GIS MAPPING OF SOIL THICKNESS SPATIAL DISTRIBUTION AS APPLICATION OF THE SLOPE ANGLE CORRELATION

Cheryl F. Daleon
Central Mindanao University, University Town, Musuan, Maramag, Bukidnon, Philippines 8710
Correspondence Contact No.: +639975183337; Email: cfdaleon18@gmail.com

ABSTRACT: *One of the most important factors controlling shallow landslides and a crucial input parameter in the slope stability analysis is the soil thickness. The spatial distribution of soil thickness is essential in deterministic landslide susceptibility assessment while it is costly and time-consuming to determine. To address this problem which is a result of laborious field investigation, efforts had been done to predict this parameter over large areas. Hence, this study derived a correlation and used it to map the soil thickness distribution in one of the mountainous areas in Bukidnon Philippines, particularly in Kibawe. The data are obtained from 30 sampling locations and the slope map is generated through a processed Digital Elevation Model (DEM) in Geographic Information System (GIS). The regression analysis is used to formulate the correlation between the two parameters. The result revealed that the slope angle has yielded a high correlation to the soil thickness with an R^2 of 0.9284. Validation is done from different locations of ten sampling sites with similar geologic classes. The derived correlation is utilized to map the soil thickness distribution of other areas with the same geologic class.*

Keywords: correlation, GIS, mapping, slope angle, soil thickness

1. INTRODUCTION

Landslides are the most widespread natural hazard on earth and had been a problem in many countries worldwide. In the Philippines, landslides are among the major geologic hazards that resulted to thousands of lives lost and millions of pesos of economic damage over the years [1]. Thus, in a country that is mostly hilly and mountainous, the utilization of land on slopes is inevitable. It is therefore very important to map out unstable areas in order to ensure the safety of the people and delineate suitable areas for development [2].

The deterministic method of landslide hazard assessment is one of the most reliable methods in providing accurate landslide risk information. Moreover, soil thickness is one of the most important factors controlling shallow landslides and a crucial input parameter in slope stability analysis. Determining its spatial distribution, especially for large-scale landslide hazard assessment is cumbersome, costly, and time-consuming.

While soil thickness distribution is difficult to obtain over large areas, the slope angle can be easily obtained through the slope map of a processed DEM from a government agency conducting mapping projects like Phil-LIDAR (Philippine-Light Detection and Ranging). Moreover, during the field investigation, the slope angle can be verified and actually measured in the site [3].

On the other hand, the study area is in the municipality of Kibawe, which is located in the province of Bukidnon in Region X Northern Mindanao, Philippines. The municipality of Kibawe is seated about 63 km south-south-west of the province's capital city of Malaybalay and about 894 km south-south-east of the Philippine main capital Manila. The geographic coordinates of Kibawe are 7° 34' 0" N, and 124° 58' 59" E. (http://www.philippine-islands.ph, 2016). Figure 1 shows that the western portion of Kibawe is a landslide-prone area with steep slopes that reach above 30^0. Kibawe, Bukidnon with its mountainous terrain had experienced tremendous landslides in recent years that brought vast damage to properties and the natural environment. In June 2014, a state of calamity has been declared in the town of Kibawe in Bukidnon after incessant rains triggered landslides in seven villages. Authorities estimated the cost of damage caused by the landslides at P5 million (news.abs-cbn.com, 2014). According to National Disaster Risk Reduction and Management Council (NDRRMC), the hardest-hit areas are Magsaysay, Sampaguita, and Kisawa, where roads were badly damaged, affecting travel and the transportation of goods. The other villages affected by the landslides are Pinamula, Sanipon, Kiorao, and Marapangi. A total of 762 families or 4071 persons were affected by the incident.

However, this portion of Kibawe is not accessible by a four-wheel vehicle which may lead to difficulty in obtaining data during field investigation. Based on the geology map in Figure 3, it has the same geology which is Pliocene-Pleistocene in the east portion, particularly the New Kidapawan and Kiorao barangays. It was also found in the slope map that these two barangays have a complete variation of the slope ranges required in the study. Hence, this part of Kibawe is chosen as the area of study.

