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A GIS Based Approach into Delineating Liquefaction Susceptible Zones Through Assessment of Site-Soil-Geology-A Case Study of Madang and Morobe Province in Papua New Guinea (PNG)

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ABSTRACT: Tectonism induced liquefaction can be a major disaster that warrants appropriate emphasis in any infrastructure development planning. Various procedures and methods are applied throughout the world to identify potential zones of liquefaction. The output results are used as tools for site selection and finding viability of funding in infrastructure development. Thus such measure is slated to preclude future loss of life and property owing to infrastructure collapse by earthquake induced liquefaction. Liquefaction is likely to occur due to saturated soils or unconsolidated sediments under the infrastructure basement that are subjected to give way due to ground shaking. Liquefaction is one of the main geohazards related to tremor. The present study aims at assessing different soil properties and geological structures of Morobe and Madang Province culminating in delineation of Liquefaction potential zones using multi-criteria evaluation and Analytical Hierarchy Process (AHP) appraisal using GIS and Remote sensing technologies. The main data layers that are chosen for carrying out the assessment consist in available geological, soil and SRTM DEM data. Several thematic layers are prepared from the data base as mentioned, followed by assigning weightage to each thematic layer generated. Weightages were further normalized using Saaty's analytical hierarchy process. The final Liquefaction potential zone was prepared using the raster calculated from ArcGIS. The output liquefaction potential zone map was delineated and reclassified into five categories such as 'very high', 'high', 'moderate', 'low' and 'very low' potential zones.

KEYWORDS: Liquefaction, Tectonism, Geohazards, Analytical Hierarchy Process (AHP), Multi-criteria evaluation, GIS

I. INTRODUCTION

Papua New Guinea is one of the countries in the Oceania-Pacific region that lies within the influence of Pacific ring of fire – an arc of active seismic belt. According to Stanaway (2008) PNG is very active tectonically, due to its location on the edge of the colliding Australian and Pacific plates. Due to collision between these two major plates, many a smaller micro plate has evolved with varying 'relative velocity vectors' at their specific plate boundaries that have resulted in PNG having been experiencing different levels of earthquake events.

During any earthquake events, the seismic wave which is the source of shaking intensity is generated and propagates from the earthquake focus (hypocenter) to the surface. As the waves propagate, it passes through certain geological or geomorphological features and soil types, where these features according to their strength/stiffness, control or determine the wave propagation to the surface where the shaking is actually felt. The propagation of waves is amplified

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once it arrives at sediments, rock or soil types that are saturated or unconsolidated might culminate in liquefaction. The shaking hazard depends on factors such as the magnitude, properties of fault plane solutions, the distance from the fault and local geologic and geomorphologic conditions (Wilige. T, 2010). Liquefaction most often occurs when these three conditions are met; (1) loose, granule sediments or fill (2) Saturation by ground water (3) strong shaking (Britton R and Britton Consultants Ltd, 2014).

The shaking intensity is the main cause of any Liquefaction to occur. Thus Liquefaction is the process in which water is combined intensely with unconsolidated soils, generally from ground motion and pressure, which causes the soils to behave like quicksand (City of Rancho Cordova, 2006). This physical acts leads to ground failure or subsidence resulting in demolition of existing infrastructure. According to NBMG (1980) Liquefaction may occur in fills, swamps, sloughs, or bogs, or other areas of loose, unconsolidated, poorly drained material that have a high water table or are prone to flooding. Soils and geologic maps can be useful in determining areas of potential liquefaction. The idea of liquefaction due to earthquake shaking hazard was also discussed by Andrew M (2005); he has introduced that, "Many of Australia's major population centres are built on alluvial plains or coastal margins characterised by significant thicknesses of unconsolidated sediment". "Such soils and sediments near the surface can modify ground shaking during earthquakes by reducing the velocity of earthquake waves and increasing their amplitude". "This amplification can increase the risk of earthquake damage in the region".

In order to plan any infrastructure development, status of liquefaction potential in a region is to be known. Liquefaction is the main reason behind where lot of potential infrastructures do collapse related to earthquakes. If a building, bridge, road or any infrastructure that are built on unconsolidated or saturated soils and sediments, these properties are prone to collapse during earthquake events of larger magnitude at shallow depth. Understanding the levels of each liquefaction potential zones, will assist in better planning for infrastructure development and hence will aid in maintaining and improving economic growth of the country.

