analyst tool in ArcGIS.

5.4 Landslide causative factors

These causative factors on the spatial distribution of landslides are very important in understanding the landslide mechanism and productivity of the landslide susceptibility map.Spatial Data Modeller Tool was used to assign the weights of each classes in curvature,lithology,distance to stream and landuse maps. Geological references were used for other maps.

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Factor	Resource	Weights
Landslide Inventory	NASA Landslide Viewer	20
Rainfall	Climate Data Org	25
Elevation	Diva-GIS	10
Slope	DEM	15
Curvature	DEM	7
Lithology	ORR & Associate	8
Distance to Stream	DEM	10
Land Use	Google Earth	5

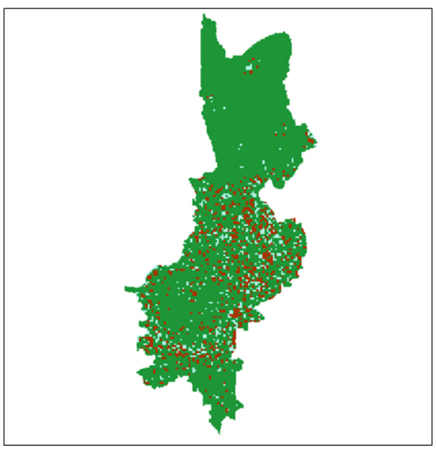
5.4.1 Slope

One of the important parameters for landslide study has a direct relation with landslide occurrence. It is frequently used in preparing a landslide susceptibility map. It is well known that landslide occurs more frequently on steeper slopes due to gravity stress. The slope map of the study area was prepared from DEM data.

This map was classified into five subclasses: 0-2.3, 2.3-5.6, 5.6-9.3, 9.3-15.2 & >15.2 degrees.

Slope	
Range(degrees)	Values
0.0 to 2.3	1
2.3 to 5.6	2
5.6 to 9.3	3
9.3 to 15.2	4
15.2 to 90	5

Slope Map



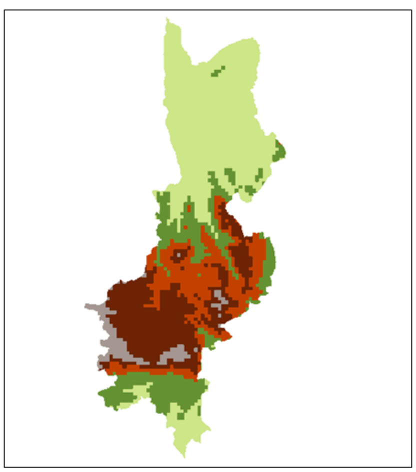
Styl...	Unique Value	Title
	1	Concave
	2	Convex
	3	Flat

5.4.2 Curvature

The curvature map of the study area was generated from DEM data and it was classified into 3 classes of concave, convex, and flat surfaces. A convex or concave slope contains more water and retains this water for a longer period during heavy rainfall. The flat area shows that the probability of landslide occurrence is very low. Curvature can be positive or negative. A positive curvature indicates that the surface was upwardly convex at that grid. A negative curvature indicates that the surface was upwardly concave at that grid. Also, the value of zero indicates that the surface is flat.

Curvature Map	
Type	Values
Flat	1
Convex	2
Concave	3

Curvature Map



Styl...	Unique Value	Title
	1	0m-312m
	2	313m-660m
	3	661m-1029m
	4	1030m-1431m
	5	1432m-2203m

5.4.3 Distance to stream

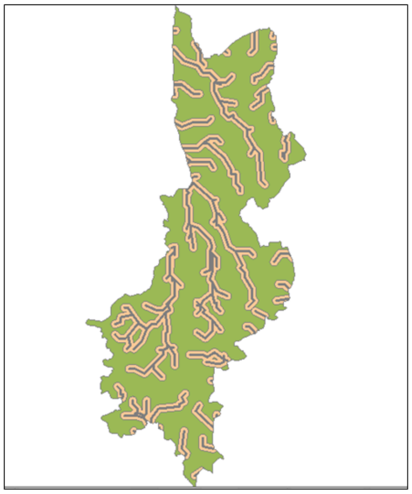
This factor dictates the landscape evolution of the area. Also, this indicates the landslide and related erosional aspects. Rivers with a number of drainage networks have a high probability of landslide occurrence as they erode the slope base and saturate the underwater section of the slope forming material (Akgun and Turk 2011).

