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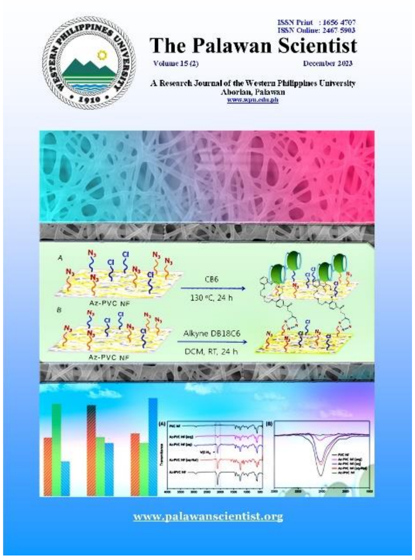

Seismic-induced landslide hazard analysis of the recreational area of the Makiling Botanic Gardens, Los Baños, Laguna, Philippines

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ABSTRACT

The Makiling Botanic Gardens (MBG) is an educational and eco-tourism site located within the vicinity of Mount Makiling, a dormant volcano susceptible to landslides, and located less than 20 km away from at least two tectonic faults. The study assessed the seismic-induced landslide hazards in the recreational area of MBG mainly based on three parameters: factor of safety (FS), yield acceleration (a_y), and slope displacement (D_n). Dynamic Cone Penetration Test (DCPT) served as the primary method for obtaining the shear strength of the soil within the area. Meanwhile, other relevant parameters, including material unit weight and internal angle of friction, were determined through laboratory testing, correlations, and available data and models. Moreover, the Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) values were obtained through an interpretation of a probabilistic seismic hazard analysis (PSHA) study of the Philippines. Using the ArcGIS software, an FS map, yield acceleration map, and slope displacement map were generated. Results showed that the slopes within the area exhibit static stability. However, in the event of an earthquake, it is expected that the amplified PGA will exceed the expected yield acceleration values of the slopes in some parts of the recreational area, which could result in dynamic instability and slope displacements as high as 130 mm. Thus, the recreational area of MBG possesses some susceptibility towards a seismic-induced landslide.

Keywords: dynamic cone penetration test, factor of safety, Newmark displacement, peak ground acceleration, spectral acceleration

INTRODUCTION

Landslides are natural hazards generally defined as the downhill movement of soil, rock, and debris on sloping and relatively flat areas such as mountainous regions. They may occur without warning and may be triggered by earthquakes, heavy rainfall, and other activities that can disrupt and displace a mass of soil and rock which are everyday events in the Philippines, especially in its mountainous regions (Lapitan et al. 2006). Mount Makiling, a dormant but potentially active volcano in the Philippines with an elevation of 1,090 m above mean sea level, is a mountainous region housing several constituents of the Los Baños municipality (KBA 2006). Moreover, according to the ASEAN Centre for

Biodiversity (2013), within Mount Makiling lies the Mount Makiling Forest Reserve (MMFR), which houses the Makiling Botanic Gardens (MBG), established under Republic Act 3523 and Makiling Center for Mountain Ecosystems (MCME), to serve as an educational and eco-tourism site for the public. However, MBG also houses several sloping areas of soil and rock that may or may not be susceptible to seismic-induced landslides. According to the Philippine Institute of Volcanology and Seismology (PHIVOLCS), as of 2013, the MMFR is located approximately 17 km away from the nearest Valley Fault System (VFS), in which the fault system extends to the municipality of Calamba. Thus, to help establish proactive measures against a possible future destructive event, a seismic hazard analysis and mapping may be deemed necessary.

Seismic hazard is a classification of hazards that refer to the statistical probability of the occurrence of seismic activities, such as earthquakes, within a geographical area (Rojas 2016). In this regard, seismic-induced landslides may occur at any point in time, considering that there is still lack of technology and data for accurate predictions of earthquake occurrence. Concerning seismic activities, peak ground acceleration (PGA) is the maximum change in speed experienced by a particle in the ground. In contrast, spectral acceleration (SA) is the change in speed experienced by an infrastructure (Bradley 2011). Both PGA and SA may be expressed in *g* or the standard acceleration value due to gravity (9.81 $m \cdot s^{-2}$). Additionally, PGA may serve as a hazard index for short buildings with a maximum of seven stories, on average, in which PGA focuses more on peak ground motion. Meanwhile, SA may serve as a hazard index for tall buildings in which SA focuses more on building behavior. Furthermore, a probabilistic seismic hazard model of the Philippines was generated by the study of Peñarubia et al. (2020). In the study, the Philippine archipelago is defined as tectonically complex and seismically hazardous due to its geographical position and its formations. In the study, a PGA map was generated for the Philippines with a 10% probability of exceedance in a period of 50 years, as shown in Figure 1. For the municipality of Los Baños in the province of Laguna, the PGA for the area ranges from 0.3 *g* to 0.5 ***g*.** In the case of MBG, a protected sanctuary, a non-intrusive seismic hazard analysis method was preferred to conform with related laws and official memorandums.

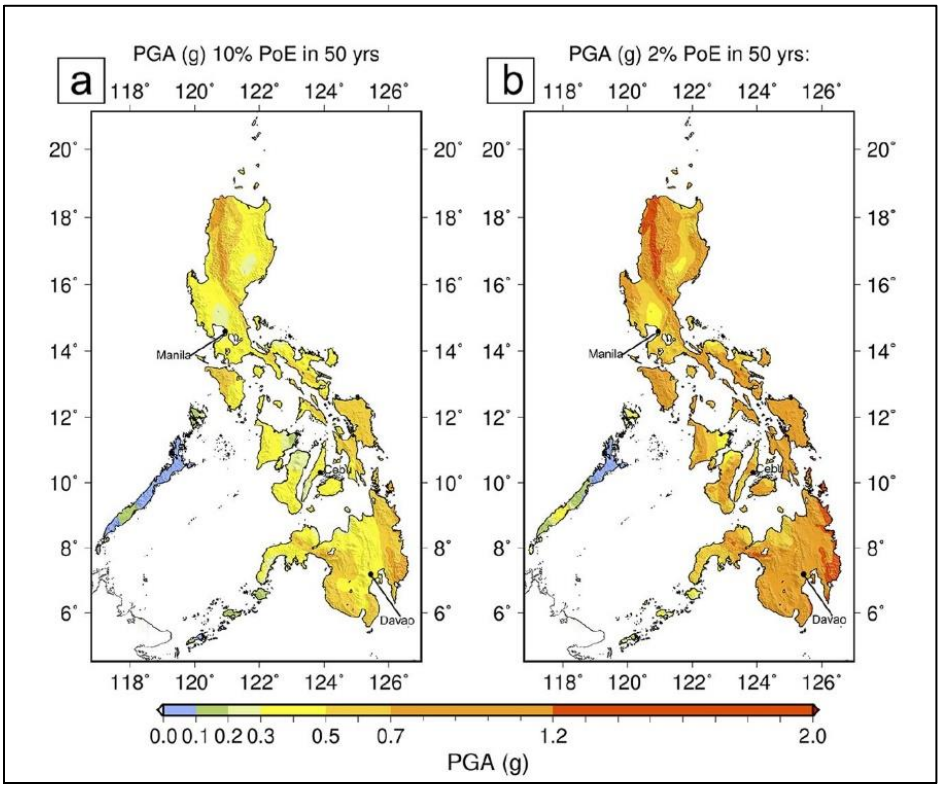

Figure 1. Mean peak ground acceleration (PGA)map for the Philippines with 10% and 2% probability of exceedance in 50 years.