There is a number of ways in which liquefaction potential zones are delineated. For the present study, the application of GIS and remote sensing technology was utilized to investigate and analyse several environmental factors like; soil factor, geological factors and SRTM DEM to delineate liquefaction potential zone for the provinces through multi-criteria and Analytical hierarchy process introduced by Saaty (1980, 1992). In case of soil, the factors are; soil available water holding capacity (AWC), soil drainage and soil taxonomy was investigated and analysed. In the case of Geology, distribution of fault structures and lithological structures in terms of consolidation capability or status were investigated and analysed. For the SRTM DEM, the terrain factor was investigated and analysed.

II. Nature of the Problem

The land mass of two provinces (Madang and Morobe) are the combination of three different micro plates; New Guinea Highlands Deformation zone, South Bismarck Plate and Woodlark Plate (Stanaway R, 2008). Within the two provinces there are major subduction fault zones called Ramu Markham Fault and Owen Stanley strike-slip fault zone which make the stretch a very seismically active zone. Thus the region continues to experience frequent earthquakes of varying strengths.

Of course, in the vicinity of study area, there has been no news of major damage or loss of lives and property due to earthquakes events. The maximum earthquake magnitude recorded in the study region was 7.1 in Richter scale at a depth of 121.1km in 2011 along the Owen Stanley fault zone. The maximum shaking hazard was 14%gal. The shaking hazard attenuation relationship was expanded further so as to cover whole of the study region including neighbouring provinces; yet there had been no records of damages (figure 1). When comparing this with earthquake event of 2001 at magnitude 6.4 and depth 9km, the maximum shaking hazard was 35%gal however the shaking attenuation did not expand further. The major shaking hazard was felt within a small belt around earthquake epicentre only (figure 1) and hence no damages were recorded. Figure 1 illustrates the shaking hazard of specific major earthquake events from year 2000 up to 2016.

From the relationships of earthquake depth, magnitude and shaking intensity as discussed above and also illustrated in figure 1, it can be determined since the study region is a seismic active zone. In the event of an earthquake magnitude between the ranges of 7.1 – 8.1 at relatively shallow depth, then the event is more likely to cause tremendous impact and widespread damages would be inevitable.

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Due to region being seismic active zone and also due to such predictions, it is better to let governing bodies or general public be aware of what level of liquefaction potential zone exists beneath their feet. Therefore, it is paramount to launch studies to derive a map showing various categories of 'liquefaction potential zones' i.e. various suitability zones for infrastructure development in a study region before any major investment decision is taken up. This will help in mitigation measure and proper planning for development. Moreover, this kind of maps will prove very handy to insurance agencies to fix premium accordingly for the property insured.

