Mathematical Exploration: Quantifying the Impact of Deforestation on Landslip Occurrences

Angel Y. Tubac
Tanjay City Science High School, Tanjay City Division, Negros Oriental, Philippines
Yesh Markjell L. Besario
Tanjay City Science High School, Tanjay City Division, Negros Oriental, Philippines
Tyra Mae N. Rodriguez
Tanjay City Science High School, Tanjay City Division, Negros Oriental, Philippines

Abstract

Landslides are a continuing problem in mountainous areas in general and in Baguio City in particular. The presence of high terrain, rainfall intensity, and progressive deforestation contributes significantly to slope instability. The impact of deforestation and re-vegetation on landslide susceptibility is explored here. The quantitative impact of deforestation and re-vegetation on slope stability and hence landslide susceptibility is explored here. The Factor of Safety (FS) derived from computational simulation based on geotechnical principles for slope stability and a geometric progression principle for re-vegetation progression per annum is discussed here. The independent variable is vegetation cover and the dependent variable is Factor of Safety. The findings show that slopes in heavily deforested areas are critically unsafe with FS values less than 1. However, a steady rise in vegetation cover improves slope stability drastically. The findings show that a gradual rise in vegetation cover improves slope stability in two to three years. Rapid re-vegetation translates into significantly high FS. This assumes importance for root resistance and re-vegetation-induced slope stabilization during high rainfall events. The findings are well within the theoretical limits proposed for vegetation slope stabilization in mountainous topography. This paper mainly focuses on re-vegetation, forest protection, and proper management of land use as effective measures to decrease landslide risk. In addition to these, the developed modeling system is also a helpful simplified tool for disaster risk management, land use planning, and further studies related to vegetation, slope stability, and landslide susceptibility.

Keywords: Factor of Safety (FS), Landslide susceptibility, Deforestation, Vegetation recovery, Slope stability

Introduction

Deforestation has also happened completely within the Philippines, thereby raising significantly the instances of landslides. Specifically, regions such as Baguio within Benguet, which experiences landslides often and is geographically predisposed to them, is a vulnerable location. This is especially because of its topography, high altitude, and high rainfall rates.

Research by Sidle and Ochiai (2006), and also by FAO (2018), illustrates that landslides are also caused by deforestation since it reduces the soil strength of an area, especially in mountainous and regions with high rainfall levels. There have been instances of dangerous landslides and fatalities documented in Baguio City; thus, there is an imperative need to investigate the relationship between forestation and landslides. There have been human activities such as cutting down trees and urbanization that have led to a reduction in forestation in this region, thus decreased soil strength and lack of natural protection. According to Global Forest Watch, there was the loss of 3 hectares of tree cover in 2023.

There exist many international studies to demonstrate that deforestation leads to a change in slope hydrology, an increase in pore water pressure, a decrease in root cohesion, and subsequently to values of FS being reduced. Vegetation stabilization techniques have proven effective in enhancing values of FS by improving soil cohesion and mitigating rainfall intensities.

The city of Baguio exhibits a high vulnerability to the occurrence of landslides owing to factors such as the topographic characteristics of the area, the presence of abundant and prolonged rainfall, and the increasing effects of human factors like the cutting down of trees and land development. Landslides have remained a critical challenge despite the mitigation measures put in place. The cutting down of trees leads to a decay in the factor of root cohesion and affects the hydrology of slopes, increasing the pore water pressure and the factor of soil shear strength, thus making the slopes instable (Sidle and Ochiai, 2006; Gray and Sotir, 1996). There seems to be a deficiency in the localized study for quantifying the relationship between the cutting down of trees and the stability of the slopes modeled mathematically.

The main aim of this research work is to quantitatively determine the influence of deforestation on the susceptibility of landslides in Baguio City through the evaluation of the variation in the stability of the slopes with respect to the Factor of Safety (FS). The aim of the proposed work is to establish the relationship between the Factor of Safety and the influence of vegetative cover through the adoption of a mathematized model, use the selected model to establish the influence of the rate of vegetative extension and reduction on the stability of the slopes, and establish the influence of reforestation on the resistance of the slopes to rainfall through the adoption of a mathematized model, with the aim of providing a technical basis for the implementation of effective plans aimed at preventing landslides in the mentioned city (Duncan & Wright, 2005; Terzaghi et al., 1996).

