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ASSESSMENT OF LANDSLIDE SUSCEPTIBILITY: A CASE STUDY OF CARABAO MOUNTAIN IN BAGUIO CITY

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ABSTRACT: Baguio City is one of the most visited places in the Philippines especially during the summer season. Due to its topography, soil characteristics, land use classification, and exposure to different calamities immense rainfall, Baguio City is prone to landslide. Lack of information and warning system regarding rainfall puts a challenge to decrease casualties and losses. The Carabao Mountain located in the north-left portion of Baguio City is chosen as the case study area because it is the most populated area. The degree of saturation of the soil and the imposed loading due to land use are considered as the main external factors for assessing the stability of earth slopes. Mohr-Coulomb failure criteria parameters are used in the determination of the initial factor of safety. Using different scenarios, a general factor of safety is obtained and then used to develop a landslide susceptibility map. The loading imposed by land-use developments such as settlement and road networks induces a great impact on the weight carried by the underlying soil which results in a greater decrease of the factor of safety. The impact of the saturation as an added weight to the soil is lower as compared to the loading of structures. The general factor of safety indicates that as the degree of saturation of soil increases, the moderate susceptible area increases, and some are close to a high susceptible degree with a factor of safety close to a value of 1, which is located at residential zone.

Keywords: Degree of saturation, Factor of safety, Land use, Landslide, Slope stability

1. INTRODUCTION

The City of Baguio is popularly known as the Summer Capital of the Philippines. It is a highly urbanized city in the Northern part of Luzon in the Philippines. Baguio City is nestled on Cordillera Mountain Range with elevation ranging from 900 to 1,600 m above sea level. Due to its geographical location in a very high plateau, Baguio is commonly exposed to storms and heavy rainfalls. With such, a landslide is very prevalent in the City. Shown in Table 1 is the list of reported landslide incidents during typhoons according to City Disaster Risk Reduction and Management Council (CDRRMC) of the City of Baguio.

Landslide is a hazard that causes properties to massive damage, and sometimes the cause of life loss. Landslides may be induced or triggered by other natural activities such as immense rain or earthquake. During storms or heavy rainfalls as well as during earthquake, landslides are prevalent to the City of Baguio, which causes the thoroughfare to stop their operations and cause damage to different properties. The closure of road arteries put a challenge in the supply of food and other commodities of the city which causes establishments to close.

Landslides cause damage to buildings, infrastructure, agricultural land, and crops. Landslides and slope stability are two important issues to consider in planning cities located in mountainous regions. Rainfall-induced landslide hazard has been growing all over the world, due to the fast population increase, often accompanied by uncontrolled urban sprawl [1]. In regions where urban residential areas coincide with mountainous terrains, the risk is higher for people and the economic costs include relocating communities, repairing physical structures, and restoring water quality in streams and rivers [2].

Landslide is one of the causes of deaths in the city during calamities. The susceptibility to a landslide of areas is high due to the formation of the terrain, type of soil, as well as changes in land use. Lack of information and warning system regarding rainfall puts a challenge to the fight to decrease casualties. Susceptibility maps that may be used as tools for predicting the movement of soil for warning system implementation will be needed.

Baguio City is prone to landslide due to its topography, soil characteristics, land use, as well as a natural factor such as rainfall. The Mines & Geosciences Bureau of Cordillera Administrative Region (MGB-CAR) of the Department of the Environmental and Natural Resources (DENR) provides GeoHazard Map that will present the susceptible areas to landslide with consideration of assessment parameters. The assessment was done with the geologists' perception of the defined tools. Upon the evaluation of the existing parameters, the assessment tools lack the technical aspect, specifically the inclusion of soil strength parameters, and some relevant triggering mechanisms such as the land use of the area, and the development of the saturation of soil due to the immense rainfall.