Therefore, this parameter was considered as one of the factors in landslide susceptibility analysis. Streamlines were also extracted from DEM data and it was classified based on stream order.

This map was classified in to five subclasses: 0 – 50, 50 – 100, 100 – 150, 150 – 200 and > 200 meter.

Distance to stream Map	
Range(meters)	Values
150 to 200	1
100 to 150	2
50 to 100	3
0 to 50	4
More than 200	5

Distance to Stream Map



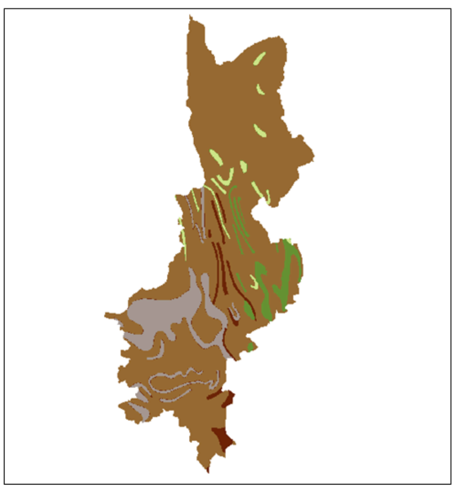
Styles	Unique Value	Title
	50	50
	100	100
	150	150
	200	200
	1000	1000

5.4.4. Lithology

Lithology is one of the most controlling parameters in slope stability. Surface composition and structure contribute directly to the strength of the slope material. The stronger rock units give more resistance to the driving forces as compared to the softer ones. A lithological map of the study area was prepared from the existing regional geological map.

Lithology Map	
Range(mm)	Values
Weathered tuff/bawalt	1
Rhyolite/trachyte	2
Residual	3
Colluvial	4
Alluvial	5

Lithology Map



Styl...	Unique Value	Title
	1	weathered Tuff
	2	Rhyolite/Trachytc
	3	Residual
	4	Colluvial
	5	Alluvial

5.4.5 Rainfall

Rainfall is considered as the most triggering influencing factor to cause slope instability. Intense and prolonged rains are controlling factors that trigger landslides by providing water. Thereby increasing underground hydrostatic levels and pore water pressure. When such pressure changes happen, water within it will create negative or upward pressure, which makes them unable to drain quickly.

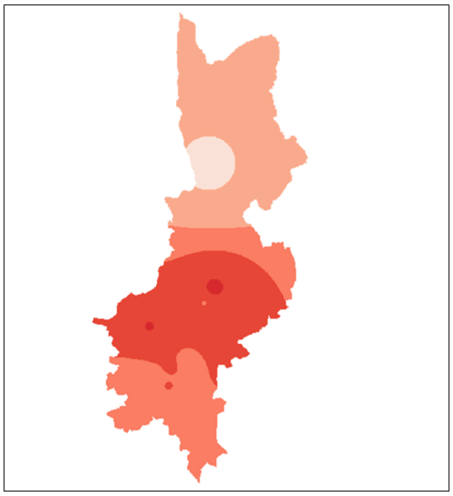
There are various interpolation techniques in ArcGIS that can be used in interpolating rainfall in a large area based on few point data(Thiessen polygon, Isohyetal, average arithmetic, inverse distance weight (IDW), and Kriging). IDW method works under the assumption that the value of an unsampled point is the weighted average of known values within the neighborhood. Hence, a scattered set of known point values can be used in assigning rainfall values to unknown points.

It can be used to compute the unknown spatial rainfall data from the known areas that are adjacent to the unknown areas. The rainfall data analysis showed that the average monthly rainfall occurs in monsoon seasons which coincides with the landslide occurrence in this area.

This map was classified into five subclasses: 0.0-72.9, 72.9-90.1,90.1-95.9, 95.9-100.1, >100.1 mm.