The study provides a quantitative computational analysis of slope stability in the Baguio City area, taking vegetation cover as its independent variable and the Factor of Safety as the dependent one. The model was developed using generalized soil, slope geometry, and vegetation parameters from existing literature and other secondary sources. However, assumptions include homogeneous soil properties, idealized vegetation growth rates, and no localized anthropogenic loading, such as buildings and road infrastructure. While the model fairly demonstrates trends and relationships, actual slope behavior may be different due to site-specific conditions, climate variability, and complex subsurface processes (Paringit et al., 2020; Abancó et al., 2021).

Although many studies in local and global frameworks verify the importance of vegetation in terms of slope stability, these studies are mainly focused on qualitative interpretation, post-event analysis, or GIS-based susceptibility mapping. Few studies have been found to date that utilize mathematical modeling in terms of quantifying progressive deforestation processes and re-vegetation in determining the Factor of Safety in tropical mountainous cities like Baguio. This specific study bridges the existing gaps in determining the importance of geometric progression in terms of analyzing slope stability to simplify the interpretation of vegetation-related modifications of landslide susceptibility (Gray & Sotir, 1996; Sidle & Ochiai, 2006; Xian et al., 2025).

In this study, researchers quantify the effect of deforestation on landslide susceptibility in Baguio City using vegetation cover as the independent variable and the Factor of Safety as the dependent variable. The researchers intend to determine the slope's stability under different land-cover scenarios through mathematical analysis. The results of the study will reduce the probability of disasters and help local decision-makers implement long-term landslide prevention strategies.

Results from this research have important applications in disaster risk reduction, management of the environment, and land use planning in areas that experience landslides. The research provides empirical evidence on the quantitative role of vegetation in stabilizing the slope and is therefore important for the promotion of re-vegetation and conservation initiatives, as well as the controlled use of land. Results from this study are also important to the LGU, engineers, and policymakers in the design of informed land use policies and slope management plans. Moreover, the use of mathematical modeling in this study adds to the body of knowledge and will help to inform similar tropical mountainous areas that experience landslides related to deforestation.

Literature Review

The assessed landslide susceptibility in Carabao Mountain, one of the most populated areas in Baguio City, using the Mohr–Coulomb failure criteria to compute the Factor of Safety (FS) under different scenarios. It examined how soil saturation and land-use loading affect slope stability, showing that residential development and road construction significantly increase the stress on slopes. Many residential zones already have FS values close to 1, meaning the slopes are near failure. Although soil saturation contributes to instability, the study concludes that structural loading from urban development has a greater impact on slope failure, emphasizing the need for stricter land-use planning and slope management in landslide-prone communities (Paringit et al., 2020).

This analysis of landslides triggered by Typhoon Mangkhut (Ompong) in 2018 in the Itogon area, Benguet, was compiled by compiling a detailed inventory of 1,101 landslides across a 570 km² region. The study examined how geomorphological features such as slope orientation, land cover, and soil type influenced landslide occurrence, identifying clay-rich, grassland and wooded slopes facing east-southeast as the most vulnerable. The findings reveal that landslides were not caused by rainfall alone but occurred when high-intensity rainfall coincided with already saturated soils. Using satellite-based rainfall and soil moisture data, the study demonstrated that near-saturation soil conditions are a critical factor in triggering widespread slope failures, highlighting the need for rainfall-soil moisture threshold monitoring for landslide early warning systems (Abancó et al., 2021).

Another related study focuses on strengthening landslide hazard mapping through community participation in Kias, Baguio City. It builds on earlier works from Peru and Malaysia that combined GIS technology with community surveys but were most expert-led and unsustainable in the long term. The Kias project highlights the need to shift from researcher-centered mapping to a model where residents are actively involved in identifying landslide-prone areas, collecting field data, and validating hazard maps (Klimeš et al., 2019).

According to Araza et al. (2021), deforestation is widely recognized as a key factor influencing landslip susceptibility in steep, tropical mountain regions. In Baguio City, located in the Cordillera Mountain Range of Northern Luzon, forest removal has been strongly associated with slope instability, particularly during the wet season and extreme rainfall events such as typhoons. High-resolution Earth observation studies indicate that areas of recent deforestation coincide with landslide scars, highlighting an immediate and localized response where vegetation loss reduces root reinforcement and slope stability, allowing rainfall to trigger rapid landslip events. This demonstrates that in tropical, high-rainfall environments like Baguio, deforestation can act as both a predisposing factor and a direct catalyst for landslides.