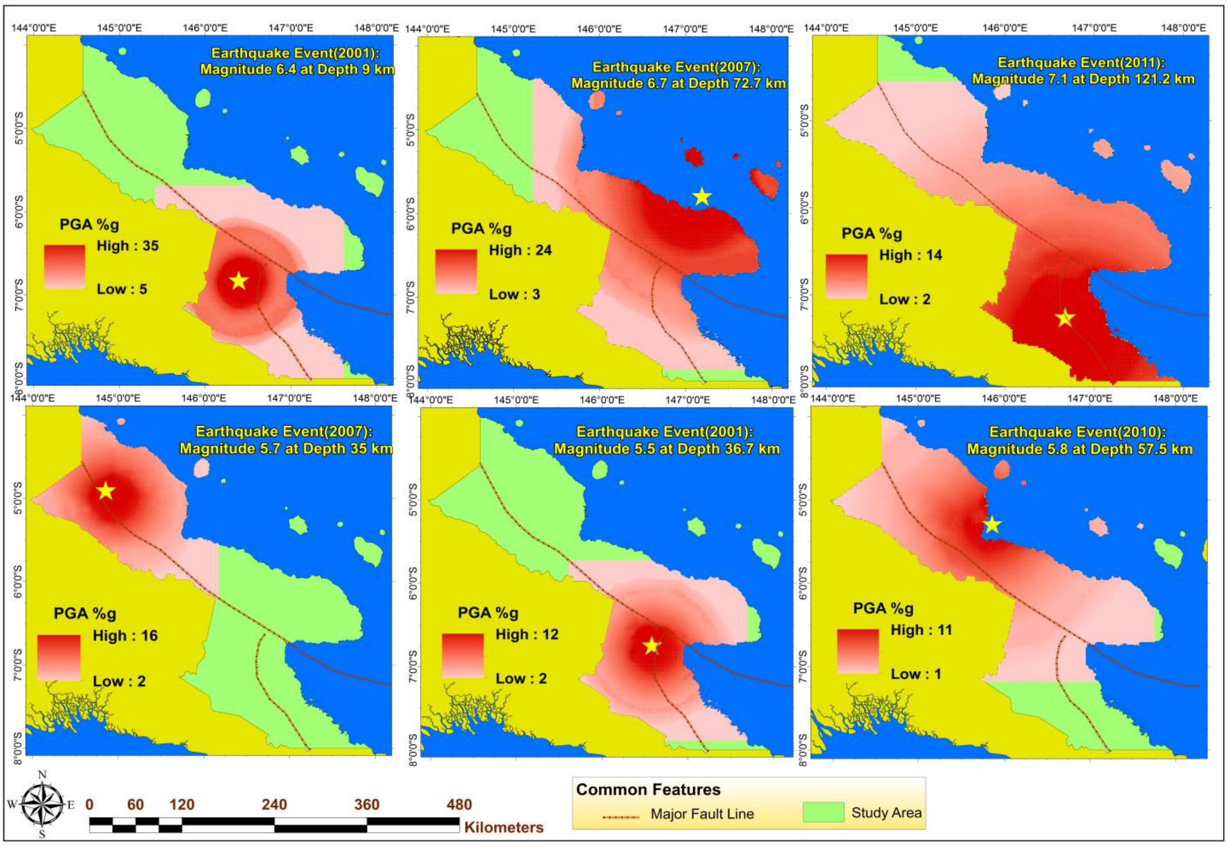

Fig 1: Ground motion attenuation relationship for specific major earthquakes recorded in history

III. Research Questions and Contributions to Knowledge

To guide the study, the following three (3) questions will form the basis of this investigation.

1. What are the main types of environmental factors that can contribute to Liquefaction during earthquake events?
2. How can liquefaction potential zones investigation and mapping assist the community and Governing body as a whole?
3. Is there any benefit in applying Multi-Criteria Evaluation (MCE) and Analytical Hierarchy Process (AHP) within GIS and Remote Sensing Environment to solve the issues of Liquefaction in a region?

The current study seeks to address above research questions and a significant contribution is expected in bolstering the knowledge of geohazards mapping.

IV. Study Area

The study area selected was two provinces of PNG viz. Madang and Morobe Provinces that are quite active seismically. The study area sits on the assemblage of three micro plates that define the distribution of major fault structures within the regions (Figure 1). The study region covers the total area of 62708.66 km2 and located around

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146° east longitudes and 6° south latitude. The topography of the study area especially Madang region is mostly covered with low lying areas with a few mountainous zones and in the region of Morobe most areas fall within mountainous landform and only a small proportion of landmass is in the low lying zones and valleys. Figure 1 illustrates the study region.