The Dynamic Cone Penetration Test (DCPT) is a non-intrusive and non-destructive soil investigation procedure performed to determine the strength of the soil and soil layers present within the study area through the Dynamic Cone Penetration (DCP) – n values (VerTek 2021). In a seismic-induced landslide study in Indonesia by Kiyota (2020), DCPT provides an inexpensive and portable procedure for obtaining in-situ soil data regardless of slope stability conditions. The method is even more crucial in obtaining soil data after the events of a landslide in which slopes are unstable. The DCPT is performed following the standards provided by the ASTM D6951. According to Look (2007), the DCP is equivalent to a third of the energy of the Standard Penetration Test (SPT) in which the DCP – n values can be correlated with the soil strength in terms of cohesion, as shown in Table 1. The DCPT may be used for obtaining soil behavior data without procuring soil samples and disturbing the stratigraphy of a protected site such as MBG.

Since the Makiling Botanic Gardens (MBG), especially the recreational area, is a tourist destination and attracts several visitors annually, it would be beneficial for the area to have established safety measures against seismic-induced landslides, especially considering the unpredictable nature of earthquakes. The main objective of this study is to assess the seismic-induced landslide hazards in the 3.5 ha recreational area of the MBG based solely on projected seismic-induced slope displacements. Specifically, it aimed to identify the geology and soil composition within the recreational area of MBG based on available soil investigation reports and data; calculate the static Factor of Safety (FS) and yield acceleration at different points and areas within the recreational area of MBG using computed and pre-determined relevant soil parameters; and calculate the slope displacements due to seismic-induced landslides at different points and areas within the recreational area of MBG.

Table 1. Strength parameters from DCPT Data. Source: Look 2007.

Material	Description	DCP – n (Blows/100 mm)	Strength
Clays	Very Soft	0-1	C_u = 0-12 kPa
	Soft	1-2	C_u = 12-25 kPa
	Firm	2-3	C_u = 25-50 kPa
	Stiff	3-7	C_u = 50-100 kPa
	Very Stiff	7-12	C_u = 100-200 kPa
	Hard	>12	C_u > 200 kPa
Sands	Very Loose	0-1	Φ < 30°
	Loose	1-3	Φ = 30-35°
	Medium Dense	3-8	Φ = 35-40°
	Dense	8-15	Φ = 40-45°
	Very Dense	>15	Φ > 45°
Gravels, Cobbles, Boulders		>10	Φ = 35°
		>20	Φ > 40°
Rock		>10	C' = 25 kPa, Φ > 30°
		>20	C' = 50 kPa, Φ > 30°

METHODS

Descriptive Summary of the Study Area

The study focused only on the 3.5 ha recreational area of MBG, (Figure 2). The area was plotted using WGS84 coordinates and described using maps regarding the local geology and tectonic setting of the MMFR. The MBG has a WGS84 coordinates of 14.1566° North and 121.2342° East. For the procurement of existing pertinent data regarding the geomorphological characterization of MBG, the following documents were requested and obtained from the Makiling Center for Mountain Ecosystems (MCME): Land cover map of the MMFR ASEAN Heritage Park, Soil cover map of the MMFR ASEAN Heritage Park, and DEM of the MMFR ASEAN Heritage Park. Through ArcGIS, the elevation map at 5 m intervals, slope angle map at 5° intervals, land cover map, and soil cover map for the 3.5 ha study area were extracted.

Figure 2. Plot and location of study area.

Determination of Soil Properties

The Dynamic Cone Penetration Test (DCPT) served as the primary procedure for obtaining primary data to determine needed soil parameters. For the 3.5 ha recreational area, 43 test points were determined and plotted to represent the study area, as shown in Figure 3. For each test point, DCPT was performed once in which an 8 kg hammer was repeatedly raised and dropped at a certain height until it reached either a depth of one meter or refusal.

The penetration depth and number of blows were recorded for each test point. Afterwards, the Dynamic Cone Penetration (DCP) Index and DCP n-values for each test point were determined based on the penetration depth at each blow, resulting in generating a DCP profile for each test point. Using Table 1, the DCP – n values were correlated with cohesion (c') values. Due to the presence of clayey soil within the study area and as per Table 1, only cohesion values can be correlated with DCP-n values. For conservative measures, the lowest cohesion value obtained within a test point served as the governing shear strength for that test point. Then, the shear strength values were interpolated using the Kriging method of ArcGIS to generate a shear strength map for the study area. Meanwhile, slope angles (α) were determined based on the generated slope angle map for the same area.

Laboratory Determination of Other Soil Properties

For each of the 43 test points within the 3.5 ha recreational area of MBG, soil samples with respective masses of at least 100 g were obtained for laboratory testing at the Department of Civil Engineering (DCE) in the University of the Philippines Los Baños (UPLB). In the laboratory, the procured soil samples were oven-dried for at least 24 h, pulverized with a hammer, and sieved using Sieve No. 200 and mechanical shaker for 3 min.

After sieving, the mass retained in Sieve No. 200 was measured and recorded. Then, the percentage composition of the recorded mass to the overall mass of the sieved soil was computed and determined. The said parameter served as the coarse percentage of the soil sample, indicating the percentage of the sample with a particle diameter of more than 75 µm. If the coarse percentage of a sample yielded a value of at least 30%, the internal angle of friction ($\emptyset'$) was determined through correlation with cohesion values using Table 2.

Meanwhile, for the determination of the material unit weight of the soil (γ), a small cylindrical container was prepared and filled with a compacted sample. The material unit weight was then computed and determined based on the contained mass of the container (in kilograms) and the inner volume of the container (in cubic meters) using Table 3.