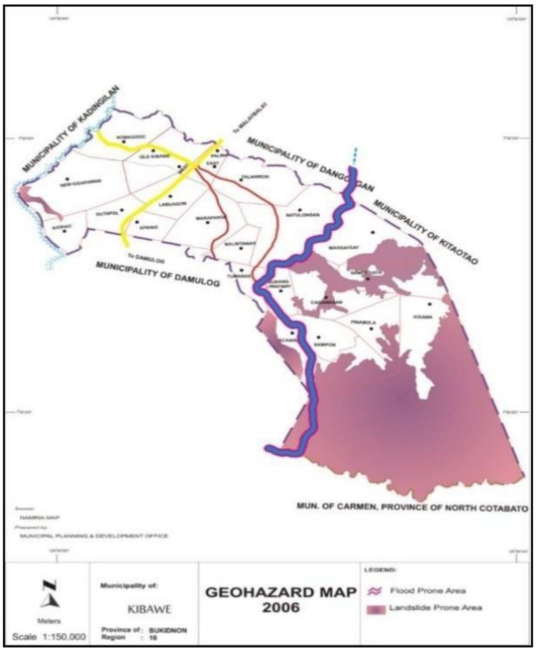

Figure 1. Geohazard Map from Kibawe Municipal Planning and Development Office (MPDO)

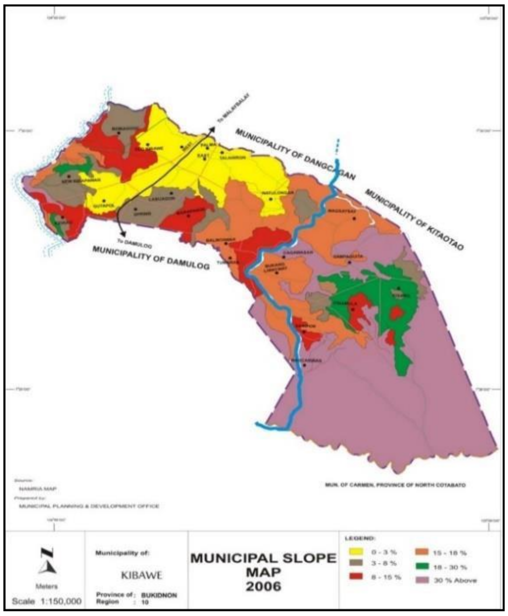

Figure 2. Slope Map from Kibawe Municipal Planning and Development Office (MPDO)

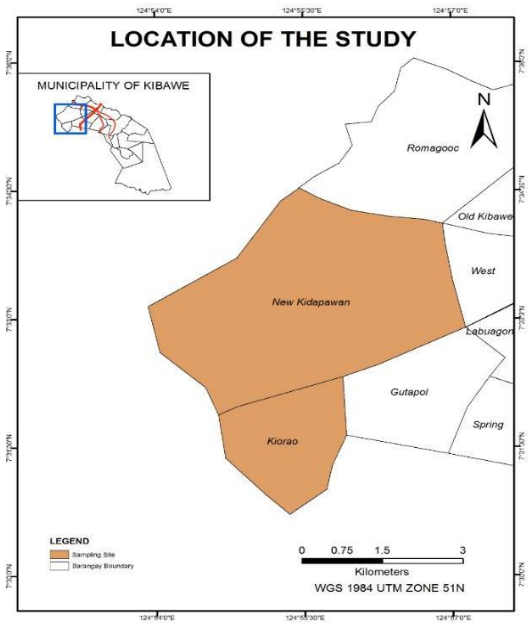

Figure 3. Geology Map of Kibawe, Bukidnon

2. METHODS

Research Locale

The study site is located at two barangays of Kibawe, Bukidnon, the Philippines specifically in New Kidapawan and Kiorao as shown in Figure 4. Based on the geology map in Figure 3, the study site has Pliocene-Pleistocene geology. Most landslide events in this municipality had occurred in this geology type. The barangays of New Kidapawan and Kiorao had various ranges of slope angles that were essential in the study.