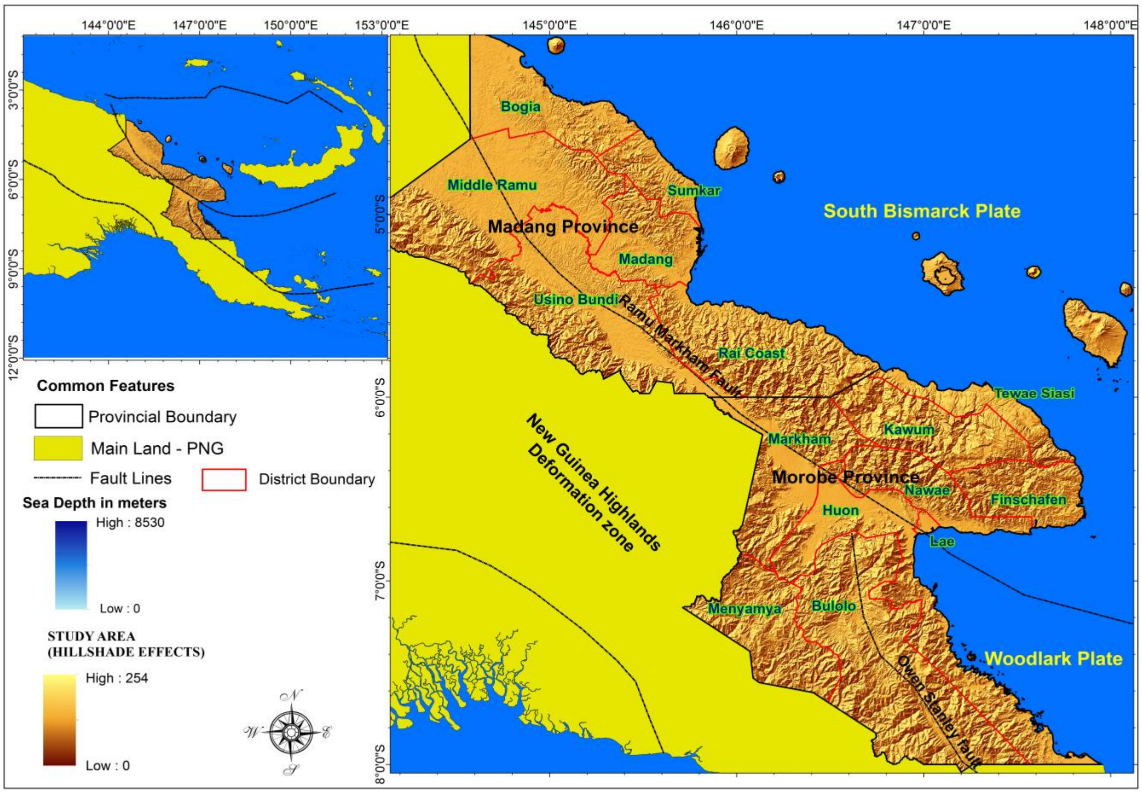

Fig 2: Study Area locality map

V. DATA USED AND METHODOLOGY

1. Preparation of thematic layers

The data type used was mainly digital data. For this study different types of data related to soil and geology were integrated within GIS environment to delineate liquefaction potential zone for the two regions. Based on the data availability and also according to the literature and scientific relevance with respect to liquefaction potential, the six layers were selected or delineated and integrated through multi-criteria evaluation techniques. Multi-criteria analysis (MCA) techniques are well known decision support tools for dealing with complex decision constellations where technological, economical, ecological and social aspects have to be covered.

The main data layers that were used to delineate liquefaction potential zone are tabulated in Table 1. The summary of Methodology applied to generate each thematic layer and produce liquefaction potential zone is shown in the flow chart in figure 3. The thematic layers, that is, Soil Available Water Holding Capacity (AWC), Soil drainage and Soil taxonomy layer were extracted from Geobook (2009). The thematic layers concerning geology, that is, lithological data (rocks and minerals) and the structure (fault, fold, lineament etc.) are extracted from PNM Geology and PNG Resource Information System (PNGRIS) metadata. The terrain data layer was generated from SRTM DEM data using slope tool in ArcGIS software.

For the fault data, the buffer zone was created with specific distance interval in kilometres (km) according to the theory that earthquakes most frequently occur along fault zones that tend to concede the central tendency of epicentre of earthquake episodes in a tectonically active region. The lithology (according to rock types formations) was reclassified or prepared based on its consolidation status, by taking into consideration the classification of rock type from Loffler

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(1974), and is based on simple criteria, such as origin, composition and grain size of parent material. Unconsolidated sediments of rock types are more prone to liquefaction and has the potential to amplify seismic waves where liquefaction can easily occur; whereas the consolidated sediments or rock types do not amplify seismic waves, rather they reduce intensity of seismic wave propagation (Andrew M, 2005). Thus this piece of information provides more insight into reclassifying lithological factors based on the degree of consolidation status. For the three factors related to soil, it was reclassified or prepared based on saturation status keeping in mind that saturated and soft soils are more prone to liquefaction or can amplify seismic waves resulting in liquefaction. For all data layers the projection and coordinate system was defined to UTM, WGS84, zone 55 southern hemispheres. Each factor was ranked according to its potential contribution to liquefaction. Also the class of each factor was assigned weightage according to its potentiality in liquefaction hazard. The assigned weight or rank for each factor or class is based on different experts' opinions; therefore, pair-wise comparison, as introduced by Saaty (1980) for weights assigned was carried out basically to normalise the weights and to calculate the consistency ratio in order to be consistent of the weights and ranks assigned (Machiwal et al, 2011). Any process of weight assigned and normalizing weights were performed outside GIS environment using Microsoft excel. All the normalized weights for both factors with their classes are then integrated in GIS environment using raster calculator in ArcGIS 10. Thus the method used to calculate final output for liquefaction potential zones was adopted from Pal et al (2007).