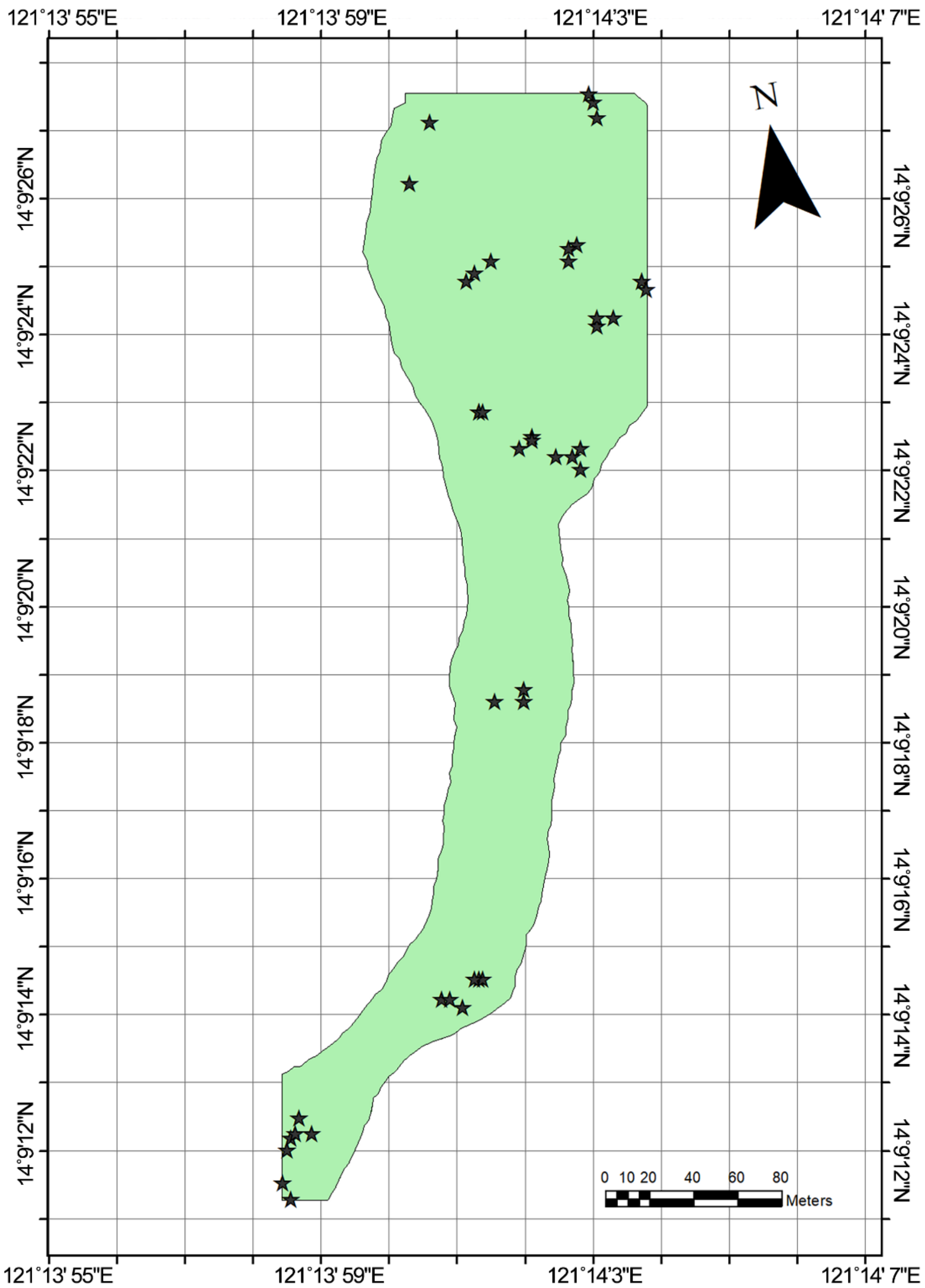

Figure 3. Map of the 3.5-hectare recreational area of Makiling Botanic Gardens showing the sampling sites (★).

Table 2. Strength values for cohesive soil. Source: Look 2007.

Type	Description	Effective Cohesion (kPa)	Friction angle (degrees)
Cohesive	Soft- Organic	5-10	10-20
	Soft- Non-organic	10-20	15-25
	Stiff	20-50	20-30
	Hard	50-100	25-30

Table 3. Corresponding material unit weight values for DCP – n values. Source: Herath 2005.

γ (kN m^{-3})	**DCP – n value (mm/blow)**
15.3	18.4
17.1	15.0
17.8	17.0
18.9	16.7
17.6	22.5
18.7	13.0
16.8	23.0
15.8	36.0
16.1	18.8
16.7	29.0
16.3	26.1
16.1	27.0
14.1	13.5
14.1	15.2
13.1	15.0
18.2	14.3
17.0	17.2
15.5	6.54
18.4	15.9
18.0	11.7
18.6	23.3
16.8	63.7
17.3	10.6
18.4	26.0

Determination of Factor of Safety

The Factor of Safety (FS) serves as a measure of slope stability within an area of interest. It is the ratio between the available shear strength of a slope and the shear forces acting on the slope that may cause landslides. Generally, an FS of greater than unity indicates a stable slope, while an FS of less than unity indicates an unstable slope prone to slope failure (Kramer 1996). The previously generated land cover map, soil cover map, slope angle map, elevation map, and shear strength map for the study area were intersected together with a set of 10 m by 10 m grids. Afterward, the newly generated map divided the recreational area of MBG into cells in which each cell had a corresponding set of attributes. Using the said attributes, the FS at each cell of the recreational area of MBG was determined using Equation 1, as shown below:

$$FS = \frac{c'}{\gamma t sin(\alpha)} + \frac{tan\emptyset'}{\tan(\alpha)} \quad (1)$$

where:

FS is the static factor of safety;
c' is the effective soil cohesion;
γ is the material unit weight of the soil;
t is the slope-normal thickness of the failure slab (3 m for shallow landslides;
α is the slope angle; and
$\emptyset'$ is the internal angle of friction of the slope.

The resulting values for the FS at each cell of the study area served as the basis for generating an FS map for the said area. The generated map provided a general overview of the static slope stability of the recreational area of MBG regarding the FS.

Yield Acceleration

In Newmark's sliding block analysis, both static and dynamic forces are incorporated to analyze slope stability, which is indicated by the yield acceleration (a_y). The yield acceleration is the minimum pseudo-static acceleration that can induce slope instability. Moreover, a mass that reaches its yield acceleration results in an FS of unity, implying that areas with yield acceleration values less than the peak ground acceleration (PGA) are susceptible to seismic-induced landslides. Regarding the FS map of the study area, the yield acceleration values, expressed in ***g***, at each cell were determined using Equation 2, as shown below:

$$a_y = (FS - 1)\, sin(\alpha) \quad (2)$$

where:

a_y is the yield acceleration of the slope;
FS is the factor of safety of the slope;
α is the slope angle.

After determining the corresponding yield acceleration values for each cell of the study area, a yield acceleration map for the recreational area of MBG was generated, thus providing an overview of the susceptibility of MBG towards landslides in terms of induced accelerations.

Determination of Slope Displacement

As mentioned previously, yield acceleration is the minimum value of acceleration to cause slope instability. Slope failures, such as landslides, result in permanent displacements. The Newmark method for measuring displacement considers the effects of dynamic forces due to seismic activities. For this study, the pseudo-empirical predictive formula for Newmark displacements derived by Veylon et al. (2017) was used, as shown in Equation 3. For the values of PGA and spectral acceleration (SA) of the study area, the study adopted the maximum average PGA, with a 475 yr return period, for the study area which was from the study of Peñarubia et al. (2020). Furthermore, the adopted PGA value was amplified based on the specifications of the American Society of Civil Engineers (ASCE) Section 7-05 and based on the site classification of the study area. Meanwhile, the recreational area of MBG was generated based also on ASCE Section 7-05, a spectral acceleration design response spectrum, with a 475 yr return period. Lastly, the corresponding SA values at each cell of the study area was based from the Spectral Acceleration Maps provided by DOST-PHIVOLCS (Figures 4 and 5).

$$\ln(D_n) = -0.56 - 2.23\frac{a_y}{PGA} + 2.8\ln(\frac{SA(1.5T_1)}{PGA}) \quad (3)$$

where:

D_n is the Newmark displacement;
a_y is the yield acceleration;
g is the acceleration under the effects of gravitational force;
PGA is the peak ground acceleration;
SA is the spectral acceleration; and
T_1 is the initial fundamental period of the structure.