Table 1 Landslide statistics during typhoons in Baguio City according to CDRRMC

Typhoon (Local)	Date	Landslide
Florida	July 11 – 14, 2006	53
Emong	May 13, 2009	1
Kiko	August 10, 20019	2
Pepeng	October 02 – 04, 2009	97
Juan	October 15 – 21, 2010	2
Mina	August 26 – September 02, 2011	16
Pedring	September 26 – 28, 2011	3
Gener	July 28 – August 03, 2012	10
Labuyo	August 09 – 13, 2013	5
Luis	September 15, 2014	1
Mario	September 18 – 22, 2014	26
Ineng	August 20 – 24, 2015	5
Lando	October 14 – 23, 2015	80

With these considerations, this study investigates if a slope is susceptible to failure using soil parameters related to slope stability and will incorporate the additional assessment tools, which will improve the existing susceptibility map. In addition, the landslide susceptibility levels and the areas that are of high susceptibility levels during massive rainfall is identified.

This study is geared to create an assessment tool for rainfall-induced landslide and identify the landslide susceptible areas at Baguio City for planning and preparedness. To attain this goal, the stability of the identified sloping areas was assessed and evaluated considering the geotechnical characteristics of the ground and incorporating other triggering factors like the saturation of the soil due to rainfall, presence of vegetation, and land use-imposed loading. Using a Quantum Geographic Information System (QGIS), a free and open-source GIS program, a landslide susceptibility map is developed for rapid assessment.

2. RAINFALL INDUCED LANDSLIDES

Slope failures occur frequently during or following a period of heavy rainfall [3]. The infiltration of rainwater causes a reduction in this negative pore water pressure and an increase in the soil unit weight (due to an increased saturation [4]), both of which have a destabilizing influence to the stability. The rainfall-initiated landslides continue to inflict damages and take the lives of many people at any place throughout the world. According to [5], the rainfall-initiated landslides involve highly dynamic hydrologic, earth surface, and ecological processes that persist over a range of spatial and temporal scales. However, the guidance for overcoming these challenges has been elusive. Based on the study of [6], the process for quantitative risk assessment are seepage analysis, slope stability assessment, and risk assessment. The triggering mechanisms for a rainfall-induced landslide have also been highlighted by the pore water pressure distributions at failure [6]. When the pore water pressure reaches a critical state, the effective shear strength of the soil diminished, inducing the formation of landslide [7].

3. LANDSLIDE SUSCEPTIBILITY ASSESSMENT

Numerous methods and practices such as frequency ratio, logistic regression, spatial regression, geographically weighted regression, and analytical hierarchy process, ordered weighted averaging, fuzzy logic and artificial neural networks [8] are used as landslide assessment tools.

The stability index is defined as the probability that a location is stable assuming uniform distributions of parameters over the uncertainty ranges. It does not predict that shallow translational slope movements will occur, but it forecasts that if they do, where they are more likely to initiate given the assumptions and input parameters used in the analysis [3].

According to the study of [9], an approach for establishment of an analytical risk assessment model to evaluate the risk index for soil erosion by water is proposed, in which the remote sensing, GIS, the analytical hierarchy process (AHP), and modeling techniques are integrated through investigation of soil erosion by water. The risk assessment model constructed through this approach in this study can be consistently used for the understanding of the risk or potential of soil erosion by water, under either current site conditions or assumed certain changes of pertinent dominating factors, in a large area of interest.

The study of [10] aimed to develop a landslide model by using GIS and remote sensing techniques for landslide susceptibility mapping. The study employs several parameters with weights that are assigned according to the potential cause of the landslide.

The studies investigated and analyzed the selected areas with different methodologies in generating the tools in identifying the state of a slope. This considers assessment scores to generate the stability score of the areas investigated. These studies served as a guide in generation and improvement of the slope stability assessment tools and scores in this study, which will be used together with slope stability analysis.

4. GEOHAZARD ASSESSMENT OF BAGUIO CITY

With the expertise and perception of the trained Geohazard Assessment Team of MGB-CAR, it was limited to the barangays and other areas of the recent typhoon and dependent on the eighty-three observation stations in landslide-prone areas. This assessment is the basis for the formulation of the existing geohazard (landslide) map of the City of Baguio as shown in Fig. 1.

The shown map is based on slope gradient, ground stability based on historical events only and visual inspection, human initiated effects, basic soil mass characterization and strength, and basic rock mass characterization and strength. The susceptibility is classified as low, moderate, high, and very high.