Comparative studies from other mountainous regions reveal that the timing and magnitude of landslide responses to deforestation can vary. In Far-Western Nepal, researchers found that forest conversion to agriculture increased landslide susceptibility by approximately 16% within 5–7 years, a delay attributed to progressive root decay and increased soil infiltration. Unlike Baguio City, where typhoon-driven rainfall often triggers landslides almost immediately following forest loss, the Nepalese case illustrates a more gradual slope destabilization. This contrast underscores the importance of climatic intensity, slope steepness, and precipitation patterns in modulating the landslide response to deforestation (Muñoz-Torrero et al., 2022)

Evidence from East Africa further supports the destabilizing effect of deforestation on hillslopes. Researchers reported that shallow landslide frequency and erosion increased by two to eight times immediately after forest removal, with elevated susceptibility persisting for up to 15 years. These findings highlight that while temporal persistence varies, deforestation consistently weakens slope stability by altering hydrological and geotechnical conditions. In Baguio City and the surrounding Cordillera Mountain Range, similar mechanisms likely occur, compounded by urban expansion, terracing, and slope modifications that amplify landslide risk in already deforested catchments (Depicker et al., 2021).

According to Liedel et al. (2024), beyond direct landslide initiation, human landscape modification, including deforestation, shapes sediment dynamics in mountain basins, which in turn reflects mass-wasting and slope instability. A quantitative provenance analysis (QPA) was used in the upper Magdalena River basin, Colombia to disentangle natural and anthropogenic controls on sediment generation and flux. Their analysis shows how geomorphology, lithology, and stochastic mass movements drive sediment production, while deforestation's contribution to suspended sediment flux is comparatively modest relative to rock type and connectivity factors.
This work underscores the need to consider both direct slope failure and broader sediment transport processes when quantifying the landscape-scale impacts of deforestation on hillslope instability and catchment sediment budgets, especially in tectonically active, tropical mountain contexts similar to the Philippines.

Methodology

This study uses a quantitative research design utilizing computational mathematics which makes it possible to replicate vegetation cover and slope stability based on the Factor of Safety (FS). By using a quantitative research design, the researchers are able to quantify environmental and physical elements into values that can be examined using geometric changes and mathematical formulas. This approach encourages fairness and precision while evaluating the impact of vegetation on landslide vulnerability as well as examining the effect of changes in the extent of the number of trees in the forest on FS. Thus providing scientific proof of the significance of vegetation management, reforestation, and land use in landslides in the region.

Factor of Safety (FS) or Factor of Stability is another criterion used extensively in slope stability analysis, which helps measure the likelihood of a landslide occurrence globally (Duncan and Wright, 2005). FS essentially defines a measure of the driving forces, which include gravity or the weight of the slope, against soil cohesion or root cohesion, which represent the resisting forces (Duncan and Wright, 2005). The underlying factors related to soil mechanics principles, governing how various parameters such as soil density, friction angle, slope geometry, and vegetation influence slope stability, were explained by Terzaghi et al. (1996). When FS values are below 1, the likelihood of a slope failure increases, but stable conditions exist when values exceed 1. This concept provides a valid scientific base for using FS as the dependent parameter to measure the risk of a landslide.

The precise formula with the x multiplier and particular C term is a specific research formulation, but the basic model is conventional. These particular versions are frequently discussed in scholarly articles or textbooks where the writers present their particular model or adaption. For instance, studies by Fredlund et al. and Brunsden and Prior (1984) examine comparable models. It is impossible to pinpoint a specific single source without additional information on the particular study that use this particular notation.

$$FS_y = x^y \frac{(C_{soil} + C_{roots0}) + (p \cdot g \cdot h \cdot cos\theta) \cdot tan\emptyset}{p \cdot g \cdot h \cdot sin\theta}$$

Where,

FS = Factor of Safety
x = common ratio/the increase of deforestation each year
y = number of years after the initial year
C_{soil}= soil cohesion
C_{roots} = root cohesion from vegetation
ρ = density of the soil
g = acceleration due to gravity (approximately 9.81 m/s²)
h = slope height
θ= slope angle
∅ = internal friction angle