Slope Angle from Digital Elevation Model (DEM)

One of the necessary input parameters in deriving the empirical model is the slope angle. This parameter was obtained from the digital elevation model (DEM). DEM data was acquired from the Phil-LiDAR CMU. The processed DEM was used in determining the slope angles present in the study site where it produced the slope map. The slope map of the two barangays used in the study is shown in Figure 5 which was generated from the GIS software.

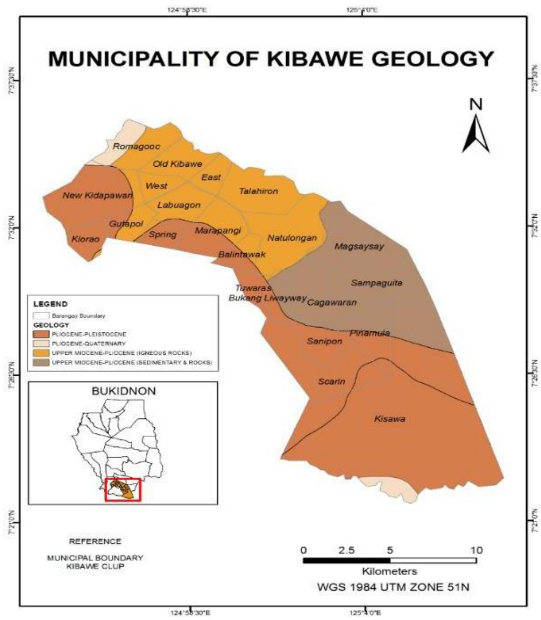

Figure 4. The study area

Field Investigation

Field exploration was conducted to obtain actual measurements of slope angle and soil thickness. Sampling points were distributed to 10 different slope angle ranges. Soil thickness of 30 locations was determined throughout the study area. The soil thickness was correlated with the slope angle using the regression analysis.

Validation of the Correlation

The derived correlation model was validated by conducting soil sampling to ten points with different slope angles at different areas but with the same geology. The sampling site used for the validation was Barangay Katipunan, Arakan, North Cotabato. This area has Pliocene-Pleistocene geology and several landslides were being experienced in the area. The soil thickness values in this sampling site were the observed values which were plotted against the predicted values computed from the empirical models. The coefficient of determination R^2 determined the validity of the model.

Generation of Output Map

The output map was generated using the GIS software. The spatial variation of soil thickness in an area was mapped using the derived empirical equation.

3. RESULTS AND DISCUSSION

Correlation of Soil Thickness with the Slope Angle

Soil is the loose material composed of weathered rock and other minerals, and also partly decayed organic matter, that covers large parts of the land surface of the earth [4-5].

Soil is the weathered and fragmented outer layer of the earth's terrestrial surface, formed initially through the disintegration and decomposition of rocks by physical and chemical processes and influenced subsequently by the activity and accumulated residues of numerous species of microscopic and macroscopic biota [5-6].

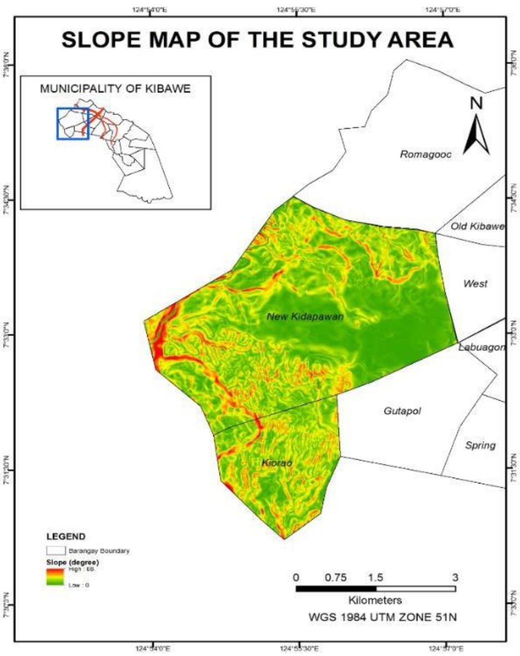

Figure 5. Slope map of the study area from GIS (Daleon and Lorenzo, 2018)

In this study, the soil thickness is referred to the depth of soil from the surface down to the weathered bedrock. This soil depth is usually the depth of failure. Some of the field methods to determine the soil thickness are by measuring the borehole, augering, and using penetrometers.

