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Landslide Hazard Investigation in Papua New Guinea-A Remote Sensing & GIS Approach

Sujoy Kumar Jana[1], Tingneyuc Sekac[2], Dilip Kumar Pal[3]

Abstract: ***Tribal communities living in the mountainous regions of Papua New Guinea (PNG), often experience frequent landslides during the rainy season. The Eastern Highlands Province (EHP) is one such landslide prone province located in the mountain regions of PNG. Landslide is classified as a natural hazard that has a critical geological process to inflict an enormous damage to civil engineering structures including other valuable assets. The research study was aimed to monitor and assess landslide hazards by remote sensing data processing and GIS spatial analysis. The occurrence of landslide is controlled by a number of morphological, geological and human factors. However, according to the availability of data, only certain principal factors are considered in the present study. The analysis focuses certain landslide contributing factors in generating landslide hazard map of the area. For this study, ranking, classification and weighted overlay analysis techniques were commonly used to generate landslide hazard map.***

Keywords: GIS, Hazard Map, Landslide, Potential Index, Remote Sensing

1. Introduction

Landslides in mountainous terrain often occur during or after heavy rainfall, human activity like indiscriminate felling of forests on steep slopes and / or natural tectonic processes inducing earthquakes result in the loss of life and damage to the natural and /or built environment [3]. When these activities happen and shear stress exceeds the shear strength of the material, then the landslide occurs. The downward movement of surface material takes place under the influence of gravity, and the mobility of such movement is enhanced by water content in the sediment [3]. Since the early 1970s, many scientists have attempted to assess landslide hazards and produced susceptibility maps portraying their spatial distribution by applying many different GIS based methods. The results of published papers show that landslide susceptibility and hazard maps have become very effective tools for planners and decision makers [5].

It is understood now that in order to delineate or generate the landslide hazard maps, in addition to tectonic instability of the terrain certain geo-morphological and geological factors like lithology, slope, rainfall, land use land cover, soil type etc. are to be considered. Thus these factors are the contributing factors to occurrence of landslide. All the factors are processed in the GIS environment to come up with landslide hazard map. Landslide hazard (LH) defines the physical attributes of a potentially damaging landslide in terms of mechanism, volume and frequency and therefore landslide hazard assessment (LHA) estimates the probability of a landslide occurrence within a certain period of time in a given area [5].

2. Study Area

The area selected for the research study for landslide hazard zonation is in the Eastern highlands province, located around Latitude 60 30’ S and Longitude 1450 30’ E. It is in the mountainous region of PNG. Whole part of the province is assessed for landslide hazard. The total study area is approximately 11,200 sq kilometres.

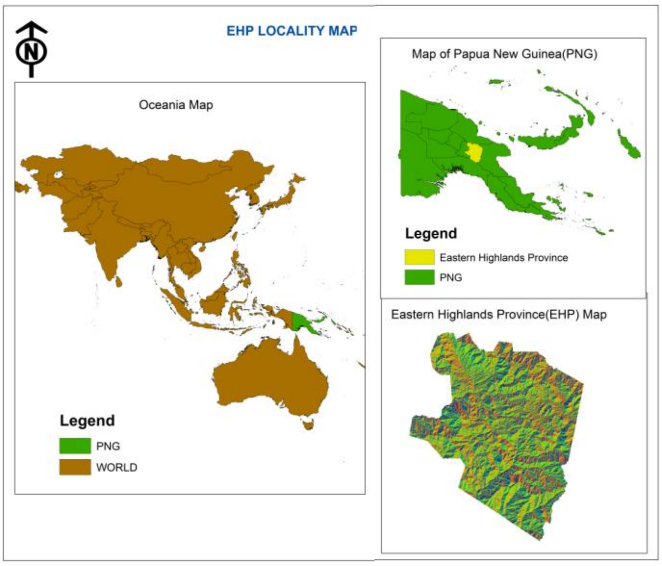

Figure 1: location map of the study area

3. Data Used and Methodology

Table 1: Different data layers/maps

Data Layer	Source
Soil data/map for EHP	PNGRIS metadata
Landsat8 Satellite data(28.5 spatial resolution) captured 2008 for whole PNG	Surveying and lands department-PNG Unitech
Landform and Lithology data/map for EHP	PNGRIS metadata
Rainfall data for EHP	PNGRIS metadata
DEM data(SRTM) for PNG(90m spatial resolution)	Surveying and lands department-PNG Unitech
Vegetation type	PNGRIS metadata
Terrain data (slope and Height)	Surveying and lands department-PNG Unitech