The factor of safety in the initial year (S_0) is represented with the formula,

$$FS_y = x^y \frac{(C_{soil} + C_{roots0}) + (p \cdot g \cdot h \cdot cos\theta) \cdot tan\emptyset}{p \cdot g \cdot h \cdot sin\theta}$$

Therefore,

$$FS_y = x^y \frac{(C_{soil} + C_{roots0}) + (p \cdot g \cdot h \cdot cos\theta) \cdot tan\emptyset}{p \cdot g \cdot h \cdot sin\theta}$$

$$FS_0 = 2^0 \frac{(10kPa + 8kPa) + (18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot cos30^{\circ}) \cdot tan25^{\circ}}{18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot sin30^{\circ}}$$

$$FS_0 = (1)0.283$$

$$FS_0 = 0.283$$

Results

This section discusses the results of the mathematical modeling in determining the influence of vegetation growth on the stability of the slope through the Factor of Safety (FS). The changes in the values of FS from the initial condition towards the end of the subsequent years were estimated using the geometric progression technique to model the annual rate of vegetation growth (tree density). The annual growth rate was incorporated into the slope stability formula to estimate the values of FS for the years that followed.

Tables 1 and 2 present the results calculated in terms of FS values, which increase progressively with an annual increase in vegetation cover area. In assessing the effect of various rates of reforestation on the progress towards stability, the results are presented on the basis of the growth of vegetation following various geometric progressions. These results distinctly bring out the role of gentle growth in improving the stability state significantly within a short span of years from an unstable to a quite stable state.

Table 1. Factor of Safety of Slope Stability in Subsequent Years

Year	Formula	Factor of Safety
Initial Year (S_0)	$FS_0 = 2^0 \frac{(10kPa + 8kPa) + (18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot cos30^{\circ}) \cdot tan25^{\circ}}{18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot sin30^{\circ}}$	0.283
1 year after (S_1)	$FS_1 = 2^1 \frac{(10kPa + 8kPa) + (18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot cos30^{\circ}) \cdot tan25^{\circ}}{18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot sin30^{\circ}}$	0.566
S_2	$FS_2 = 2^2 \frac{(10kPa + 8kPa) + (18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot cos30^{\circ}) \cdot tan25^{\circ}}{18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot sin30^{\circ}}$	1.132
S_3	$FS_3 = 2^3 \frac{(10kPa + 8kPa) + (18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot cos30^{\circ}) \cdot tan25^{\circ}}{18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot sin30^{\circ}}$	2.264

In Table 1, the researchers saw that S= initial year (S_0), 1 year after the initial year (S_1), (S_2), (S_3), (S_4), that the total yearly factor of safety on the S year is equal to $FS_y = x^y \frac{(C_{soil}+C_{roots0})+(p \cdot g \cdot h \cdot cos\theta) \cdot tan\emptyset}{p \cdot g \cdot h \cdot sin\theta}$. Thus, the researchers express the following formula. The number S must always be a positive, decimal, and whole number. Hence, for all positive, decimal and whole numbers, the factor of safety is represented by

$$FS_y = x^y \frac{(C_{soil} + C_{roots0}) + (p \cdot g \cdot h \cdot cos\theta) \cdot tan\emptyset}{p \cdot g \cdot h \cdot sin\theta}$$

Assume that the number of trees increases each year by 3 times after the initial year, while all parts of the formula is still the same, during the initial year what will be the risks of the 2 years and 3 years after the initial year? Using the formula,

$$FS_y = x^y \frac{(C_{soil} + C_{roots0}) + (p \cdot g \cdot h \cdot cos\theta) \cdot tan\emptyset}{p \cdot g \cdot h \cdot sin\theta}$$

The researchers altered the equation by substituting x with 3 instead of 2 from the former decrease of trees each year after the initial year.

$$FS_2 = (9)0.283$$
$$FS_2 = 2.547$$

$$FS_3 = 2^3 \frac{(10kPa + 8kPa) + (18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot cos30^{\circ}) \cdot tan25^{\circ}}{18kN/m^3 \cdot 9.81m/s^2 \cdot 12m \cdot sin30^{\circ}}$$

$$FS_3 = (27)0.283$$
$$FS_3 = 7.641$$

Based on the problem mentioned above, if the number of trees is increased by 4 times each year after the initial year, the factor of safety 2 years after the initial year will be 2.547, and 3 years after the initial year will be 7.641. Therefore, the tested conjecture is modified to be true. The problem states that the number of trees is increasing two times each year after the initial year. The factor of safety must be twice as big as the previous year after the initial year.