T_1 measures the vibratory characteristics of the slopes, which can be associated with the height of the slope and its stiffness. Thus, T_1 was determined using the formula from Veylon et al. (2017), shown in Equation 4 below:

$$T_1 = \frac{2\pi}{2.4}\frac{H}{\sqrt{G_{max}/\rho}} \quad (4)$$

where:

H is the height of the slope;
G_{max} is the maximum shear modulus of the material; and
ρ is the density of the material of the slope.

After determining the projected slope displacements at each cell of the recreational area of MBG, a slope displacement map was generated using ArcGIS. The map provided estimates of permanent displacements at different points and areas of the 3.5 ha recreational area of MBG in the event of a seismic-induced landslide occurrence.

RESULTS

Geology and Soil Composition of the Recreational Area of the Makiling Botanic Gardens

Makiling Botanic Gardens (MBG) is an eco-tourism site within the Mount Makiling Forest Reserve (MMFR) ASEAN Heritage Park. Figure 6 shows the local geology of the MMFR ASEAN Heritage Park, which defines the lithology and structures present within the area. To further support the implications of the local geology of the MMFR ASEAN Heritage Park, the presence of a particular type of soil suitable for plant growth and development was considered since the recreational area of MBG contains a diverse range of flora and fauna. For general visualization of the soil composition of the study area, Figure 7 shows the soil cover map for the recreational area of MBG, which was extracted from MMFR ASEAN Heritage Park soil cover map provided by the Makiling Center for Mountain Ecosystems (MCME). Concerning the soil cover map of the study area, Figure 8 shows the land cover map for the same area extracted from the provided MMFR ASEAN Heritage Park land cover map by MCME.

A Digital Elevation Model (DEM) from the National Mapping and Resource Information Authority (NAMRIA 2015) for the MMFR ASEAN Heritage Park was provided by MCME, which served as the basis for mapping the elevations and slope angles of the study area in which Figures 9 and 10 show the varying elevations and slope angles present within the area, respectively. At each of the 43 test points, a Dynamic Cone Penetration Test (DCPT) was performed, in which each test point generated a Dynamic Cone Penetration (DCP) n-value profile

(Figure 3). Then, the obtained DCP n-value profile was correlated to shear strength values (Table 1). The shear strength values at each point were then correlated to generate a shear strength map for the study area (Figure 11).

Static Factor of Safety and Yield Acceleration

Through ArcGIS, all the previously generated maps were combined and intersected. Fishnets were established using 10 m by 10 m grids, resulting in a generated map with 1,388 individual cells with their own unique sets of attributes. The static FS of each of the 1,388 cells was determined using Equation 1 and added as an attribute, resulting in an FS map shown in Figure 12. After determining the FS values at each cell and using Equation 2, the yield acceleration values for each of the 1,388 cells of the plotted recreational area of MBG were determined and added as an attribute, resulting in a yield acceleration map (see Figure 13).

Seismic-induced Slope Displacements

For the determination of projected slope displacements due to seismic-induced landslides, the peak ground acceleration (PGA) and spectral acceleration (SA), with a 475-year return period, for the recreational area of MBG were determined and considered. Considering the amplified PGA for the recreational area, a conservative value of 0.85***g*** was considered for the PGA of the said area. Meanwhile, using the generated site-specific spectral acceleration design response spectrum for the same area, each of the 1,388 cells of the study area was assigned a spectral acceleration value based on the fundamental period computed for each cell using Equation 4. Finally, using Equation 3, the slope displacement for each cell was determined and assigned as an attribute, resulting in the slope displacement map (see Figure 14).

DISCUSSION

Geology and Soil Composition of the Recreational Area of the Makiling Botanic Gardens

The local geology of the MMFR ASEAN Heritage Park is composed mainly of volcanic materials and residues based on Figure 6. The subsurface material present within the area is part of the Macolod Volcanic Complex, which is composed of volcanoes and volcanic features originating from the Pliocene era (5.3 mya) to the Pleistocene era (11 mya) in which Mount Makiling is part of the said complex (Peña 2008). Moreover, due to the active volcanic processes circulating within the area, tectonic features are influenced by these processes, resulting in a volcanotectonic fault located around 10 km east of the campus of the University of the Philippines Los Baños (UPLB). Additionally, the soil composition for the recreational area of MBG is mainly Macolod clay, a loam-clay soil (Figure 7) which is a common variety of soil in the Philippines that is suitable for agricultural purposes due to its high nutrient value and water retaining capacity (Montecillo 1983). However, Macolod clay is a relatively soft soil, which may indicate an increased risk for seismic-induced landslides. Additionally, the majority of the recreational area of MBG is built-up, implying the presence of structures such as roads, pavements, and buildings (Figure 8). The presence of these structures may further indicate that slope stabilization measures within the vicinity of the structures have been established and implemented. According to the California State of Water Resources Control Board (2001), slope stabilization measures are established in sloping areas prone to surface runoff and erosion, such as Mount Makiling. The presence of several infrastructures in such an environment may imply that stabilization measures were established to increase the slope's factor of safety and to stabilize the soil. However, based on existing records and observations, some portions of the built-up areas have exhibited signs of degradation due to age and environmental factors. Such a case may further result in outdated structures with unstable frameworks, which may serve as a factor for increased disaster risk in the event of seismic-induced landslides.

Regarding elevations in the study area, the recreational area of MBG exhibits increasing elevation from the entrance (northeast portion of the area) to the *Dipterocarp* area (southern portion of the area) (see Figure 9). The area yielded a maximum elevation of 140 m above mean sea level and a minimum elevation of 85 m above mean sea level, resulting in a maximum slope height of approximately 55 m. Moreover, the immediate changes in elevation in the *Dipterocarp* area and Molawin Creek area (northwest portion of the area) indicate the presence of relatively steep slopes within the said areas. Furthermore, the slope angles within the recreational area range from a minimum angle of 0° to a maximum angle of 20° (Figure 10). This indicates that the highest slope angles of the recreational area are present within the Molawin Creek area (Figure 9). The slope angles were one of the main parameters of interest to determine the static Factor of Safety (FS) values within the recreational area. Lastly, the shear strength of the Macolod clay within the recreational area of MBG ranges from a minimum shear strength of 12 kPa to a maximum shear strength of 26 kPa (Figure 11).