The soil thickness and regolith at any point will depend on the relative rates of soil removal and soil formation. In thin soil, very little water is retained and weathering rates are low. In very thick soils, water moves so slowly towards the weathering front that the rate of weathering is again below the potential maximum. Thus, weathering and soil formation are at a maximum at intermediate soil thickness. The soil thickness strongly affects relative slope stability, yet the spatial variation in soil thickness in landslide-prone areas is rarely estimated (two exceptions are [9-10]) [5, 7, 8]. Soils are typically thin to absent on sharply defined ridges and thickest in unchannelled valleys.

In this study, the resulting empirical model between soil thickness and slope angle with its coefficient of determination (R^2) is presented. Results showed that the best fitting model that can describe the relationship is an exponential function [3]. This finding agreed with the observation of [11-13]. Figures 6a to 6e show the different trendlines of the correlations of soil thickness with the slope angle.

Moreover, this finding conforms to the general fact being cited in the literature that soil thickness decreases with increasing slope angle. The average depths are 2.16 m for gentler slopes (< 28°), decreases to about 1.0 m for the modal class slopes (28°- 32°), and to more or less 0.5 m for the steepest slopes (> 32°).

The empirical model has a high coefficient of determination $R^2 = 0.9284$ which means that there is a high correlation between these two parameters.