Table 2. Factor of Safety of Slope Stability from Initial Year to Year 2

Year	Factor of Safety
Initial Year	**0.283**
S_1	**0.566**
S_2	**1.132**

Where, 0.283 · 2 = 0.566

Then, 0.566 · 2 = 1.132

The researchers used the concept of the geometric sequence where x is the common ratio. If x=2, the increase of the number of trees is increased by two times compared to the previous year. If x=3, the increase of the number of trees is increased by 3 times compared to the previous year. As the value x increases, the factor of safety also increases.

It can be seen from Table 1 that, starting from the initial year, the FS of the slope increases continuously to 0.566 in the first year, 1.132 in the second year, and 2.264 in the third year. In fact, this increase follows a geometric series in which FS is approximately doubled each year. Since FS is greater than 1, indicating a stable slope, these data indicate that slope condition improves gradually from highly unstable in the initial year to relatively stable by the second or third year.

The strong effects brought about by vegetation, mainly tree roots, on the stability of slopes are further illustrated by this conjecture and verification. When the assumed rate of increase for trees is changed from two times to three times a year, the FS values increase much more rapidly, at 2.547 in the second year and 7.641 in the third year since the initial year. The results obtained suggest that with accelerated reforestation or vegetation recovery, root cohesion and shear resistance increased significantly, thus rapidly improving the overall stability of the slope.

In general, the result verifies that Factor of Safety is directly proportional to the rate of vegetation growth described by the geometric progression with common ratio x. With the increase of x, the Factor of Safety also increases. This shows that the importance of continuous reforestation and management of vegetation cannot be overemphasized as a long-term approach to reducing landslides in areas like Baguio City.

Discussion

The results of mathematical modeling establish a clear correlation between vegetation coverage, stability of slopes, as well as Factor of Safety (FS). As per geotechnical criteria, regions with FS < 1 depict the onset of a potential slope failure. Thus, the initial value of FS, being 0.283, illustrates a critically unstable slope condition (Duncan & Wright, 2005). Tables 1 and 2 illustrate how incrementing changes in vegetation, modeled by a geometric progression of tree growth, lead to equal increments in FS, eventually exceeding the stability limit within two to three years.

It also puts in perspective the significance of root cohesion (C_{roots}) as a factor affecting stability in the FS equation. The more the vegetation, the higher the density of the root networks, which act to link soil particles and provide mechanical strength, thereby enhancing the shear strength of the soil. This agrees with Gray and Sotir (1996), who demonstrated that root systems function like organic soil reinforcements within slope stability equations and serve to increase resistive forces directly. Similarly, Sidle and Ochiai (2006) stated that vegetation enhances cohesiveness and reduces pore-water pressure during rainfall events, therefore improving mechanical and hydrological slope resistance.

However, the strongly beneficial, nonlinear effect of reforestation on slope stability is evident in the geometric rise in FS values, particularly in conditions under which the projected vegetation growth is estimated to triple or quadruple in a year. This is evident because FS values soared to 2.547 in the second year and 7.641 in the third year as the common ratio (x) increased from 2 to 3. This clearly indicates that the slope stability is in a highly stable position, indicating that the effects of landslides could easily be mitigated by accelerating the process of vegetation development. This observation is in conformity with the study performed by Norris et al. (2008), who noted that bio-engineering techniques involving re-vegetation techniques significantly improve the stability of the slope in a short duration of time.

Hydrological factors contributing to the significance of vegetation, included in the FS model, are soil density (ρ), gravitational force (g), slope height (h), and slope angle (θ). Rainfall infiltration decreases effective stress and shear strength in deforested slopes by increasing pore-water pressure. Indeed, according to Bathurst et al. (2010), wooded slopes develop a better drainage behavior with lower runoff velocities and thus directly reduce the risk of landslides during heavy precipitation. In Baguio City, where typhoon-induced rainfall commonly saturates the soils and leads to slope failure, this mechanism is particularly relevant (Abancó et al., 2021).