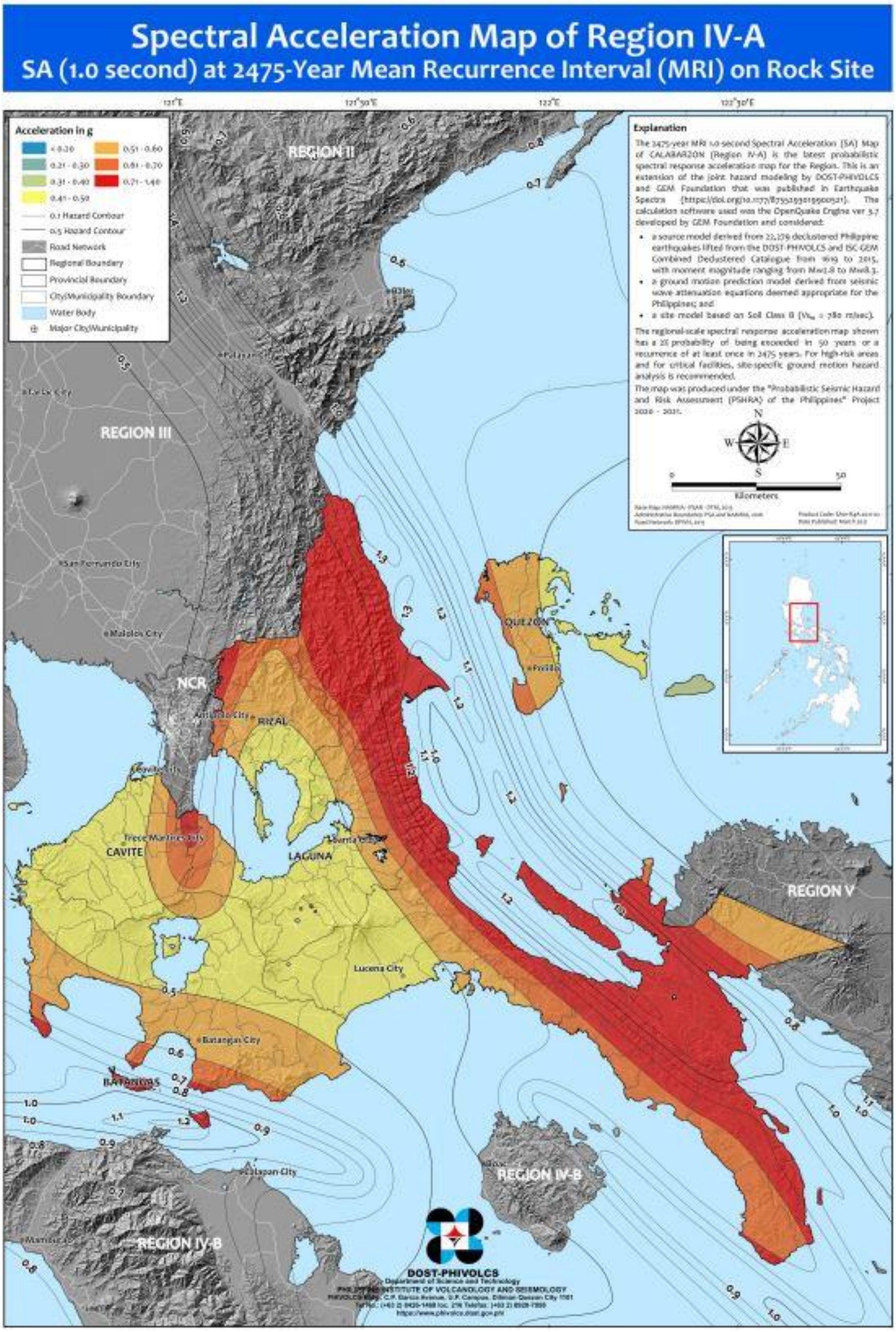

Figure 4. Spectral acceleration map of Region IV-A at 1.0 second.

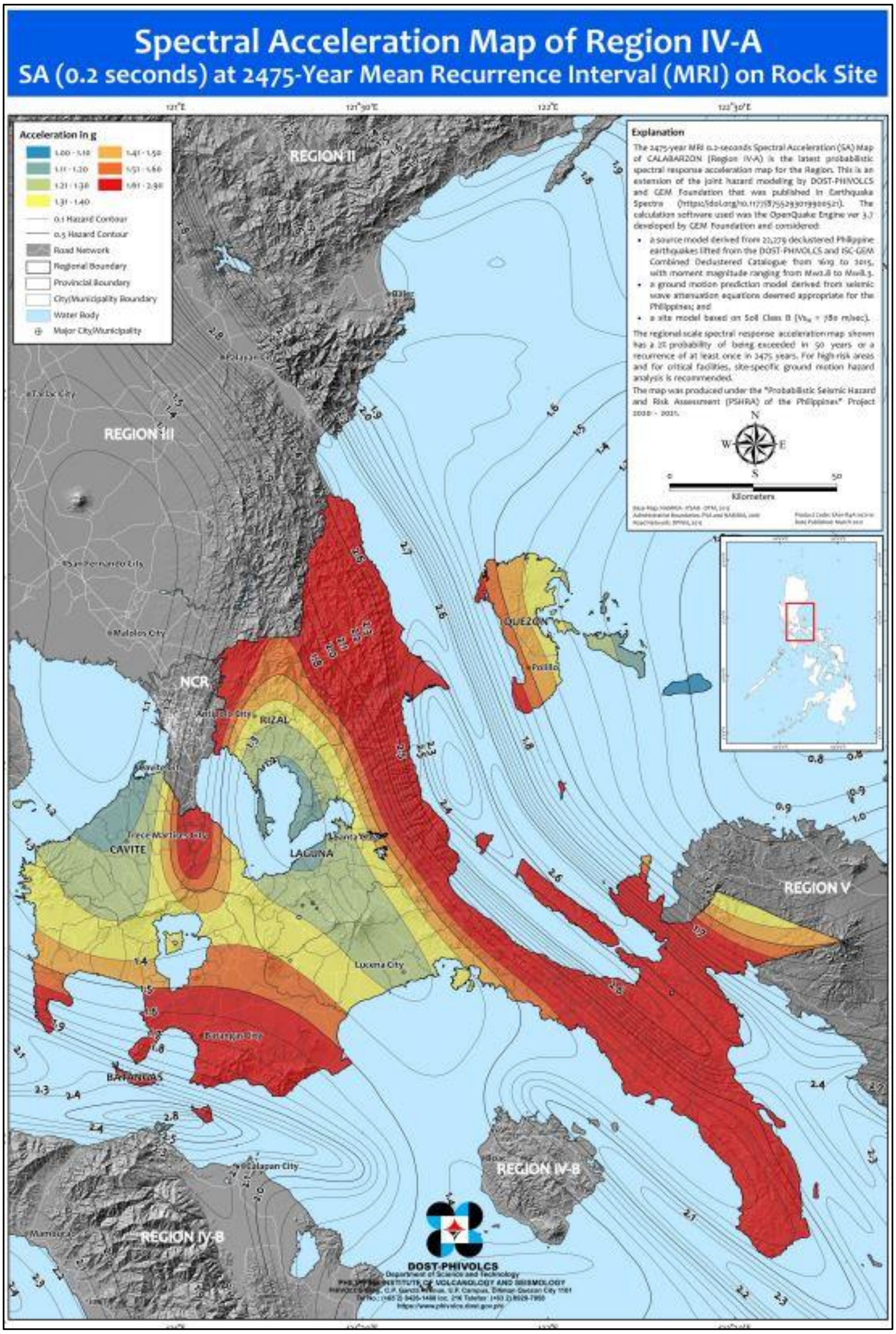

Figure 5. Spectral acceleration map of Region IV-A at 0.2 second.