Soil, rainfall, landform, vegetation type and lithology data for Eastern highlands province was collected from surveying and lands department at The PNG University of Technology. The data was again in the GIS environment was updated using the satellite images and according to PNGRIS data, it was again reclassified and was assigned a specific value. The metadata was rectified to WGS 1984 UTM zone 55. Land use and land cover type for the EHP were prepared from

Landsat8 satellite data, captured 2008. For the slope and altitude for EHP, it was prepared using the SRTM DEM data for PNG at 90m spatial resolution by using the extraction and slope analysis tools in ArcGIS 10. The entire data bases were prepared and arranged using the ArcGIS 10 and ERDAS Imagine 8.5 software and was all projected to the same projection system. MapInfo Professional 10.1 was used to convert tab format vector data to shape file, where it was readable by ArcGIS 10 software. From there, all vector layers that is soil, rainfall, lithology and landform were rasterized to produce the maps according to PNGRIS metadata. The entire data base were prepared and arranged for generating landslide hazard zonation. The data prepared, are the common factors that can contribute to generating landslide hazard mapping.

4. Results and Discussion

Soil type: Soil is one of the common factors that determine the susceptibility of landslide prone areas in a particular regions/province. The topsoil cover on a slope has an influence on landslide occurrence or in the steep slope area or on the hill top. The soil data for EHP was collected from Surveying and Lands department at PNG University of technology; it was then geo-referenced to match the satellite image. According to PNGRIS metadata the soil map was reclassified and then followed by assigning weightage. It was found out from PNGRIS metadata that the soil type of the area are mainly fine to coarse loamy soil and fine loamy calcareous/chalky. The loamy calcareous soil is highly prone to landslide. (Pareta.et al, 2014). According to that, it was given a weight. The type of soil identified or demarcate for the EHP is shown in figure 2 (A)

Land use land cover: As illustrated in figure 2(B), it is the land cover type of EHP that was extracted from Landsat8 satellite image and was classified in the ERDAS Imagine software 8.5. Thus land cover type plays an important role in determining the occurrence of land slide. For example if the pristine forests near the hill top of an extremely steep mountain area was once cleared for the agricultural purpose, then at that particular area, the landslide can initiate because there is no strong roots to bind the soils. Once heavy rain and / or earthquake happen, then that particular area can be prone to land slide. In the land cover map above, from classification, certain areas are shown. It was weighted in terms of vulnerability for landslide occurrence.

Lithology: Lithology data for EHP was collected from the surveying and lands department at PNG University of technology. In the GIS environment, the data was updated with satellite image and with PNGRIS metadata. Lithological data are the data about types of rocks found in the study area. It was found out that the type of rocks as illustrated in figure 2(C) are: limestone, metamorphic, igneous, pyroclastics and alluvial deposits. These are the rock types commonly found in EHP. Based on the rock types, weather it is strong or weak the area becomes vulnerable to landslides of varied ferocity.

Landform: The data for types of landform found in EHP was collected from surveying and lands department at PNG University of technology. According to PNGRIS metadata, the landform map was produced by editing its attribute table in ArcGIS and was reclassified. Figure 2(D) illustrate the landform types found in EHP. It can be confirmed that the bulk of area for landform type in EHP is covered by Mountains, hills, cliff. The hilly or mountain areas can be more prone to landslide activity, however the vulnerability will be determined by types of rocks or soil or land cover out there. Therefore all the factors are to be weighted and rank accordingly to produce a final output map for landslide hazard zonation.

Slope and Height morphology: Slope and height play an important role in governing the stability of a terrain. As the slope increases, chances of slope failure also increase. (Pareta.et al, 2014). But however, there are some controlling factors like soil and or rock type or land cover may also determine the slope failure in a steep slope. Like for example if the soil is fine loamy chalky soil, then landslide may not occur. The shape of a slope influences the direction of and amount of surface runoff or subsurface drainage reaching a site [1]. Concentration of subsurface drainage within a concave slope, resulting in higher poor water pressures in the axial areas than on flanks, is one possible mechanism responsible for triggering landslides [2]. Figure 3 (E) & (F) illustrate the terrain slope and height For EHP.