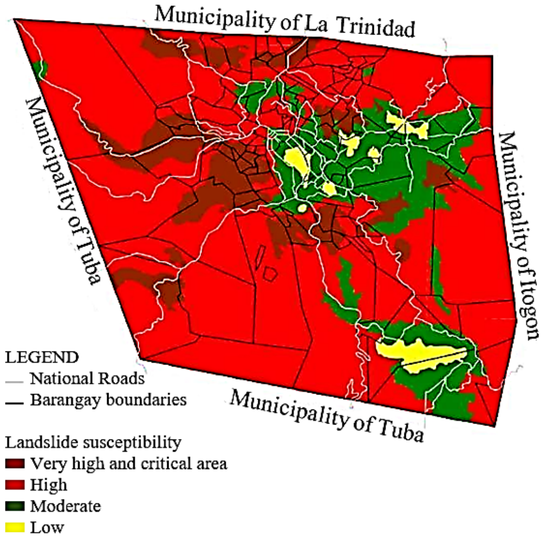


Fig. 1 GeoHazard map of Baguio City [11]

5. RAINFALL WARNING SYSTEM

A warning system was established by the Philippine Atmospheric, Geophysical, and Astronomical Service Administration (PAG-ASA) for monitoring, alert, and evacuation purposes. This system is presented in three different colors based on the rainfall intensity which are presented in Table 2. These new color-coded advisories aimed to help the communities and concerned government agencies prepare for floods, landslides, and dam spills.

Table 2 PAG-ASA Warning system.

Color Code	Rainfall Intensity, mm/hr	Rainfall Type	Remarks
Yellow	7.5 to 15.0	Heavy	Monitor
Orange	15.0 to 30.0	Intense	Alert
Red	> 30.0	Torrential	Evacuation

6. METHODOLOGY

The study employed descriptive and analytical research. Descriptive research was used to describe, classify, measure and compare the present state of the area for the identification of scores for the different assessment tools. Analytical research was used to analyze the current situation of the area and make a critical evaluation as to the susceptibility of the area to landslide based on the assessment tools.

6.1 Population and Locale of the Study

Baguio City occupies about 57 square kilometers of hilly land in the southwestern portion of the Cordillera Central mountain range in northern Luzon in the Philippines. The weather follows the typical Philippines' seasons: Dry Season from October to May and Wet Season from June to September.

The research covered the north - left portion of the Central Business District of the City of Baguio, since these areas are of high density and prone to landslide as per CDRRMC of Baguio City as shown in Fig. 2. This area is popular by its name as the Carabao Mountain which was intended to be the pastureland of the Camdas Clan. The portions of the Carabao Mountain considered are Quirino Hill and Pinget area which is limited by the yellow boundaries.

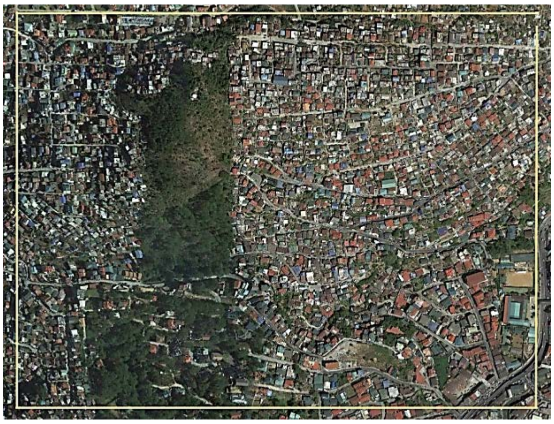


Fig. 2 Carabao Mountain, Baguio City

As of 2015 census as per Philippine Statistics Authority - Cordillera, Baguio has a population of

345,000 which is about 20 percent of the region's population. The population density during that time is about 6,005 persons per square kilometer. The average annual population growth rate is 2.36 [12].

6.2 Research Design

The study evaluated the state of the slope with the aid of a computer program and incorporating the effects of triggering factors. Figure 3 summarizes the research design of the study. The geotechnical data was requested from BIP Steadfast Grounds Inc. The topographic map was issued by the City Planning and Development Office.