Moreover, regional and international case study research connecting deforestation with the triggering of landslides can also be validated by the outcome of this model. Araza et al. (2021) concluded that landslide scars in Baguio City are geo-located inside recently deforested areas, which signify that deforestation works as a trigger factor as well as an indirect factor. Comparable findings were discovered in Far-Western Nepal, where root decrement and the enhancement of soil percolation functioned as the cause for deforestation, improving the susceptibility of landslides by 16% in a couple of years (Muñoz-Torrero et al., 2022). However, the fundamental parameters of vegetation cover, root factors, soil saturation, and slope geometry are unchanged since the time when this present FS model uses the identical parameters despite regional variations in climatic intensity.

The mathematical model, however, considers homogeneous soil conditions and idealized vegetation recovery rates, even though it successfully models the relationship between vegetation growth and FS variation. In reality, the rate of FS increase may be modulated by variations in soil type, root depth, species composition, and anthropogenic loading-several of these factors could contribute to a greater or lesser degree depending on urban growth. Even in those cases where the FS seems marginally stable, showed how structural loads from infrastructure can offset rises in stability due to vegetation (Paringit et al., 2020). This would, therefore, seem to indicate that reforestation, in itself, may not be sufficient in heavily urbanized slopes without complementing engineering efforts.

In summary, the debate affirms the model's mathematical expression and empirical evidence for earlier research stating the direct proportionality of the Factor of Safety to vegetation-driven root cohesiveness. The integration of geometric growth into FS calculation provides a simple yet effective framework for demonstrating how deforestation promotes instability and how reforestation may reverse this tendency. These results bring into focus the necessity for consistent vegetation management, stringent land-use regulations, and integrated slope stabilization techniques that could reduce the long-term risk of landslide occurrences in slope-prone cities like Baguio.

Conclusion

This research proves that the factor of vegetation cover plays an important role in the stability of slopes, where the factor of safety (FoS), attained under deforested slopes is very low, and even slight increases in vegetation cover greatly and progressively improve the stability of slopes. The findings of this research are in agreement with the views expressed by certain researchers who found the role of vegetation in the stabilization of slopes under extreme rainfall to be very important (Gray and Sotir, 1996; Sidle and Ochiai, 2006; Araza et al., 2021).

Based on the results, reforestation, protection of the forests, controlled conversion of the land, and a combination approach involving vegetation, drainage, and slopes be adopted and recommended as important approaches or strategies related to the management and planning of land. This strategy has been recognized and supported by the local and national policies on the environment and proved to be successful in reducing the susceptibility to landslide disasters in tropical mountainous areas (Bathurst et al., 2010; Norris et al., 2008; Paringit et al., 2020). For future research, the following can be recommended: the proposed model can be enhanced or improved through the consideration of soil type variation, plant species, and root depth, and the influence of rainfall intensity, soil moisture, and climate change events. Validation and testing using different approaches and methodologies involving field data, remote sensors, and the production of landslide inventories using GIS can be recommended and adopted (Abancó et al., 2021; Klimeš et al., 2019; Xian et al., 2025).

References

Abancó, C., Bennett, G. L., Matthews, A. J., Matera, M. a. M., & Tan, F. J. (2021). The role of geomorphology, rainfall and soil moisture in the occurrence of landslides triggered by 2018 Typhoon Mangkhut in the Philippines. *Natural Hazards and Earth System Sciences*, *21*(5), 1531–1550. https://doi.org/10.5194/nhess-21-1531-2021

Araza, A. B., Castillo, G. B., Buduan, E. D., Hein, L., Herold, M., Reiche, J., Gou, Y., Villaluz, M. G. Q., & Razal, R. A. (2021). Intra-Annual identification of local deforestation hotspots in the Philippines using earth observation products. *Forests*, *12*(8), 1008. https://doi.org/10.3390/f12081008

Bathurst, J. C., Bovolo, C. I., & Cisneros, F. (2010). Modelling the effect of forest cover on shallow landslides at the river basin scale. Ecological Engineering, 36(3), 317-327.

Biotechnical and soil bioengineering slope stabilization. (n.d.). Google Books. https://books.google.com.ph/books/about/Biotechnical_and_Soil_Bioengineering_Slo.html?id=kCbp6IvFHrAC&redir_esc=y

Depicker, A., Govers, G., Jacobs, L., Campforts, B., Uwihirwe, J., & Dewitte, O. (2021). Interactions between deforestation, landscape rejuvenation, and shallow landslides in the North Tanganyika–Kivu rift region, Africa. *Earth Surface Dynamics*, *9*(3), 445–462. https://doi.org/10.5194/esurf-9-445-2021

Elevation of Baguio, Philippines Elevation Map, Topography, Contour. (n.d.). https://www.floodmap.net/Elevation/ElevationMap/?gi=1728930

Epic Force Project - papers. (n.d.). https://research.ncl.ac.uk/epicforce/papers.htm
Brunsden, D., & Prior, D. B. (1984). Slope instability. John Wiley & Sons.