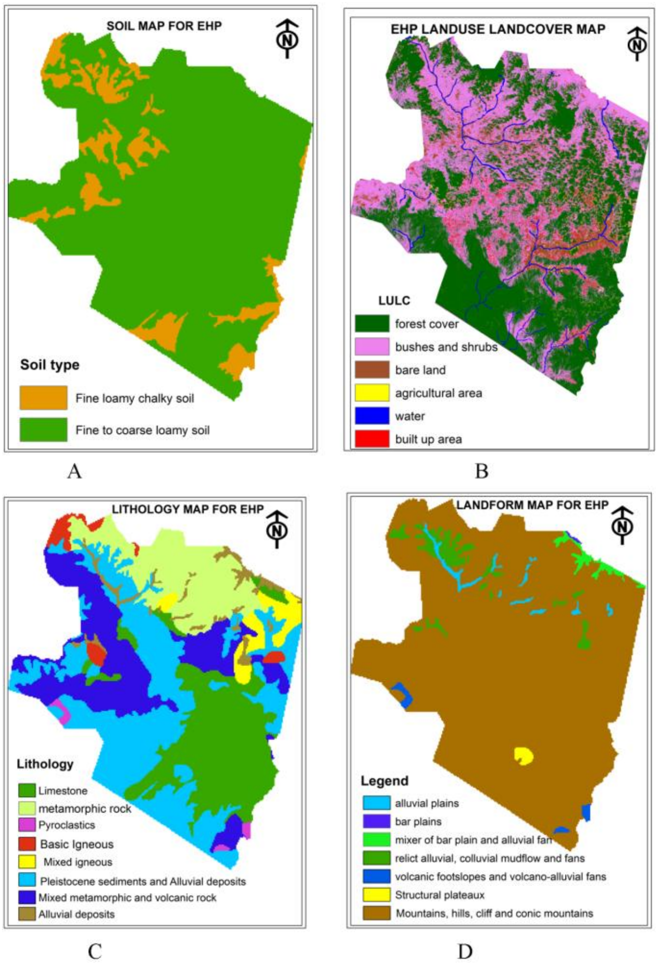

Figure 2: Thematic layer of soil, land cover, lithology and lanform

Rainfall: Rainfall is one of the main factors that lead to trigger landslide. Rainfall pattern of the certain locations of the study area, determines how frequent the landslides are to occur. However there are other controlling factors besides

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rainfall that will combine with rainfall pattern to show the susceptibility areas for landslide. The rainfall data was collected from surveying and lands department at PNG University of technology. According to PNGRIS metadata, the rainfall pattern of EHP was edited and reclassified to produce a final map for rainfall pattern for EHP and was given rank and weightage according to the amount of rainfall. Figure 3(G) illustrates the rainfall pattern for EHP.

Vegetation: Type of vegetation like dense vegetation, sparse and mixed vegetation of the study area, can be a very helpful information or data to combine with other landslide controlling factors to delineate landslide prone areas. Thus the type of vegetation data for EHP was collected from surveying and lands department at PNG University of technology. According to the PNGRIS metadata and the vegetation attribute table for EHP the vegetation map was prepared. Figure 3(H) illustrate the type of vegetation found in EHP. Like dense vegetation, may not be more prone to landslide activity; however sparse vegetation or no vegetation will be more prone to landslide activity.