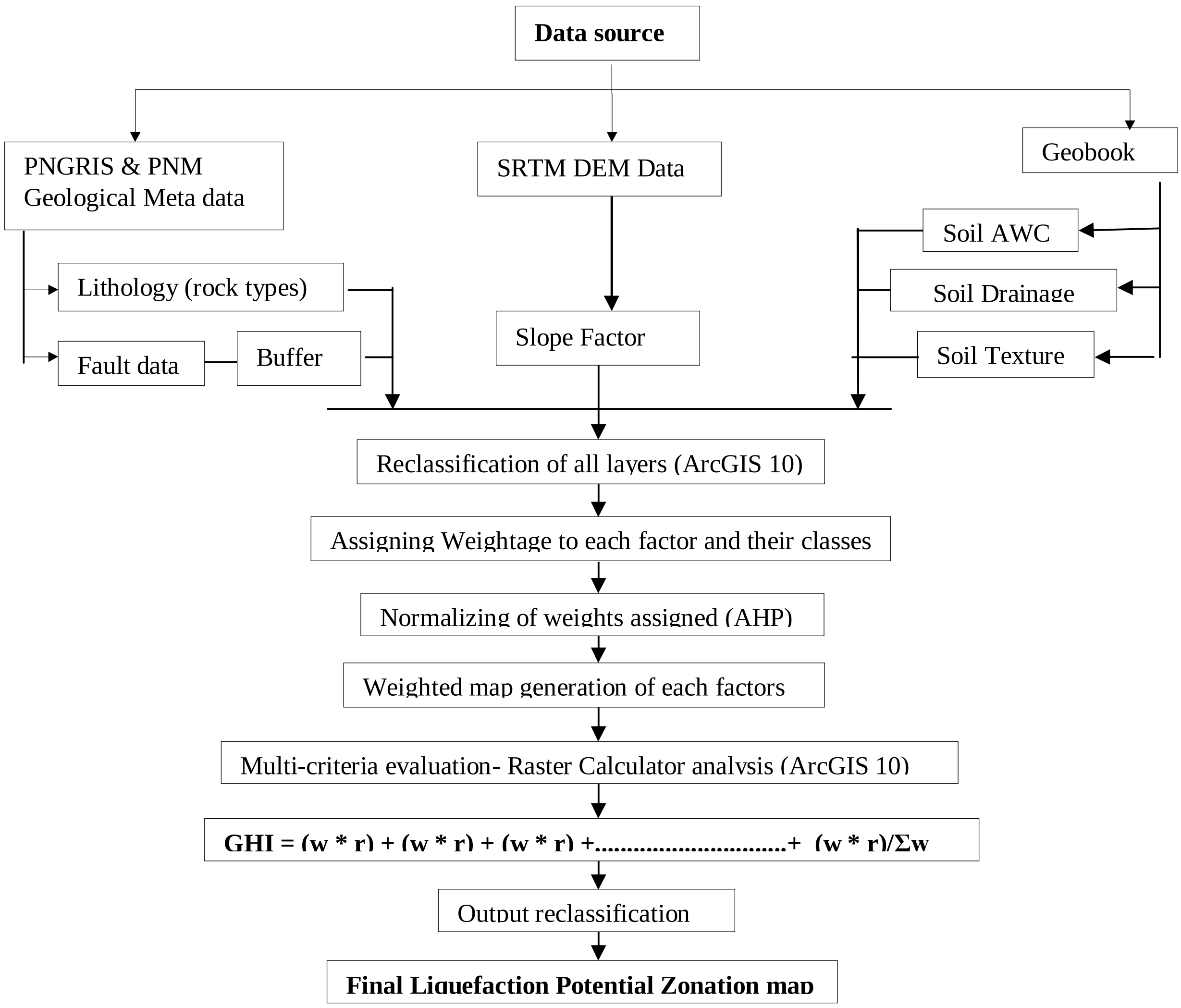

Fig 3: Methodological Flow Chart

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Table 1: Data layers used

Data layers	Description	Source
Slope factor	Extracted from PNG SRTM DEM	PNG University of Technology
Soil AWC	Derived from Geobook	PNG University of Technology
Soil Drainage	Derived from Geobook	PNG University of Technology
Soil Texture	Derived from Geobook	PNG University of Technology
Geology (according to rock types available in geologic formation)	Derived from PNGRIS metadata and PNM geological metadata	PNG University of Technology
Fault line buffer zones	Derived from PNM Geological metadata and from Downloaded base maps	PNG University of Technology