Rainfall Map	
Range(mm)	Values
0.0 to 72.9	1
72.9 to 90.1	2
90.1 to 95.9	3
95.9 to 100.1	4
100.1 to 150.7	5

Rainfall Map



Styl...	Unique Value	Title
	1	0.0mm-72.9mm
	2	73.0mm-90.1mm
	3	90.2mm-95.9mm
	4	96.0mm-100.1mm
	5	100.2mm-150.7mm

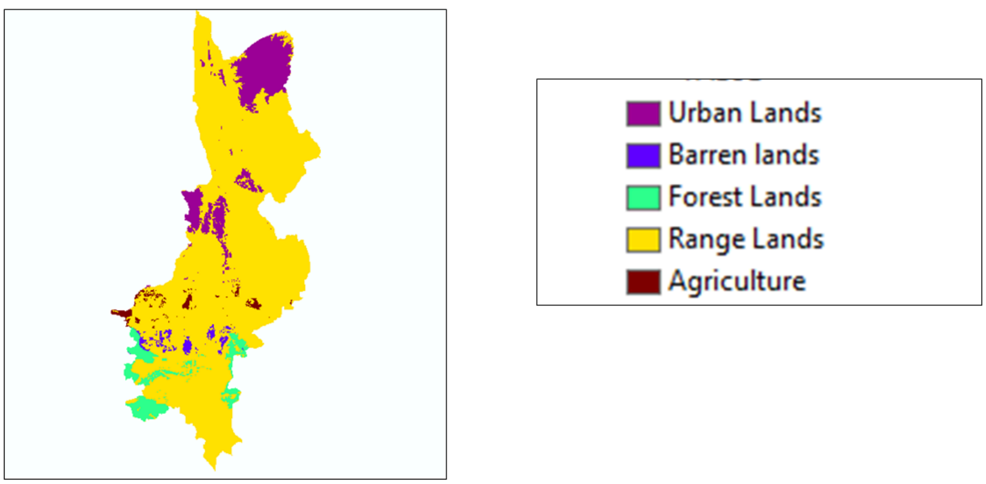
5.4.6 Land use

Land-use change is one of the most important factors influencing rainfall-triggered landslides. Human activities like deforestation, overgrazing, intensive farming, and cultivation on steep slopes can change land cover which causes slope instability. Vegetation does a major impact in resisting slope movements. Vegetation has a well-spread network of root systems. These root systems increase the shearing resistance of the slope material because of the natural anchoring of those slope materials.

Vegetation also reduces the action of erosion and adds to the stability of the slope. This also means that the barren or sparsely vegetated slopes are exposed to erosion and & make an effect of increasing slope instability. This land-use map was prepared from the Google Earth image of 2020 and the analysis was done in ArcGIS. About seven land-use types were identified including moderate forest land, urban land, rangeland, agricultural land, and barren land.

Land use Map	
Feature	**Values**
Urban Lands	1
Forest Lands	2
Rangelands	3
Barren Lands	4
Agriculture	5

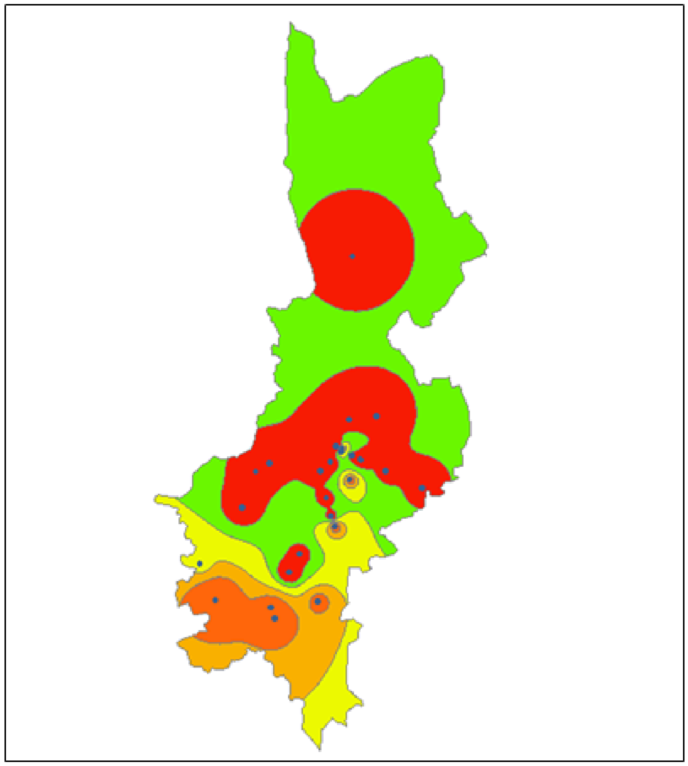
Landuse Map



5.4.7 Elevation

The elevation of a geologic location is the height of below or above a fixed reference point. Elevation effects for landslides. We can implement the mobile application for user input elevation.