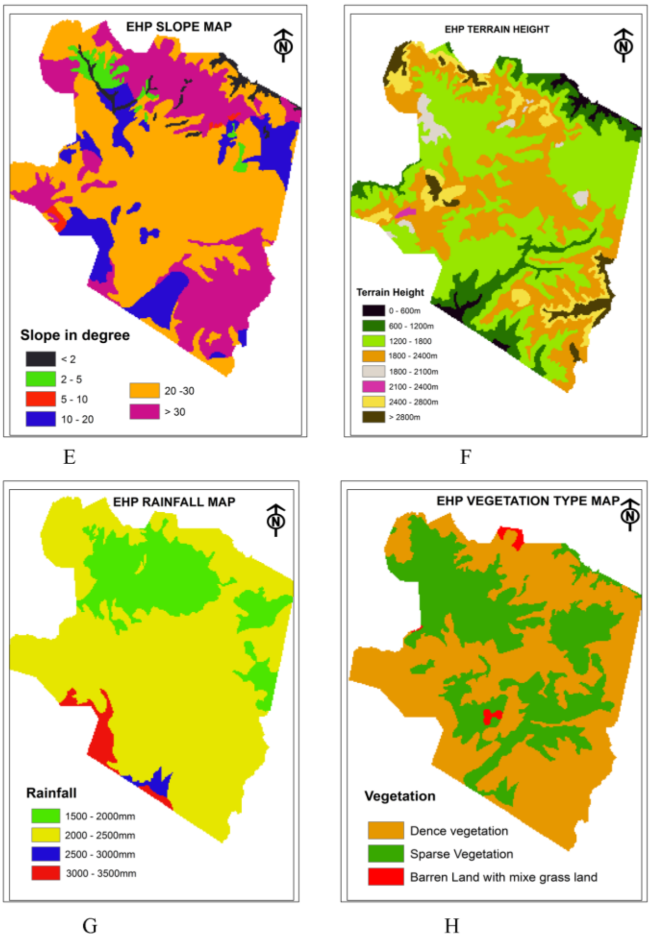

Figure 3: Thematic layer of slope Height, rainfall and vegetation

4.1 Formulations of Thematic data layers for landslide hazard zonation

The landslide examination and hazard zonation mapping study involves preparation of number of thematic databases such as terrain slope, terrain height, drainage density/drainage pattern, soil type, landform, lithology, vegetation type and land cover (Pareta.et al, 2014). When formulating and combining the thematic layers by applying weighting, ranking or applying some form of statistical calculation in ArcGIS 10 software, the landslide hazard zonation map can be produced. Thus the hazard map can be more important or useful to civil engineers for construction purpose and also to community of mountainous region, where landslide hazard map can give better idea or let them be aware of landslide prone areas in their area. Thus mitigation or adaptation measures can be put forward.

4.1.1 Numerical scheme towards preparation for landslide zonation

The identification of potential landslide areas requires that the factors considered be combined in accordance with their relative importance to landslide occurrence. This can be achieved by developing a rating scheme in which the factors and their classes are assigned numerical values [4]. The rating scheme is a formulation that identifies the probability of each factor and each factor's classes that are prone to landslide activities. That is to say, each factor is assigned ranks at a scale of 1 to 8, depending on the number of factors and each class pertaining to the factors are assigned weights between 0 and 8 in order of importance. The weights and ranks are assigned according to its relative significance towards occurrence of landslide. Thus Ranks and Weights of causative factors (parameters) need to be assigned in order to generate a landslide hazard zonation map. The relevant factors for landslide hazard zonation mapping should include; slope, rainfall, terrain height, and vegetation type of EHP, soil type, land cover, lithology and landform. These are the factor/data for EHP that was collected and prepared for assigning ranks and weightings to generate landslide hazard map of the province. Table 2 illustrates the ranks and weightings of factors for landslide.

Table 2: ranks and weights for factors and their classes

Factor	*Classes*	*Ranks*	*Weights*	*remarks*
Slope	< 2	8	1	Steep slopes are more susceptible to landslide, so weight is given >30. Slope factor is highly prone to landslide, so it is rank 8
	2 – 5		2	
	5 – 10		4	
	10 – 20		6	
	20 - 30		7	
	>30		8	
Terrain Height	0 - 600	7	1	Terrain height more than 2800 highly prone to landslide activity. The rank was given to terrain height as 7.
	600 -1200		2	
	1200 - 1800		3	
	1800 - 2100		4	
	2100 - 2400		5	
	2400 - 2800		6	
	>2800		8	
Rainfall	1500 – 2000	6	2	Higher the rainfall frequency at a particular area, the landslide is more likely to happen
	2000 – 2500		5	
	2500 – 3000		6	
	3000 - 3500		8	
soil	Fine to Coarse Loamy Soil	5	4	Fine loamy chalky soil, defined by its name is highly prone to landslide. Hilly or mountain areas that have this type of soil, the
	Fine Loamy chalky Soil		8	
Vegetation type	Dense vegetation	4	1	Bare land with mixed grassland is more prone to landslide activity. The rainfall hits the soil directly causing accelerated erosion, also there is no vegetation type like thick forest to hold the soil columns
	Sparse vegetation		5	
	Bare land with mixed grassland		8	
Lithology	Basic igneous rock	3	1	Alluvial deposits, that is; clay or silt or gravel carried by rushing streams and deposited where the stream slows down, are highly prone to landslide activity
	Mixed igneous rock		2	
	Pyroclastics		3	
	Metamorphic		4	
	Mixed metamorphic		5	
	Limestone		6	
	Pleistocene sediment		7	
	Alluvial deposits		8	
Landform	Structural plateaux	2	1	Type of landforms that was identified as mountains, hills or cliffs are more prone to landslide activities
	Alluvial plains		2	
	Bar plains		3	
	Mixer of bar plain and alluvial fans		5	
	Relict alluvial		6	
	Volcanic foot slopes		7	
	Mountains, hills, cliffs		8	
Land use land cover	Water	1	0	Bare land or built up areas like road construction, buildings, are more prone to landslide activities
	Forest cover		1	
	Bushes and shrubs		3	
	Agricultural area		5	
	Built up area		7	
	Bare land		8	