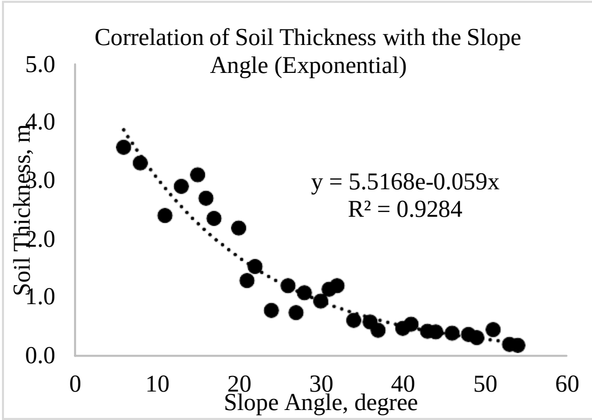

Figure 6a. Exponential

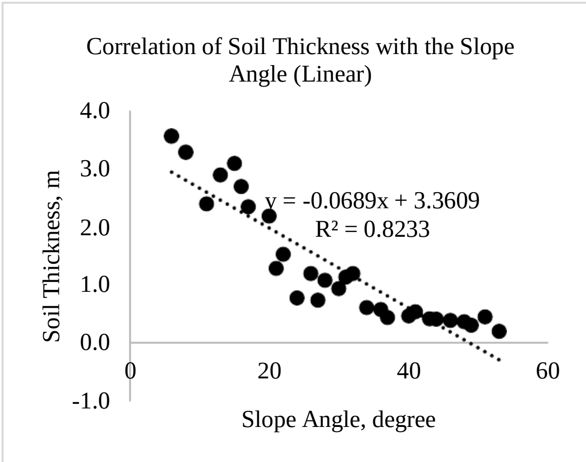

Figure 6b. Linear

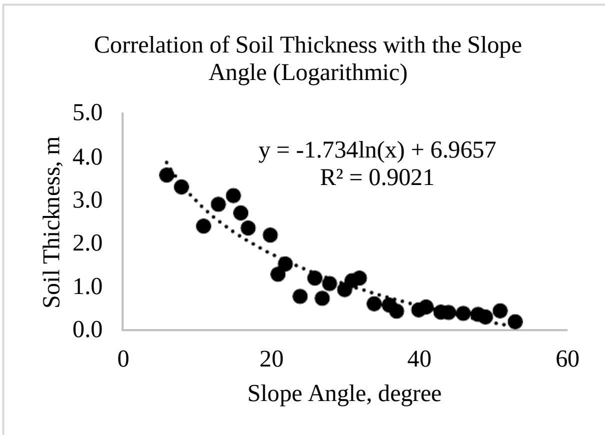

Figure 6c. Logarithmic

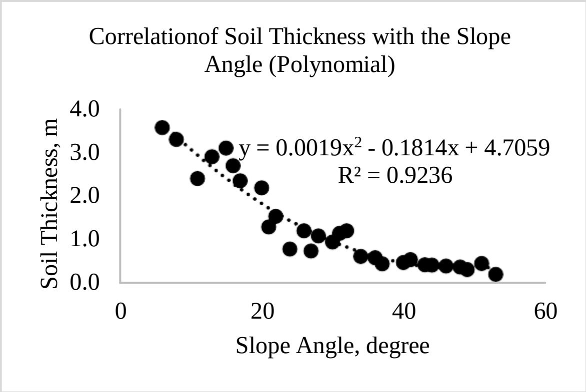

Figure 6d. Polynomial

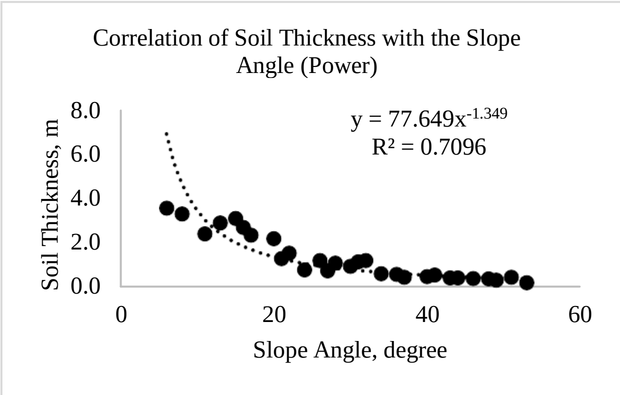

Figure 6e. Power

Hence, the resulting equation is a good empirical model to predict the spatial distribution of soil thickness with less uncertainty, especially over a large area with Pliocene-Pleistocene geology. The good correlation between soil thickness and slope angle is attributed to the fact that a steeper slope has accelerated erosion if the rate of erosion is greater than the rate of soil development it will result to thin or no soil. On the other hand, soil in low-lying areas has higher water content and more weathering resulting in thicker soils.

Validation of the Model

The quality of a regression relationship depends on the ability of the relationship to predict the dependent variable for observation on the independent variables that were not used in estimating the regression coefficients [14-15]. Hence, in order to verify the derived empirical equation between the slope angle and the soil thickness, the empirical equation derived was used to predict the soil thickness of the other 10 boreholes which were not used in the regression analysis. These 10 sites are used for validation and they are from different locations but of the same geology. Figure 7 shows the relationship of the predicted and measured soil thickness. The resulting relationship has high value of R^2 of 0.9326, which indicates that the established equation is statically reasonable and can be used to predict soil thickness of slopes located in the same geologic class.

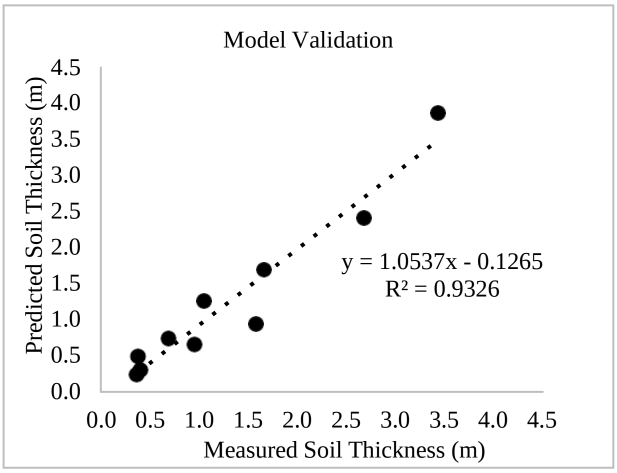

Figure 7. Predicted vs measured soil thickness (Daleon and Lorenzo, 2018)