5.4.8 Inventory Map



5.5 Weights of evidence (WoE) model

WoE model is a log-linear form of the probability model for landslide susceptibility assessment that uses landslide occurrence as a training point to drive prediction outputs. It calculates both the unconditional and conditional probability of landslide hazards.

Factor	Resource	Weights
Landslide Inventory	NASA Landslide Viewer	20
Rainfall	Climate Data Org	25
Elevation	Diva-GIS	10
Slope	DEM	15
Curvature	DEM	7
Lithology	ORR & Associate	8
Distance to Stream	DEM	10
Land Use	Google Earth	5

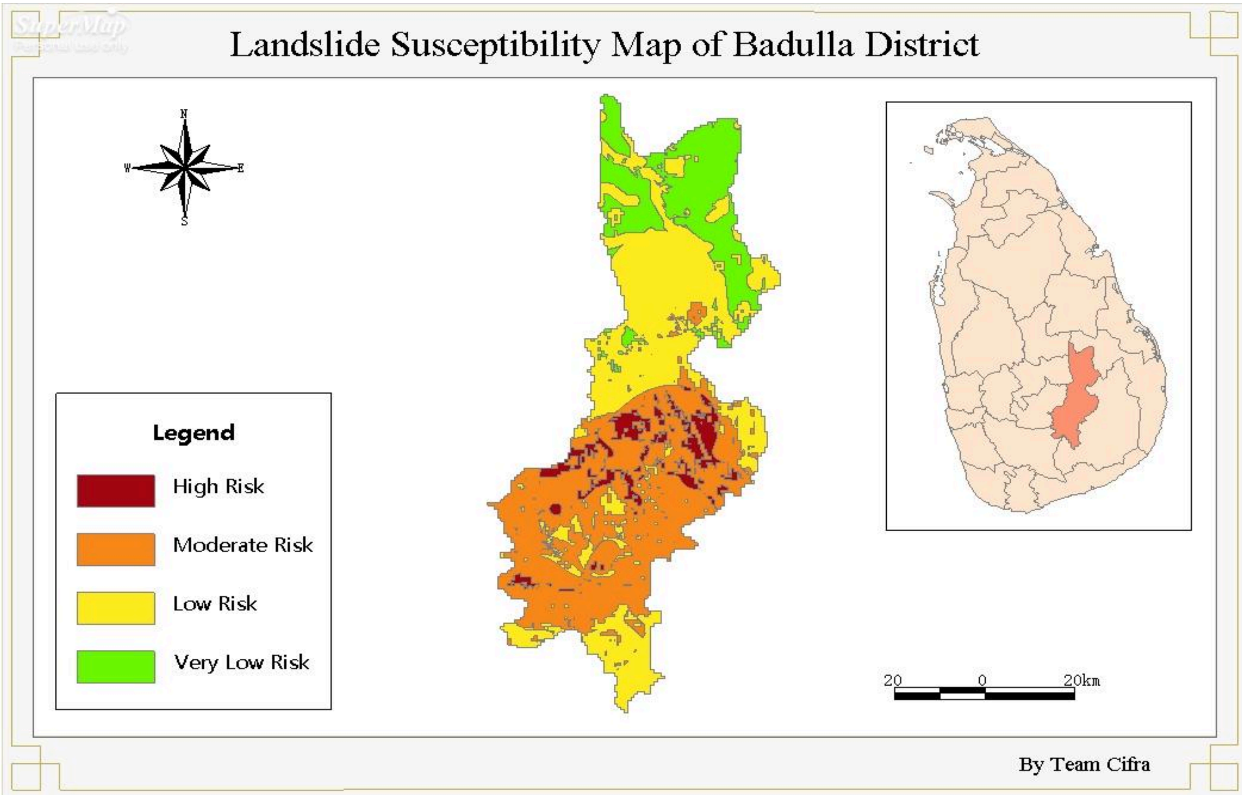
Landslide Susceptibility Index (LSI)

In the LSI model, reclassified factor maps were overlaid and weights ranging from 0% to 100% were assigned to each factor. For this study, the weight values were assigned based on the percentage of landslides in the highest ranked category of individual factors. This information was transferred in the GIS database and the Raster Calculator of the spatial analyst tool was used to calculate LSI as shown in the equation.