2. Weights assigned and Analytical Hierarchy Process

The other phase of the task or study was to process and assign weightage to each factor and their classes based on different experts' opinions where it is to be normalized using the Saaty’s analytical hierarchy process (AHP). The analytical hierarchy process (AHP) was developed by Saaty (1980, 1989, 1992), specifically to assess or synthesize judgments or decisions made by the experts to achieve their set goal and to evaluate and check the consistency of judgment made. It is one of the best known and most widely used multi-criteria analysis (MCA) approaches. It allows users to assess the relative weights of multiple criteria or multiple options against given criteria in an intuitive manner. It allows efficient group decision-making, where group members can use their experience, values and knowledge to break down a problem into a hierarchy and solve it by AHP steps. Thus the AHP technique was adopted in this study as a decision aiding method to finalize the weights and ranks assigned to different thematic layers with their classes that were employed in delineation of Liquefaction potential zone. After preparing all the factors (slope factor, soil AWC, Soil Drainage, Soil texture, Lithological factor, fault line buffer), their individual classes were reclassified using “reclassify” tool in ArcGIS 10 according to the weights scale range of 1 to 4. The weights were assigned to each class depending on their relative importance in Liquefaction potential. Thus in terms of Liquefaction potential contribution, the weight 1 indicates “low” whereas weight 4 indicates “high”. For example, the class “D” in the factor Soil texture was given the weight of value “1” because this class corresponds to minimal contribution to liquefaction, that is, the soil group “D” the infiltration rate is minimum that reflects soils are a bit compact and not loose, and thus this can indicate low vulnerability to liquefaction. On the other hand, the class "A" is given the weight of ”4” which is the highest value because it is the factor that can contribute to more liquefaction because the soils with the highest infiltration rates are loose enough and are more susceptible to liquefaction. Thus the weightage assigned for each factor or class was decided based on lessons gleaned from literature, formal discussion and interview process. Therefore, all the other factors with their classes were given weightage or rank following the similar procedures. The weightage assigned for each class and its factors are normalised by Saaty's Analytical Hierarchical Process. One of the strengths of AHP is that it allows for inconsistent relationships while, at the same time, providing a consistency ratio (CR) as an indicator of the degree of consistency or inconsistency (Forman and Selly, 2001). In order to be consistent about the weightage assignment the consistency ratio (CR) value should be calculated to be less that 0.10 (Saaty 1980, 1986, 1992). If the consistency ratio is greater than 0.10 then the weight assignment is to be re-evaluated to avoid inconsistency. Also the CR denotes the possibility that the matrix ratings were randomly generated. CR is calculated as follows:

$CR = \frac{CI}{RI}$ ....Equation 1

Where CR = Consistency ration, CI = Consistency index, RI = Random Index

Consistency Index (CI) is calculated after the normalised weight is derived from pair- wise comparison matrix (Table 3). The CI for assigned weights for classes or factors was calculated following the procedure suggested by Saaty (1980, 1992):

$CI = \frac{(\lambda m - n)}{(n-1)}$ ....Equation 2

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Where CI = Consistency Index, n = order of matrix, λm = normalised weights multiplied by each column total.
The consistency random index (RI) is the average value of CI for random matrices. The average consistency of square matrices of various orders n was calculated by Saaty (1977) up to matrix order of 15 and is shown in Table 5.

Table 2: Random indices for matrices of various sizes (n)

n	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0.52	0.90	1.12	1.24	1.32	1.41	1.46	1.49	1.51	1.48	1.56	1.57	1.59

Source: (Saaty 1977)

The normalised weights and assigned weights for 6 factors are shown in Table 4. It indicates that lithological factor (based on consolidation statues) was ranked the highest with a normalised weight of 0.383 while Slope factor was considered as the least with respect to liquefaction contribution with a normalised weight of 0.044. The assigned weights were normalised and consistency ratio was calculated. Pair- wise comparison matrix for 6 factors assessed for the delineation of liquefaction potential zone is shown in Table 3. For each factor's class, the summary of all weights assigned, normalised weight including ranking and total area coverage are presented in Table 6.
After normalising and being consistent about the weight assigned for each factor and class, the spatial analyse tool; raster calculator in ArcGIS 10 was employed to derive the final thematic map for Liquefaction potential zones for Madang and Morobe Province. Based on the weights assigned and the calculation process, the Geohazards intensity number/weight was derived (Table 7), the potential zones were reclassified to four (5) classes according to Geohazards intensity number/weight derived. The five Potential zone classes are: “very low” “low”, “moderate,” “high” and “very high” potential zones.