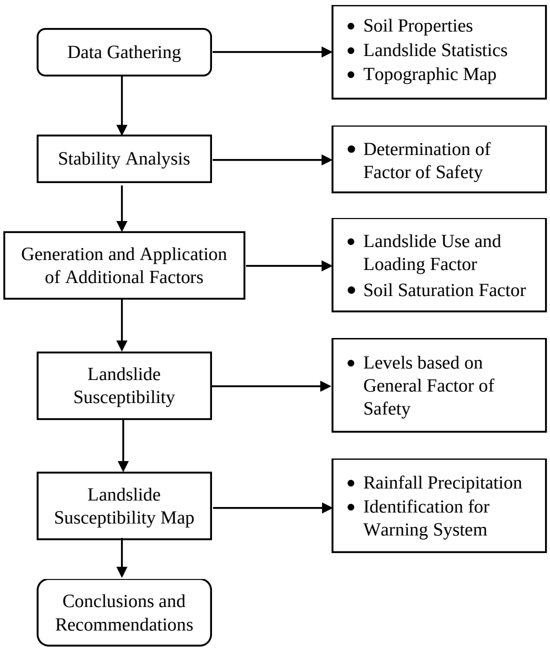


Fig. 3 Research design

6.2.1 Slope Stability Analysis

The SPT was used in predicting the value of soil shear strength parameters namely, cohesion and angle of internal friction. The data was processed and analyzed using a deterministic slope stability software considering the Mohr-Columb Failure Criteria. The slope was analyzed whether it is safe or susceptible to a landslide. The input parameters are the cohesion, angle of internal friction, and unit weight of soil, as well as the topography of the slope. The stable slopes were further processed by considering other triggering factors in the form of landslide assessment additive factors.

6.2.2 Landslide Assessment Tools

The addition of loading will decrease the strength of soil, therefore the value of the factor of safety will decline. These additional factors are land-use change in the form of vegetation, settlement and roads, and rainfall which will increase the unit weight of soil due to saturation.

There are several methods available to weigh the evaluation criteria including direct ranking, swing weights ranking, rating, pairwise comparison, a trade off analysis, and qualitative translation. This study employed the use of an additional rating method.

The values of the additional factors were generated based on the difference of a factor of safety of the initial state of the slope and the slope affected by the triggering factors. These values underwent a regression process to identify possible relationships. The regression model defines the formula which determined the values of the additional factors for the tools which were used for the assessment.

6.2.3 General Factor of Safety, FS_G

The General Factor of Safety was obtained from the sum of the initial factor of safety from slope stability analysis and external factors as presented in Eq. (1). This was derived by the methodology employed by [10] which is the summation of the impact of every factor. The values were then evaluated to generalize the susceptibility levels of the area and compare it to Table 3.

$$\boldsymbol{FS_G = FS + L_i + S_i} \quad (1)$$

Where:

$\boldsymbol{FS_G}$ = General Factor of Safety
$\boldsymbol{L_i}$ = Land Use and Loading Tool
$\boldsymbol{S_i}$ = Saturation of Soil due to Rainfall Tool

Table 3 Susceptibility Levels

Factor of Safety	Color Coding	Susceptibility Level
1.5 ≤ FS	Yellow	Low Susceptible
1.0 ≤ FS ≤ 1.5	Orange	Moderate Susceptible
FS < 1.0	Red	High Susceptible

6.2.4 Landslide Susceptibility Map

The evaluated scores and identified hazard-prone areas at a different group of rainfall intensities criteria were digitized using QGIS for easier view and appreciation. The scale of the map was based on the proximity of the span of the test evaluation. An evacuation site was recommended based on the results. An evacuation site is sitting at the safe or almost flat zone that is free from landslide and accessible to different utilities and needs.

6.2.5 Rainfall Intensity and Warning System

The slopes ponding time and infiltration capability were determined based on the criteria of Green and Ampt parameters for the subsurface soil with a soil type that is ML or Silty Loam. The parameters were used to generate different values of ponding time and the saturation depth of the soil as the time of constant rainfall increases. The values were examined and compared with the PAG-ASA rainfall warning system for developing the warning systems which will be used for landslide susceptibility maps during rainfall, as well as the response guidelines by the CDRRMC.