Home | Food and Agriculture Organization of the United Nations. (n.d.). FAOHome. https://www.fao.org/home/en/?fbclid=IwY2xjawPWpcJleHRuA2FlbQIxMABicmlkETFZajJaUGdKQ0oyeWNkbEF3c3J0YwZhcHBfaWQQMjIyMDM5MTc4ODIwMDg5MgABHjVvBO3jtNeZGf5drYsdhAUAF9AaPkm_JIddARH5ajLe30vzUHRJYKMQvQeA_aem_ywGkdAMyTnJJfeis0MB0cA

Kim, T., Bong, T., & Kim, D. (2025). Probabilistic analysis of infinite slope stability considering variation in soil depth. *Applied Sciences*, *15*(2), 936. https://doi.org/10.3390/app15020936

Klimeš, J., Calvello, M., & Auflič, M. J. (2019). Objectives and main results of "Community Participation for Landslide Disaster Risk Reduction" thematic papers. Landslides, 16(9), 1745–1746. https://doi.org/10.1007/s10346-019-01246-z

Landslides. (n.d.). Google Books. https://books.google.com.ph/books/about/Landslides.html?id=MEPwAAAAMAAJ&redir_esc=y

Lu, N., & Godt, J. (2008). Infinite slope stability under steady unsaturated seepage conditions. *Water Resources Research*, *44*(11). https://doi.org/10.1029/2008wr006976

Libretexts. (2024, March 22). *9.3: Geometric sequences and series*. Mathematics LibreTexts. https://math.libretexts.org/Bookshelves/Algebra/Advanced_Algebra/09%3A_Sequences_Series_and_the_Binomial_Theorem/9.03%3A_Geometric_Sequences_and_Series

Manchado, A. M., Ballesteros-Cánovas, J. A., Allen, S., & Stoffel, M. (2022). Deforestation controls landslide susceptibility in Far-Western Nepal. *CATENA*, *219*, 106627. https://doi.org/10.1016/j.catena.2022.106627

Norris, J. E., Stokes, A., Mickovski, S. I., Cameraat, E., Rens, V. B., Nicoll, B. C., & Achim, A. (2008). *Slope stability and erosion Control: Ecotechnological solutions*. https://doi.org/10.1007/978-1-4020-6676-4

Paringit, M. C. R. (2020). ASSESSMENT OF LANDSLIDE SUSCEPTIBILITY: a CASE STUDY OF CARABAO MOUNTAIN IN BAGUIO CITY. *International Journal of Geomate*, *19*(71). https://doi.org/10.21660/2020.71.9261

Remondo, J., Sánchez-Díaz, M., & Cuesta-Albertos, J. A. (2025). An increasing trend of landslides as a consequence of the global change. *Earth Systems and Environment*. https://doi.org/10.1007/s41748-025-00685-0

Soil Strength and Slope Stability, 2nd Edition. (n.d.). Wiley.com. https://www.wiley.com/en-us/Soil+Strength+and+Slope+Stability%2C+2nd+Edition-p-9781118651650

Soil Mechanics in Engineering Practice (1996), by Karl Terzaghi & Ralph B. Peck & Gholamreza Mesri : Free download, borrow, and streaming : Internet Archive. (2022, April 2). Internet Archive. https://archive.org/details/soil-mechanics-in-engineering-practice-1996-by-karl-terzaghi-ralph-b.-peck-gholamreza-mesri/page/n3/mode/2up

Slope Stability Analysis. (n.d.). Geoengineer.org. https://www.geoengineer.org/index.php/education/slope-stability/slope-stability-analysis

Xian, J., Zhu, J., Leung, A. K., Wu, C., Feng, S., & Zhang, J. (2025). Using global sensitivity analysis to quantify the uncertainty of root reinforcement in vegetated slope stability. *Plant and Soil*, *513*(2), 1741–1771. https://doi.org/10.1007/s11104-024-07162-z