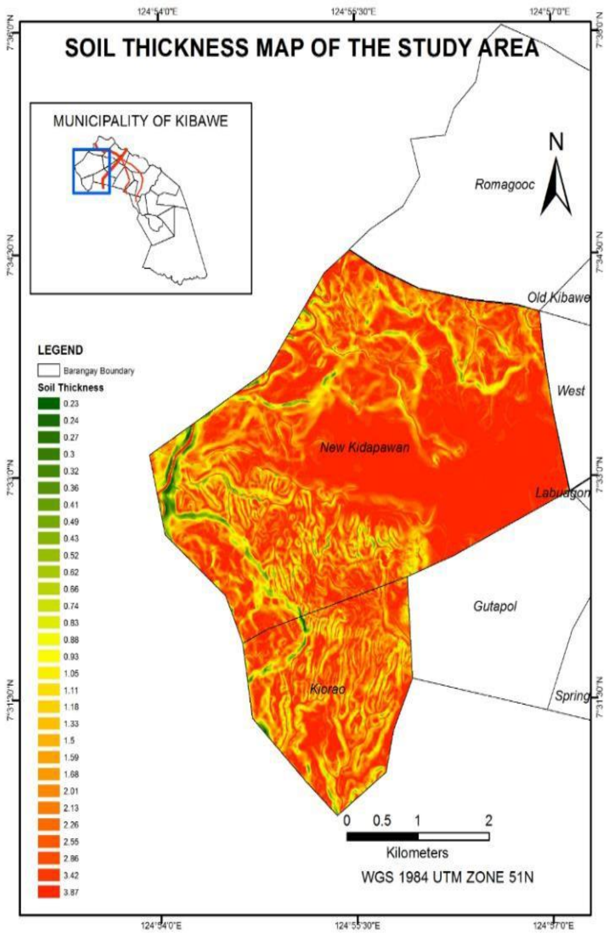

Figure 8 Soil thickness spatial distribution of Kiorao and New Kidapawan, Kibawe, Bukidnon (Daleon and Lorenzo, 2018)

The spatial distribution of soil thickness in the study area was predicted as shown in Figure 8 using the derived correlation.

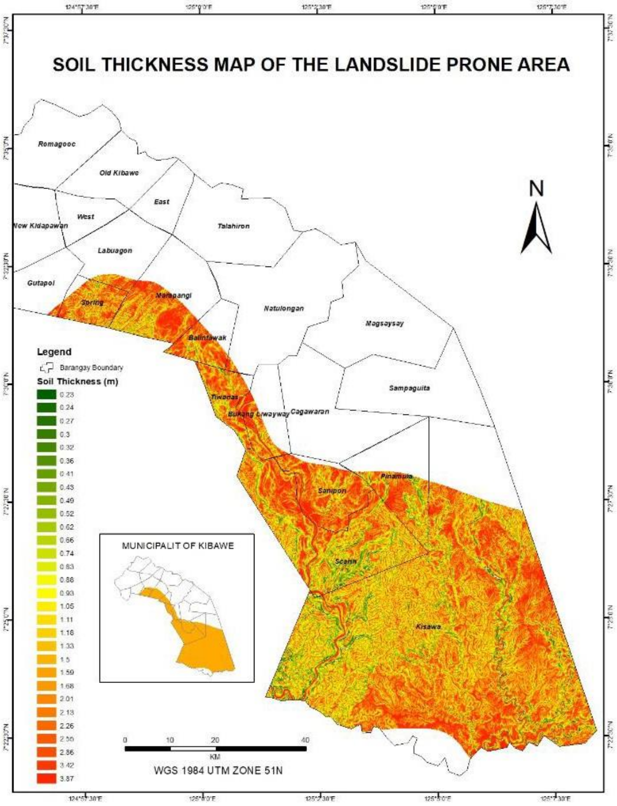

Figure 9 Spatial distribution of soil thickness of the landslide-prone areas

Figure 9 shows the spatial distribution of soil thickness in the same geology and landslide-prone areas as an application of the derived correlation of soil thickness and slope angle.