7. RESULTS AND DISCUSSIONS

7.1 Soil Data

The data obtained from BIP Steadfast Ground Inc. includes standard penetration test (SPT) number, *N*, unit weight of the soil, γ, specific gravity, G_S, compression index, C_C, liquid limit, *LL*, plasticity index, *PI*, and moisture content, *w*, and percent finer than the No. 200 sieve. The data which were used for the study is the unit weight and SPT number which was used for calculating the cohesion and angle of internal friction. The type of soil in the area is ML which is classified as Silty Loam. The SPT data considered is about 1.5 m (5 feet) below the ground surface. Inverse-distance weighing interpolation method [13] is used to assume the soil data which represents the soil properties that are along the critical slope.

7.2 Land Use Assessment Additive Factor, L_i

The three different land-use factors that are considered in the study are vegetation (open space and with trees), road network, and settlement (buildings). For the generation of the factor, a 10 m tributary width for load distribution was considered. Shown in Table 4 are the factors used.

Table 4 Distributive Load for Land Use Impact and Land Use Tool (L_i)

Details	Distributive Load	L_i
Vegetation		
Open Space/grassland	0.0 kN/m	0.000
Pine Trees	141.9 kN/m	-0.081
Road Network		
Reinforced Concrete Pavement	67.2 kN/m	
Converted Truck Load	130.0 kN/m	
Total	197.2 kN/m	-0.136
Factored Residential Load (3 storeys)		
Dead Load	360.0 kN/m	
Live Load	91.2 kN/m	
Total	451.2 kN/m	-0.390

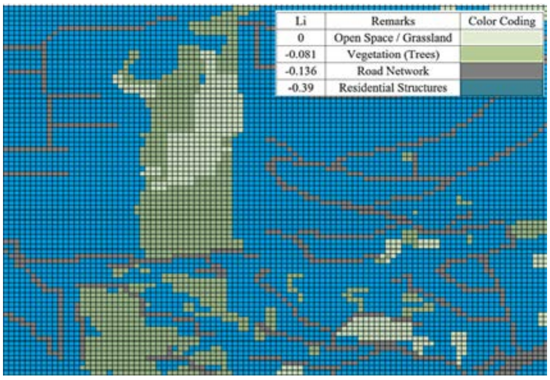


Fig. 4 Color coding based on land use

7.3 Saturation of Soil Assessment Additive Factor, S_i

The saturation of soil additive was based on the degree of saturation of the soil. With the preliminary values of soil parameters and computing the values of void ratio (e) and degree of saturation (S), the value of soil unit weight with different saturation was calculated which must be higher than the saturation level of the soils being considered that is about 70%. The factors for the degree of saturation is given in Table 5.

Table 5 Saturation of Soil Tool (S_i)

Degree of Saturation	S_i
70%	0.000
80%	-0.018
90%	-0.036
100%	-0.054

7.4 General Factor of Safety

Using Eq (1), the general value of the factor of safety combined with the external factors were identified. The addition of the land use additive was added first. By using the available satellite imagery by google earth, the portions of the different land use were established. This data was added to the initial factor of safety and to the different saturation levels of the soil.

The color coding established in Table 4 was used for the easier construction of maps. Majority of the area is safe, but as the saturation increases some are already exposed to danger since the value of the lowest factor of safety for saturation values of 70%, 80%, 90%, and 100%, are 1.061, 1.043, 1.025, and 1.007, respectively. The critical area or the area with the lowest factor of safety was highlighted in Figure 6 is at Barangay Pinget, Baguio City. Portions that are close to a value of one are already on the verge of failure, necessary precautions, and engineering interventions must be accounted for.

7.5 Susceptibility Map of the Area

The map was created using Quantum Geographic Information System (QGIS). Color coding specified in Table 4 was used to identify the level of susceptibility of the respective area.

Figure 5 is layered with the actual satellite map, presents the level of susceptibility of the area to landslide due to varying saturation of the soil. The areas that are still in yellow code are still safe. Some areas are near the critical value, which is 1 presented in orange color, therefore it needs caution when massive rainfall occurs.

Based map developed, the critical portion is a residential area, which is located at Barangay Pinget, Baguio City. If the area exceeds the assumed loadings, there will be a decrease in the factor of safety which will now result in soil slip failure, mass movement or landslide.

The area which is under moderate susceptibility is increasing as the value of saturation increases. The areas that are now susceptible to landslide are portions of Barangay Pinget and Barangay Quirino Hill in Baguio City.