$$LSI= \frac{((w1*x1)+(w2*x2)+(w3*x3)+(w4*x4)+(w5*x5)+(w6*x6)+(w7*x7)+(w8*x8))}{8}$$

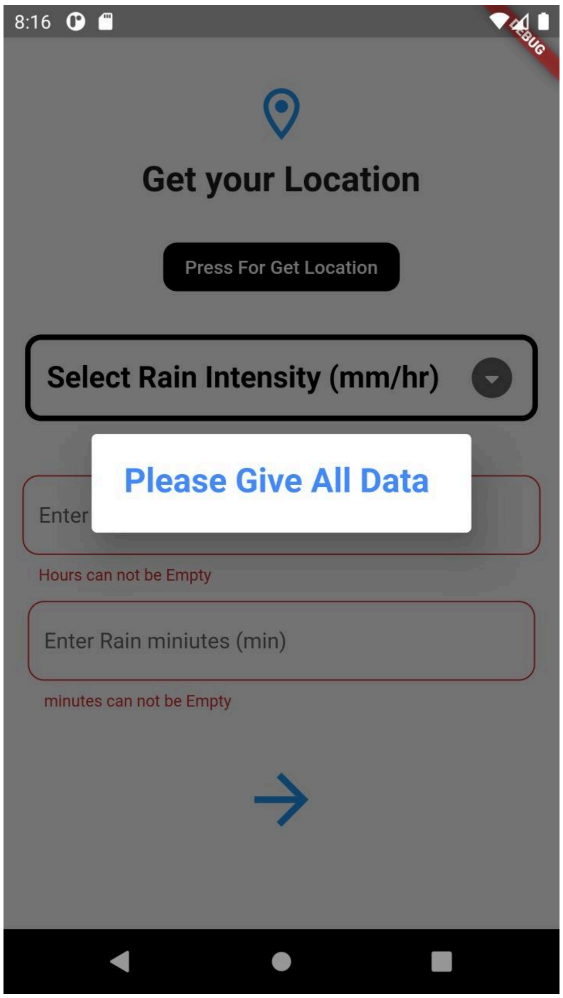
Where, Wi(i=1 to 8) are the weights of the classes (factors), Xi (i = 1 to 8) are the categories of the factors, and 8 is the number of factors. Finally, LSI was classified into susceptibility categories (very low, low,moderate and high). This type of model should be modified carefully depending on the local variability in geology, hydrology, landuse pattern, etc.