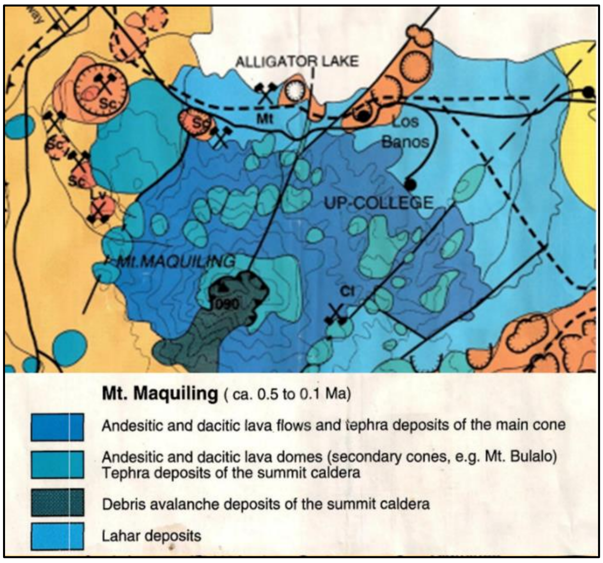

Figure 6. Local geology of Mount Makiling Forest Reserve ASEAN Heritage Park.

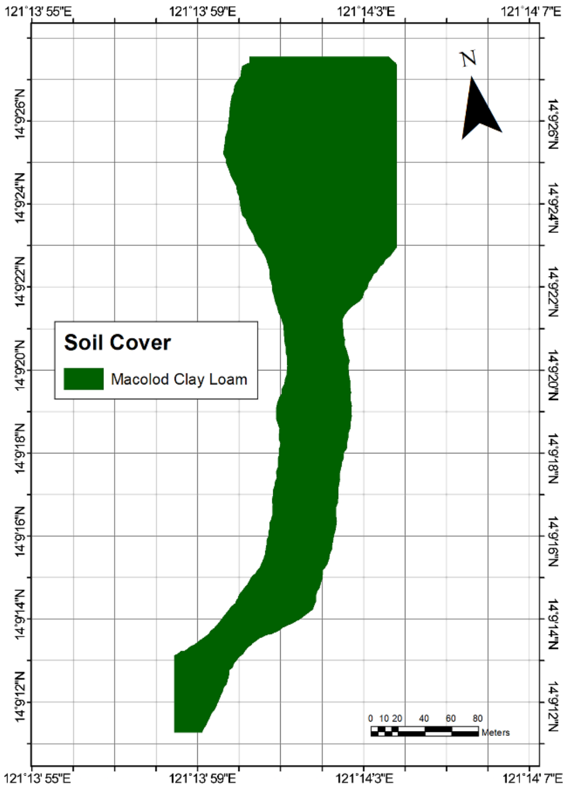

Figure 7. Soil cover map of the recreational area of Makiling Botanic Gardens.

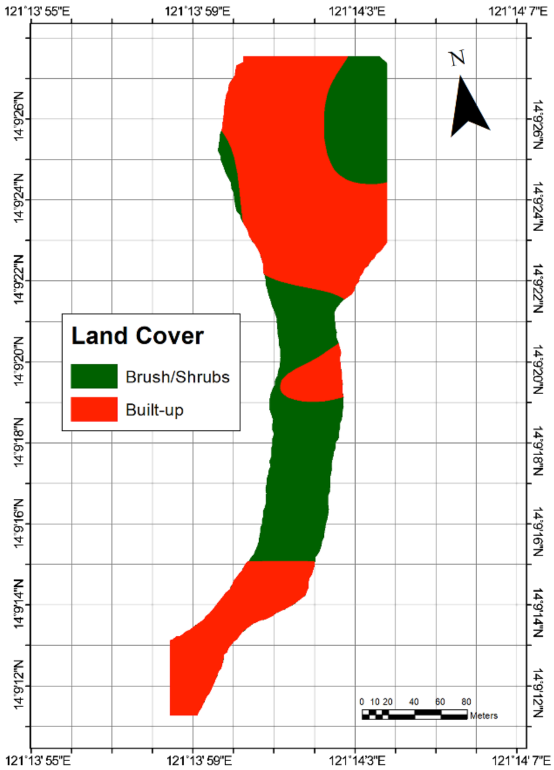

Figure 8. Land cover map of the recreational area of Makiling Botanic Gardens.

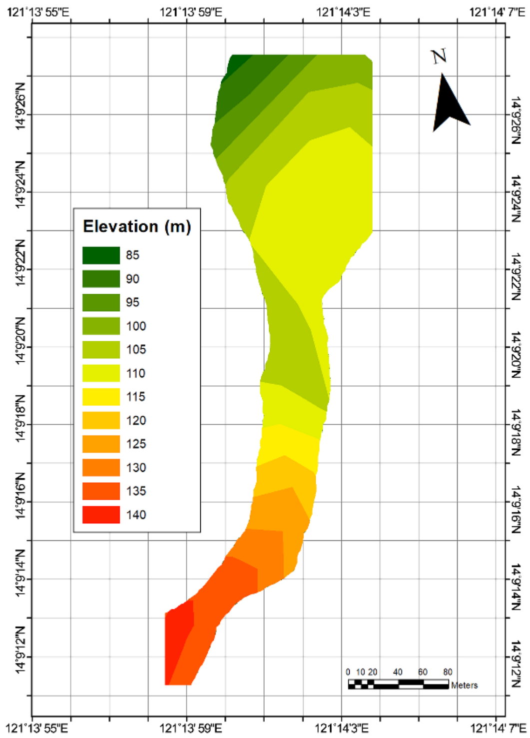

Figure 9. Elevation map of the recreational area of Makiling Botanic Gardens.

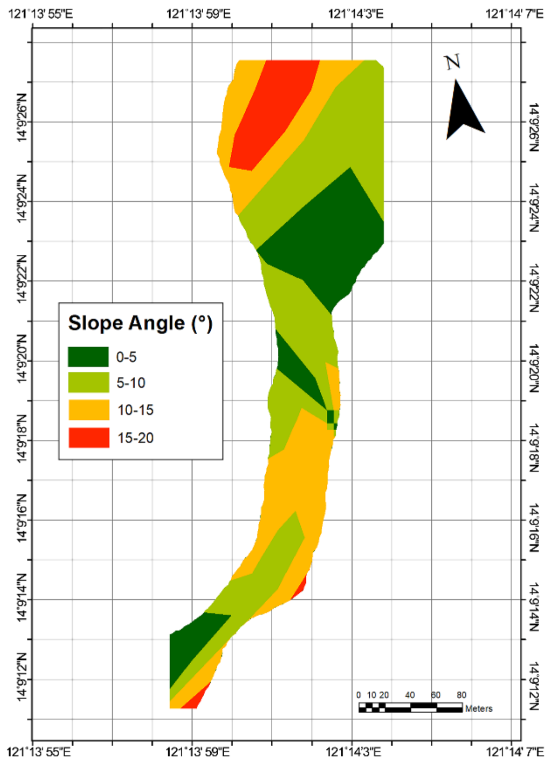

Figure 10. Slope angle map of the recreational area of Makiling Botanic Gardens.