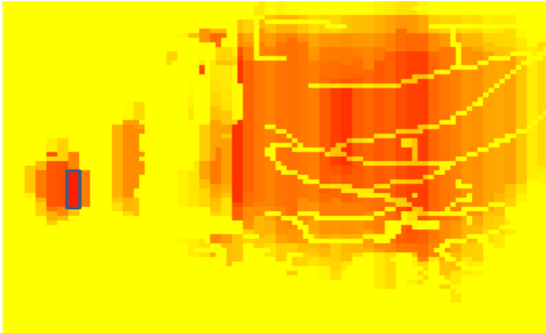
7.6 Time of Ponding for Different Rainfall Intensities

Based on the values of ponding time, the values for rainfall intensity which are 20 and 30 are 56.26 and 21.55 mins, respectively. It can be noticed that the time for the surface to be saturated is quite long before infiltration occurs.

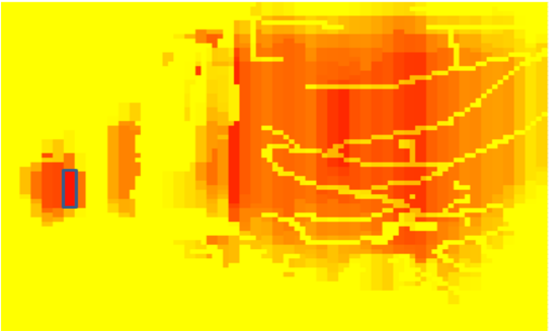
Comparing to the warning system of PAGASA, 15 to 30 mm/hr precipitation is under the orange rainfall advisory. On the other hand, the rainfall intensity which is 40 and above has a shorter period of ponding, thus, infiltration is accelerated.

According to [14], a continuous rainfall of 40 mm or over will cause slope failures. Comparing to the warning system of PAGASA, greater than 30 mm/hr precipitation is under red rainfall advisory. At this level of precipitation, the depth of soil under saturation state escalates as time increases, thus the early warning system of PAGASA might be adopted for the landslide warning system.

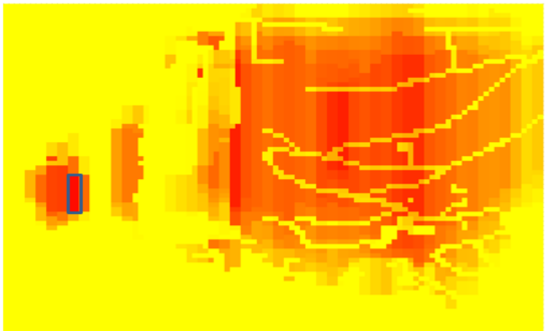
At 40 mm/hr or more rainfall, the soil will begin to saturate, therefore, the factor of safety of the soil will be the general factor of safety that considers saturated soil additive, which is presented as the saturated soil susceptibility map. At this rainfall precipitation, evacuation at the susceptible areas such as Barangay Quirino Hill and Portions of Barangay Pinget must be raised for the safety of the residences.



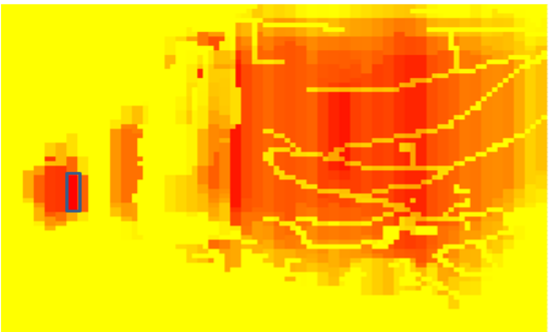
(a) Initial degree of Saturation (S = 70%)



(b) 80% degree of Saturation



(c) 90% degree of Saturation



(d) 80% degree of Saturation

Fig. 5 Color coding map based on the general factor of safety

8. CONCLUSION

This study was intended to predict the possible role of external factors such as land use and saturation of soil due to rainfall on the factor of safety of slopes which is the deterministic factor of stability of earth slopes. Based on the results, land use loading and saturation of soil reduce the shear strength of the soil thus reducing the factor of safety of the soil.