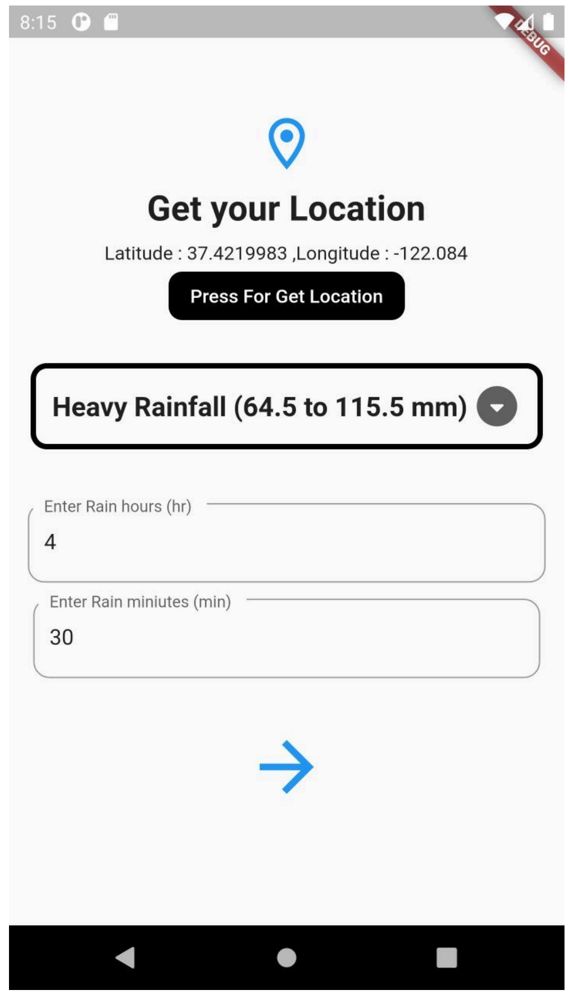
5.6 Landslide Susceptibility Map

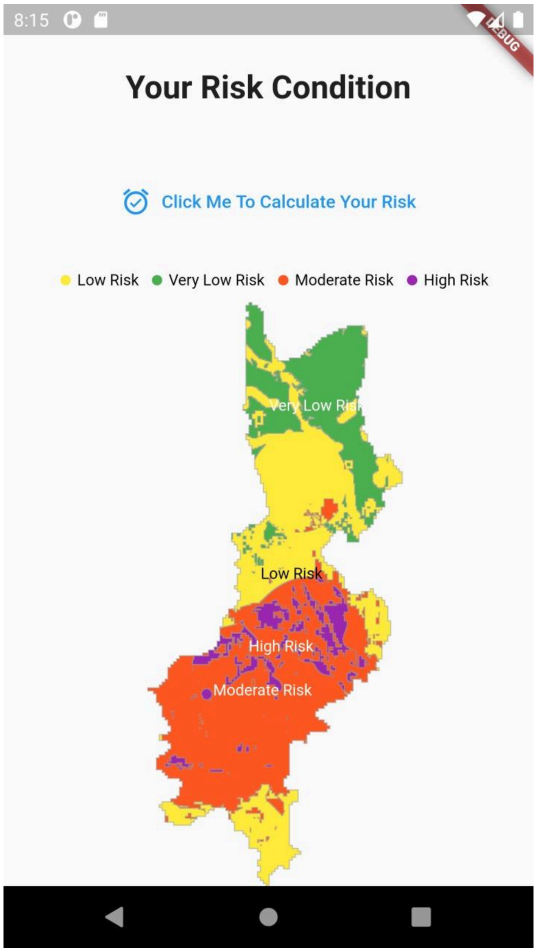


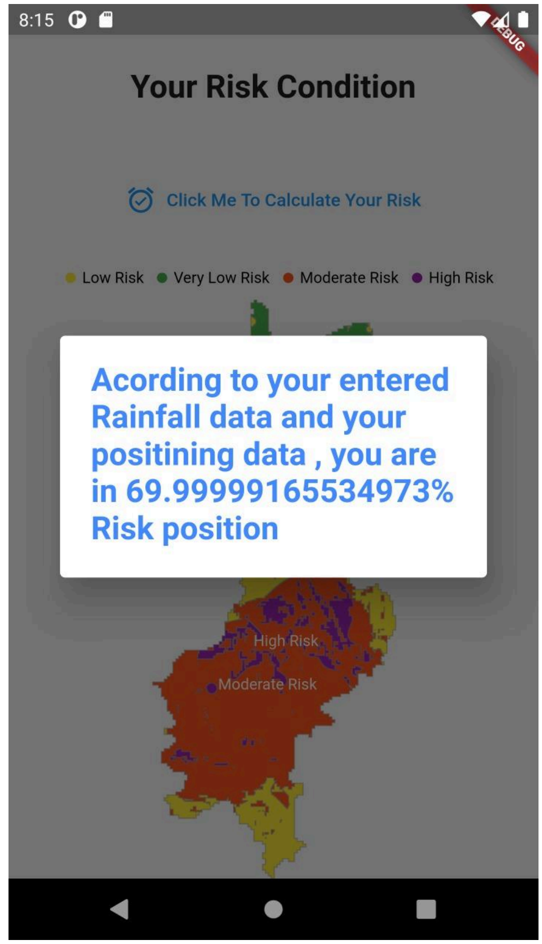
- Landslide susceptibility Map was used for mobile application as follows.

5.7 Mobile Application









Mobile app demo click here

Project demo click here

6.Further developments

- Give directions to a safer location after creating a GIS network map of low risk areas & connect them with our mobile application.
- Display data regarding past hazard scenarios which enables users to be aware of the seriousness of the situation.
- Enable the users to report a hazard through our application which can be used in future implementations.
- Automatically notify the user about risk level

7.References

- GIS Data:-https://www.diva-gis.org/gdata
- World Landslide:-https://gpm.nasa.gov/landslides/resources.html
- Landslides:-
  - https://pmm.nasa.gov/applications/global-landslide-model

    https://gportal.jaxa.jp/gpr/?lang=en
  - https://www.usgs.gov/natural-hazards/landslide-hazards/data-tools
  - https://earthdata.nasa.gov/