4.1.2 Landslide Susceptibility Mapping

All the thematic data layers were assigned ranks according to its potential in triggering landslide hazard. On the other hand, the weights were also assigned to each class of each factor. The numerical data layers representing weight values of the factor classes as attribute information were generated from the thematic data layers for data integration and spatial analysis in the GIS. The input data layers were multiplied by their corresponding ranks and were added up, to obtain the Landslide Potential Index (LPI) [4] i.e:

LPI = $\sum_{i=1}^{8}(Ri * Wij)$

(SLP * 8) + (ALT * 7) + (RN * 6) + (SL * 5) + (VEG * 4) + (litho * 3) + (lndfm * 2) + (LULC * 1)

Where Ri denotes the rank for factor i and Wij denotes the weight of class j of factor i.

SLP = slope factor, ALT = altitude (height), SL = soil, RN = rain, VEG = vegetation, LULC = land use land cover, lndfom = landform and litho = lithology

Thus this was the algebraic mathematical formula that was performed using raster calculator tool in ArcGIS 10 to generate final landslide hazard zonation according to weights and ranks given.

The landslide potential index once organised and computed, ranges from 676 to 3922. Thus these values are reclassified into 5 landslide hazard susceptible zones and these are: low potential zone, medium potential zone, and medium to high potential zone, high potential zone and very high potential zone. Thus this was the final output map for landslide potential zonation generated from contributing, weighting and ranking all factors that are illustrated in Figure 2 (A, B, C, D) & Figure 3 (E, F, G, H). Figure 4 illustrate the EHP landslide hazard potential zone.