Table 3: Pair-wise comparison matrix of different factors

Themes	**Themes**					
	Lithology	**Soil Texture**	**Soil AWC**	**Fault Zone**	**Soil Drainage**	**Slope**
Lithology	1					
Soil Texture	1/2	1				
Soil AWC	1/3	1	1			
Fault Zone	1/4	1/3	1/2	1		
Soil Drainage	1/5	1/4	1/3	1/2	1	
Slope	1/6	1/5	1/4	1/3	1/2	1

Table 4: Assigned and normalised weights of 6 factors

Factors	**Assigned weights**	**Normalised weights**
Lithology(Geology)	6	0.382826354
Soil Texture	5	0.225101209
Soil AWC	4	0.17968953
Fault Zone	3	0.103019351
Soil Drainage	2	0.065766675
Slope	1	0.043596882
Total		**1**
CR		**0.02**

VI. Results and Discussion

Multi-criteria evaluation or analysis technique is applied in different categories of field, like flood hazard assessment, ground water potential investigation, malaria hazard risk investigation, and so forth. The technique consists of

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processing and overlaying several environmental factors in the GIS environment. Multi-criteria evaluation works well with AHP to synthesise and normalise the decision made. The spatial analyse tool; weighted overlay raster calculator and reclassify tool in ArcGIS 10 are mainly used for these types of analysis. The weights, ranks or percentage influences are assigned to each factor and each class of factors of interest and AHP was carried out. The present study is intended to involve multi-criteria evaluation or analysis technique with AHP in the GIS environment to assess and analyse six (6) major geological and geomorphological factors of Madang and Morobe region area as was discussed. Their effectiveness or importance in contributing to Liquefaction is discussed in the next section. For those factors selected to do liquefaction potential zone mapping are all related to each other in contribution for Liquefaction to occur. As was discussed in the introduction part; liquefaction are most likely to occur on unconsolidated sediments and soft, loose and saturated soils. For example, when a particular area is demarcated as unconsolidated sediments or rocks then it could be the area of alluvial / colluvial deposits. When we figure this out with respect to soil types then it can be classified as soft and loose soils. Thus it can be figured out if they are related to each other in contribution to liquefaction during earthquake.

1. Geology (According to rock types)

According to classification of rock type by Loffler (1974) for the country PNG that is based on simple criteria such as origin, composition and grain size, the analysis was done to evaluate Liquefaction potential zones of the study region. From the rock types, Loffler (1974) has again reclassified the rock types in terms of their specific status of consolidation, i.e. consolidated, unconsolidated and semi consolidated. Thus in order to decide earthquake hazard leading to Liquefactions for a region, the consolidation statues of the sediment type or rock types are to be decided and evaluated. As the seismic wave propagates from the earthquake focus to the surface, the consolidation status of the materials determine the level of amplification or reduction of the strength of the seismic waves. If the sediments are defined as unconsolidated then the seismic wave are more likely to be amplified and hence might lead to liquefaction and concomitant collapse of overlying infrastructure. If the sediments or rock types are defined as consolidated, then the amplification of seismic waves and liquefaction possibility is negated. Based on this understanding the rock types were assessed and the thematic map (figure 4A) was prepared. The unconsolidated sediments are mainly the deposits of past geological activities such as erosion and weathering deposits and hence it is mainly a flood plain or alluvial / colluvial deposits. These types of deposits or formation are more prone to liquefaction.