For rapid assessment, the study considered the land-use tool and saturation of soil tool. As factors to slope stability, these tools are additives to the initial factor of safety. The values of additives tools for land use and loading are 0, -0.081, -0.136, and -0.390 for open space/grassland, trees, road network, and residential structures, respectively for land use tools. The values of additive tools for saturation of soil are 0, -0.018, -0.036, and -0.054 with varing degree of saturation which includes 0.7 as initial, 0.8, 0.9, and 1.0.

The loading imposed by land-use developments such as settlement and road networks induces a great impact on the weight carried by the underlying soil which results in a greater decrease of a factor of safety that is about 0.39. The impact of the saturation as an added weight to the soil is lower as compared to the loading of structures since it only decreases the factor of safety to about 0.054.

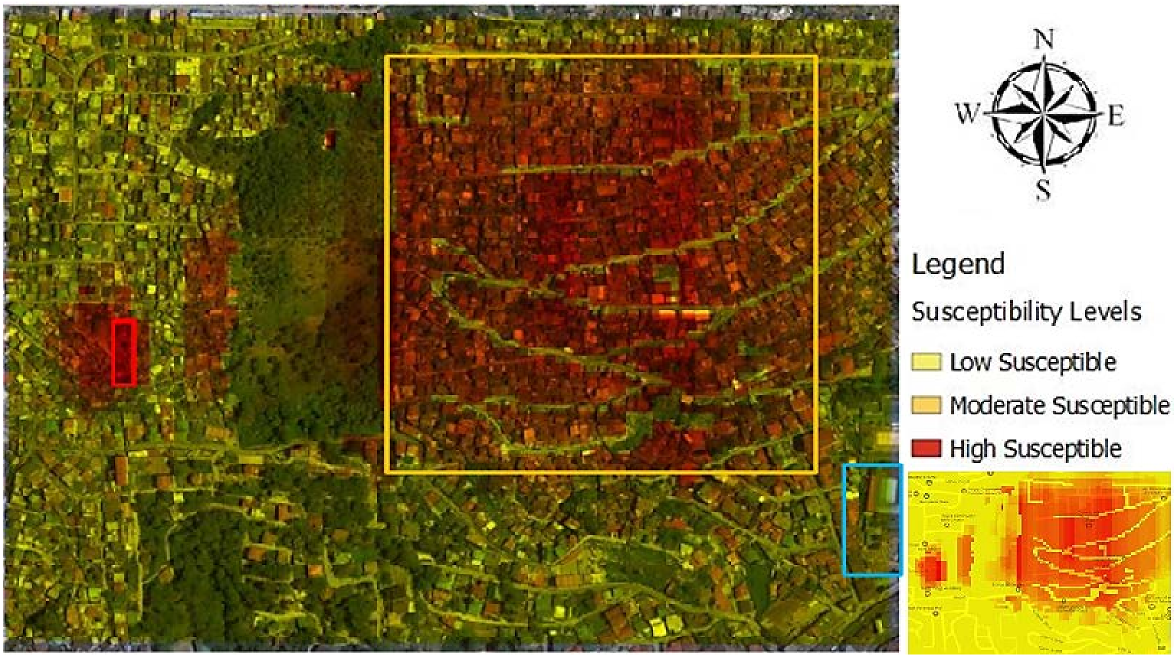


Fig. 6 Landslide Susceptibility Map showing the critical area (red) and the proposed evacuation area (blue)

The area that is close to the critical factor of safety which is 1 is a residential area located at Barangay Pinget, Baguio City as presented in Figure 6 which is highlighted in the red box, thus the addition of loading on that area would be risky. The residential areas at Barangay Quirino Hill, Baguio City, highlighted in the blue box, are already below the ideal factor of safety which is 1.5. This implies the possibility of a landslide in the area, especially if the load in the area is higher than the assumed values. The map generated can be used as a guide in identifying the areas that are susceptible to a landslide.

This landslide susceptibility map shall be used together with a warning system for necessary actions during immense rainfall.

The warning system of PAGASA which is red warning will be adopted for precipitation which is 40 mm/hr and above. At this level, upon the release of the PAGASA warning, the preemptive action will be an immediate evacuation rendered by the concerned government bodies such as CDRRMC.

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