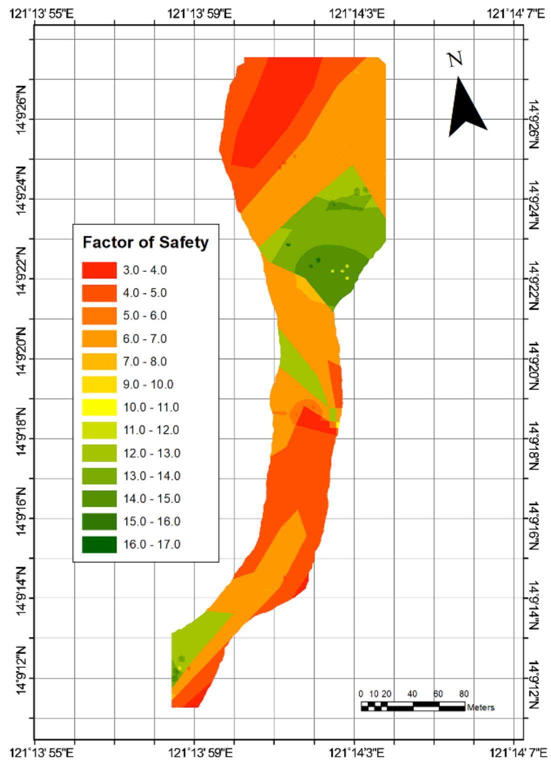

Figure 12. Factor of safety map for the recreational area of Makiling Botanic Gardens.

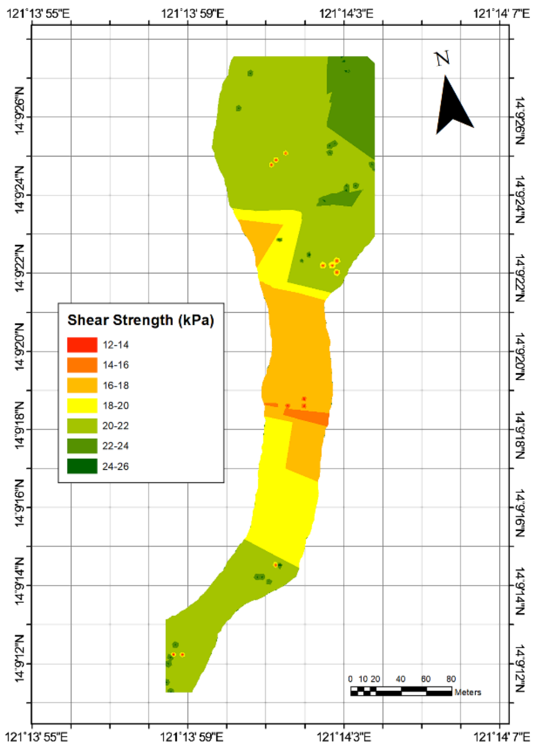

Figure 11. Shear strength map of the recreational area of Makiling Botanic Gardens.

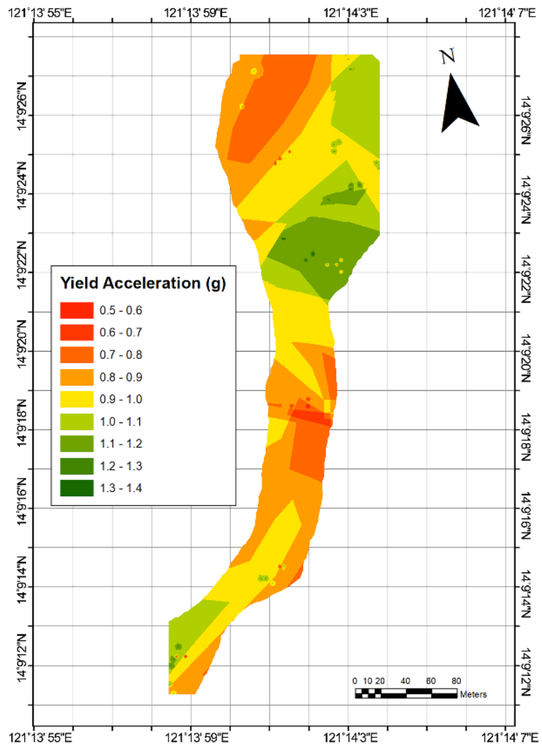

Figure 13. Yield acceleration map of recreational area of Makiling Botanic Gardens.

Relatively, low shear strength is observed in the central portion of the area, while relatively high shear strength is observed in the northern and southern portions of the area. Like the slope angles, the shear strength values served as one of the main parameters of interest to determine the static FS values within the recreational area. Additionally, due to the lack of Standard Penetration Test (SPT) data within the recreational area of MBG, the shear strength map served as the basis for the site classification of the study area. According to Atkinson (2008), shear strength values of less than 20 kPa and between 20 kPa and 40 kPa indicate the presence of very soft soil and soft soil, respectively. Based on Table 4, site classification E corresponds to an area with a soft soil profile. Thus, the 3.5 ha recreational area of MBG has a site classification of E due to soft soil (Figure 11). The site classification served as a basis for adjusting seismic parameters in the seismic-induced landslide hazard analysis of the said area.

Table 4. Soil profile types. Source: National Structural Code of the Philippines 2015.

Soil Profile Type	**Generic Description**	**Average Soil Properties for Top 30 m of Soil Profile**		
		Shear Wave Velocity, Vs ($m \cdot s^{-1}$)	**SPT, N (blows/ 300 mm)**	**Undrained Shear Strength, S_u (kPa)**
S_A	Hard Rock	> 1500		
S_B	Rock	760 to 1500		
S_C	Very Dense Soil and Soft Rock	360 to 760	> 50	> 100
S_D	Stiff Soil Profile	180 to 360	15 to 50	50 to 100
S_E[1]	Soft Soil Profile	< 180	< 15	< 50
S_F	Soil Requiring Site-specific Evaluation			