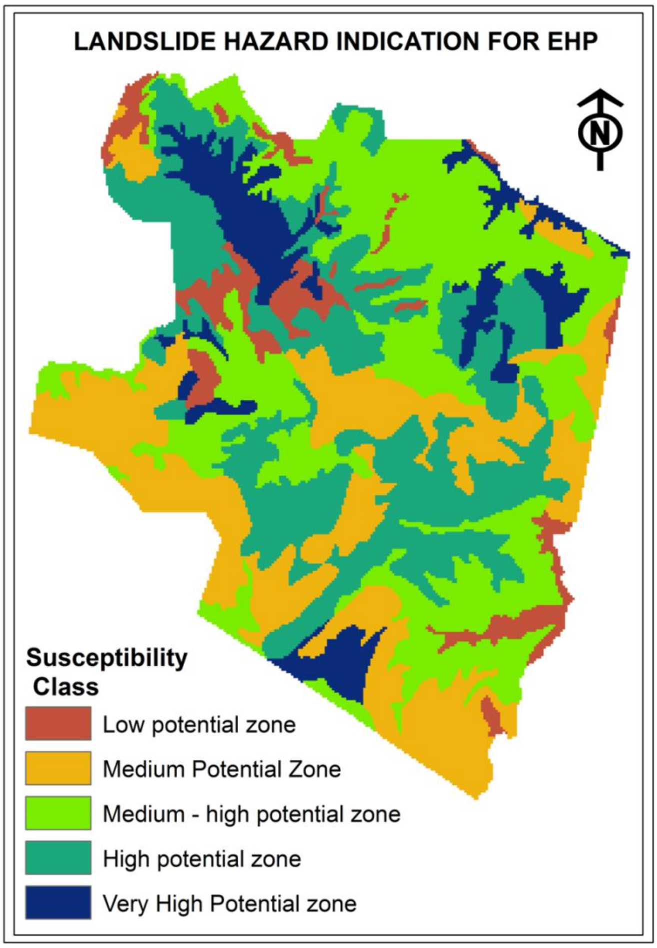

Figure 4: Landslide hazard zonation map for EHP

The landslide potential index ranging from 676 to 3922 is reclassified and arranged into 5 susceptible zones. Zones are demarcated as 5 landslide potential areas for the entire EHP as shown in figure 4. Thus table 3 shows the tabulation of Landslide potential index ranges, the susceptible zones were decided according to each ranges of LPI and finally the area covered by each susceptible classes of landslide are shown in square kilometre and percentage.

Table 3: Landslide potential index (LPI), susceptibility classes and area in percentage and km2

Susceptibility Class	LPI	Area (km2)	Area (%)
low potential zone	676 - 1288	5211.77	5.22
medium potential zone	1288 - 1845	25843.69	25.81
medium to high potential zone	1845 - 1887	33001.67	32.96
high potential zone	1887 - 2134	26964.73	26.93
very high potential zone	2134 - 3922	9097.59	9.09
Total		100119.45	100

5. Conclusion

Landslide hazards are common in mountainous areas experiencing high downpour. The hazard is aggravated by deforestation and improper land use. Moreover, such hazards further being exacerbated by frequent earthquakes are thus becoming a permanent menace to the inhabitant communities, also with respect to civil engineering construction. Events like tectonic activism, high rainfall, geology and inherent soil conditions are beyond the control of humans to manoeuvre, but pernicious human fiddling on the face of the slope by way of indiscriminate deforestation, unscientific engineering construction of building, dams etc., clearing pristine forests for agriculture should have to avoided.

In this context the research study brings out a definite relationship between the remote sensing and GIS techniques, which play a significant role in landslide zonation mapping. All the data were processed and analysed in GIS environment. The landslide hazard zonation of EHP can give clear view to the community living in EHP and civil engineers on the varied potential zones for landslide as depicted on the map. These can be a stepping stone for communities to look ahead, plan and manage their lands in a way that they can have the appropriate preparedness to mitigate the impact of landslide in such mountainous areas.

References

[1] Dai, F.C., and Lee, C.F., 2002. Landslide Characteristics and slope instability modelling using GIS, Lantau Island, Hong Kong. Geomorphology (Elsevier), Vol. 42, pp. 213-228.

[2] Dhakal, A.S., Amada, T., and Aniya M., 1999. Landslide hazard mapping and the application of GIS in the Kulekhani watershed, Nepal. Mountain Research and Development, Vol.19, pp. 3-16.

[3] Pareta. K, Kumar. J and Pareta. U, 2014. Landslide Hazard Zonation using Quantitative Methods in GIS, International Journal of Geospatial Engineering and Technology Vol. 1, No. 1, pp. 1-9

[4] Sarkar. S and D.P. Kanungo, 2004. An Integrated Approach for Landslide Susceptibility Mapping Using Remote Sensing and GIS. Photogrammetric Engineering & Remote Sensing Vol. 70, No. 5, May 2004, pp. 617–625.

[5] Vahidnia M.H, A.A Alesheikh and A. Alimohammadi, Hosseinali, 2009. Landslide Hazard Zonation using Quantitative Methods in GIS, International Journal of Civil Engineering. Vol.7, No. 3.

Author Profile

Dr. Sujoy Kumar Jana is currently employed as a Lecturer & Course Coordinator, M. Sc in Remote Sensing & GIS, Department of Surveying & Land Studies at The Papua New Guinea University of Technology, Lae, Morobe Province, Papua New Guinea.versity

Tingneyuc Sekac is currently pursuing Master of Philosophy in Geomatics, Department of Surveying & L/S, The Papua New Guinea University of Technology, Lae, Morobe Province, Papua New Guinea

Professor Dilip Kumar Pal, HOD, Department of Surveying & Land Studies at The Papua New Guinea University of Technology, Lae, Morobe Province, Papua New Guinea.versity.