4. CONCLUSIONS

The soil thickness and slope angle yielded a good correlation with a high coefficient of determination. The derived empirical correlation can be utilized in mapping the spatial distribution of soil thickness in other areas with the same geologic class which can be helpful in the landslide susceptibility assessment of areas that are difficult to obtain data due to limited access. Different empirical correlations may be established with respect to other geologic classes. Hence, it helps resolve the issue of the determination of soil thickness distribution over large areas for application to deterministic landslide susceptibility assessment.

5. REFERENCES

[1] Opiso, E. M., Puno, G. R., Detalla, A. L., and Alburo, J. P., “Rainfall-induced landslide susceptibility zonation along with the Cagayan de Oro City – Bukidnon –Davao City Route Corridor”, *KCE, Journal of Civil Engineering*, **20**(6), 2506-2512 (2014).

[2] Rabonza, M. L., Felixa R. P., Ortiza I. J. G., Alejandrinoa I. K. A., Aquinoa D. T., Ecoa R. C., & Lagmaya A. M. F. A., “Shallow landslide susceptibility mapping for selected areas in the Philippines severely affected by Supertyphoon Haiyan”, (*Project NOAH open-file reports*). ISSN 2362 7409, **3**, 28-36, (2014).

[3] Daleon C. F. & Lorenzo, G. A., “Empirical models for predicting the spatial variation of soil thickness and shear strength for landslide susceptibility assessment”, *Journal of Nepal Geological Society*, **55** (Sp. Issue), 25-31 (2018).

[4] Wild, A., “Soils, land, and food: Managing the land during the twenty-first century”, *Cambridge University Press*, ISBN 0521527597, 9780521527590, (1993).

[5] Kobiyama, M., Gean P. Michel, G. P., “Soil depth estimation and its spatial (and temporal) distribution”, *3rd Brazilian Soil Physics Meeting (BSPM)*. Brazil, (2015).

[6] Hillel, D., “Introduction to environmental soil physics”, *Elsevier Academic Press*, Massachusets, USA (2003).

[7] Gerrard, J., “Soil Geomorphology. An integration of pedology and geomorphology”, *London: Chapman & Hall*, pp. 269 (1992).

[8] Dietrich W. E., Reiss R., Hsu M., & Montgomery D. R., “A process-based model for colluvial soil depth and shallow landsliding using digital elevation data”, *Hydrol. Process*, **9**, 383–400 (1995).

[9] Okimura, T., “Prediction of slope failure using the estimated depth of the potential failure layer”, *J. Natural Disaster Sci*. **11**, 67-89 (1989).

[10] DeRose, R. C., Trustrum, N. A., & Blaschke, P. M., “Post-deforestation soil loss from steepland hillslopes in Taranaki, New Zealand”, *Earth Surf. Process Landforms*. **18**, 131-144 (1993).

[11] Tan, C. H., Ku, C.Y., Chi S.Y., Chen Y. H, Fei, L.Y., Lee, J. F. & Su, T. W., “Assessment of regional rainfall-induced landslides using 3S-based hydro-geological model”, *Landslides and Engineered Slopes*. ISBN 978-0-415-41196-7 (2008).

[12] Salciarini, D, Godt, J. W., Savage, W. Z., Conversini, R., Baum, R. L., & Michael, J. A., “Modelling regional initiation of rainfall-induced shallow landslides in the eastern Umbria Region of central Italy”, *Landslides*, **3**, 181–194 (2006).

[13] DeRose, R. C., “Relationships between slope morphology, regolith depth, and the incidence of shallow landslides in eastern Taranaki hill country”, *Zeitschrift fur Geomorphologie Supplementband*. **105**, 49–60 (1996).

[14] Haan, C. T., “Statistical methods in hydrology”, *Affiliated East-West Press Pvt. Ltd*. New Delhi, India, (1994).

[15] Akayuli, C. F. A. & Ofosu, B, “Empirical model for estimating compression index from physical properties of weathered Birimian Phyllites”, *CSIR-Building and Road Research Institute. EJGE*, **18**, 6135 – 6144. KNUST-Kumasi, Ghana (2013).