Static Factor of Safety and Yield Acceleration

The entirety of the recreational area of MBG has a static FS of more than 1.5, implying that the area has safe and stable slopes on average since all FS values are higher than unity based on Figure 12. These values further indicate that the resisting forces in the soil and slopes are sufficient to resist the shear forces acting within the soil. Additionally, a conservative value of 1.5 for the FS is generally acceptable as the basis for the design of a stable slope (Das 2010). An FS of less than 1.5 or close to unity may imply that the slope is close to failure with additional loads. Moreover, an FS of precisely unity indicates slope failure when the applied load reaches the design load. At the same time, an FS of less than unity indicates slope failure even without the application of loads. Since the FS of the recreational area of MBG yielded a value of more than 1.5, the area is suitable for some infrastructure developments since loading and environmental conditions are not severe (Maria 2016). Specifically, the minimum FS value yielded by the recreational area is around 3.02, in the Molawin Creek area and some portions of the *Dipterocarp* area. The relatively low FS value yields are consistent with the previously observed trends within the same areas. This implies that these areas have relatively very steep slopes (Figure 9) with large slope angles, which are both factors that affect slope stability. A steeper slope or a higher slope angle would result in a decrease in slope stability, which further increases its susceptibility to landslide occurrence due to the increasing effects of gravity as the plane becomes more inclined with respect to the horizontal plane. The remaining areas of the recreational area of MBG have relatively flat slopes with small slope angles, resulting in relatively very high FS values compared to the Molawin Creek area and the *Dipterocarp* area. Nevertheless, due to a high FS of 3.02, the Molawin Creek and *Dipterocap* areas have safe and stable static slopes.

Meanwhile, the entirety of the recreational area has a yield acceleration value ranging from 0.5 *g* to 1.4 *g* (Figure 13). The obtained value indicates that a minimum pseudo-static acceleration equal to the acceleration due to gravity multiplied by a factor of 0.5 must be induced to cause slope instability and landslide occurrence in some portions of the recreational area. Furthermore, the Molawin Creek and *Dipterocarp* areas yielded relatively low yield acceleration values, ranging only from 0.5 *g* to 0.8 *g* (Figure 12). These areas also yielded the lowest FS values, which served as the main factor for the differences in yield acceleration values at different areas of the recreational area of MBG. Based on the peak ground acceleration (PGA) maps of Peñarubia et al. (2020), the PGA for the area of Los Baños, Laguna, ranges from 0.3 *g* to 0.5 *g* considering a return period of 475 years. Following the American Society of Civil Engineers (ASCE) Section 7-05 and consideration of the site classification (E) of the recreational area, an amplification factor was applied to the PGA values, resulting in an amplified PGA for the recreational area of MBG, ranging from 0.70 *g* to 0.85 *g*. As a result, in the event of an earthquake, slope instabilities and movements are highly likely to occur in the Molawin Creek area and *Dipterocarp* area since their respective yield acceleration values are less than or within the range of the amplified PGA for the recreational area of MBG.

Seismic-Induced Slope Displacements

Some portions of the recreational area have minimal projected slope displacements in the event of a seismic-induced landslide ranging only from 0 mm to 10 mm (Figure 14). However, some portions of the recreational area have large and significant slope displacements in the event of a seismic-induced landslide (Figures 12 and 13). Specifically, the Molawin Creek area and *Dipterocarp* area yielded the relatively highest projected slope displacements in the event of a seismic-induced landslide ranging from 80 mm to 130 mm. While the said areas have stable slopes in terms of static factors (Figure 12), the same areas have unstable slopes in terms of dynamic factors (Figure 13) resulting to significant seismic-induced slope displacement values. These dynamic factors generally consider the stability of the slopes against dynamic forces such as seismic-induced forces. Unfortunately, the Molawin Creek and *Dipterocarp* areas yielded relatively low resistance against these forces. As a result, in the event of an earthquake, the slopes within the Molawin Creek and *Dipterocarp* areas are high and likely to be significantly and progressively displaced which could lead to slope failures and seismic-induced landslides.

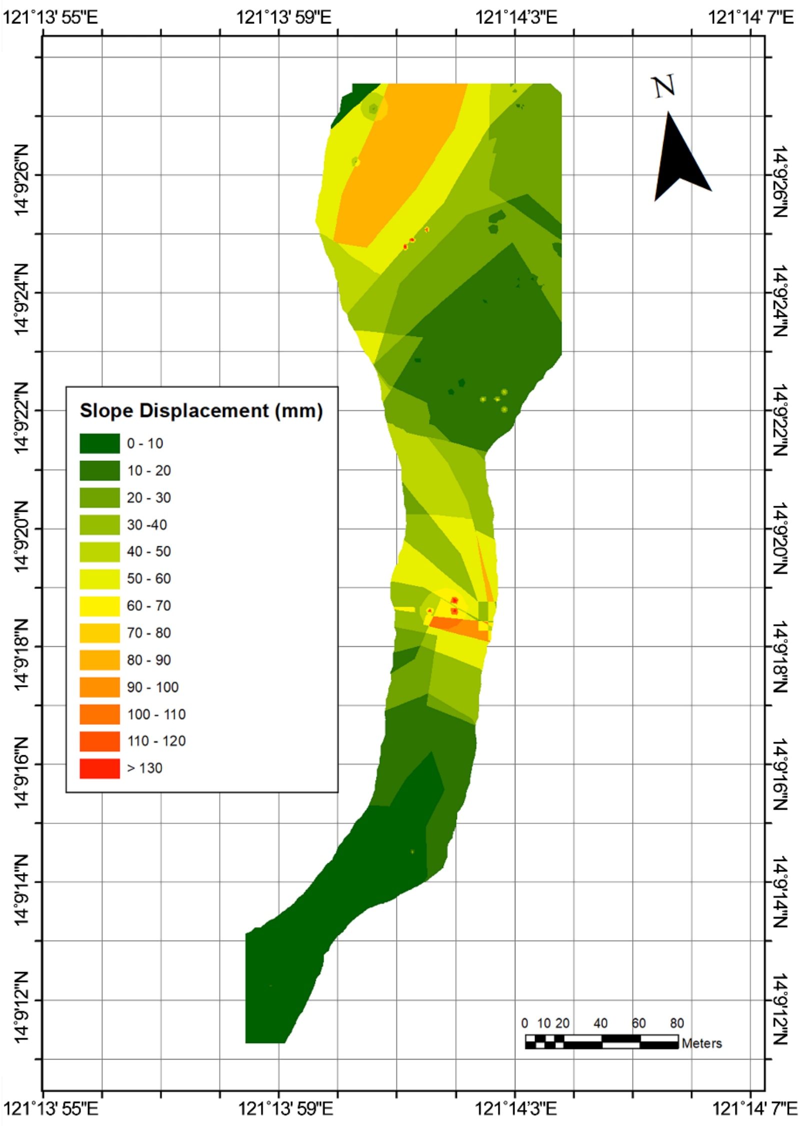

Figure 14. Slope displacement map of the recreational area of Makiling Botanic Gardens.

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ETHICAL CONSIDERATIONS

Test points used for landslide hazard analysis was safe and practical for researchers to avoid accidents and injuries. Studies conducted in a protected area employed non-intrusive and non-destructive methods to preserve the environment and ecosystem of the said area. Studies conducted during the COVID-19 pandemic observeed proper protocol and guidelines imposed by the agencies and institutions involved in the study.

DECLARATION OF COMPETING INTEREST

The authors declare that there are no competing interests to any authors.

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