2. Soil Attributes

Soil class was assessed based on saturation capacity where soil deposits of loose granule materials or particles are to be evaluated and assessed. According to NISEE (1997) if the soil consists of deposits of loose granular materials it may be compacted by the ground vibrations induced by the earthquake, resulting in large liquefaction or differential subsidence of the ground surface. Also according to MARC (2015) Liquefaction is a phenomenon where saturated sand and silt take on the characteristics of a liquid during the intense shaking of an earthquake. The liquefaction during earthquake is more likely to occur within loose soils. Thus Soil liquefaction is the condition where soil will changes from solid to liquid because too much water is retained in the soil (saturated). This condition normally occurs in varieties of soils that are granular and in soils with poor drainage (Ravat. R & Singhat. A 2015). According to PNGRIS Hand book 3rd edition (2008) there are about fifteen (15) soil categories developed. Out of these 15, three types of soil attributes were selected according to literature and interview processes. The selected attributes can contribute to analysis and evaluation of Liquefaction potential zones. The three soil attributes selected are discussed bellow.

2.1 Soil Texture

Soil texture being the relative proportion of sand, silt and clay has profound influence in infiltration process. The hydrological Soil groupings of Soil Conservation service (SCS, USDA) consist in four classes based on infiltration rate (table 5); A, B, C, D. The infiltration rate of soil group “A” is highest while infiltration rate of soil group “D” is the lowest. Thus according to County of San Diego low impact development handbook (2009), infiltrating storm water into soils has the potential to cause adverse geotechnical or geohazards conditions under certain circumstances, thus the other concerns with regard to infiltration of storm water to soils are the potential for liquefaction during earthquakes, expansion of clay soils, or compression of fill or alluvium. It was found out that, if the infiltration rate is high it leads to increased of volume of water in the soil mixed with soil. During any earthquake events, the areas can easily liquefy. On the other hand if the infiltration rate is high it can be concluded that the soil particles at where the infiltration rate is high are loose with lots of void air spaces. Thus during any earthquake events liquefaction can easily occur. According to these ideas, the soil texture was reclassified and assessed to delineate liquefaction potential zones. Figure 4(B) illustrates the soil texture distribution of the region.

Table 5: Classes of HSG

HSG	A	B	C	D
Soil Texture	Sand	Silt Loam/ Loamy soil	Sandy Clay Loam	Silty Clay Loam
	Loamy Sand/ Sandy loam			Sandy Clay
				Silty Clay
				Peat

2.2 Soil AWC

The soil Available water holding capacity (AWC) was one of the soil attributes that were assessed to evaluate liquefaction potential. Soil AWC is the amount of water held in a soil or is the soil available of water holding capacity. In the study region the areas of AWC was from moderate, low to very low. Thus according to seismic hazard analysis due to liquefaction, the soil region that has high rank of AWC can be term as saturated soils and are more prone to liquefaction. Based on this knowledge the weightage and ranking was fixed for the factor and its classes. Figure 4(C) illustrates the soil AWC.

2.3 Soil Drainage

Soil drainage has been one of the soil attributes that was assessed to evaluate liquefaction potential zones. Based on drainage capability due to soil, it was discovered that the poorly drained soils are more susceptible to liquefaction because they have high water table. The well drained soils are not susceptible to liquefaction. Base on this knowledge, the factor was reclassified from well drained to poorly drained soil. Thus Drainage Class (natural) refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed (CT ECO, 2010). Higher weightage was assigned to poorly drained soil because they are more susceptible to liquefaction and low weightage were assigned to well drain soil. Figure (4E) illustrates the soil drainage distribution of study region

3. Fault Structure

Buffering of major fault zones was one of the common factors that were integrated with other factors to delineate liquefaction potential zones of the study region. It is obvious that earthquakes do frequently occur at fault zones. Thus areas closer to fault zones do experience huge shaking than areas further apart. The attenuation ground motion relationships decreases out from the epicentre of earthquakes. Due to these relationships the liquefactions are most likely to occur at strong shaking zone that is the areas close to the fault zones. With this in mind, the buffer zone was created to highlight classes of zones relating to liquefaction potentials. Total of four zones were created. The zones closer to the fault lines were given higher weightage than zones further away from fault lines. Figure 4(D) highlights the fault zones created.

4. Slope Factor

Slope was one of the factors that was used to integrate with other factors to delineate liquefaction potential zones of the study region. It is obvious that during any earthquake shaking or earthquake events, the steeper slopes to gentle slope are more likely to liquefy. The slope factor was reclassified to four classes and the weightage was assigned to each class based on how effective it can contribute to liquefaction. The steeper slopes were given higher weightage while low slope areas were given low weightage. Figure 4(F) highlights the slope distribution in degree.

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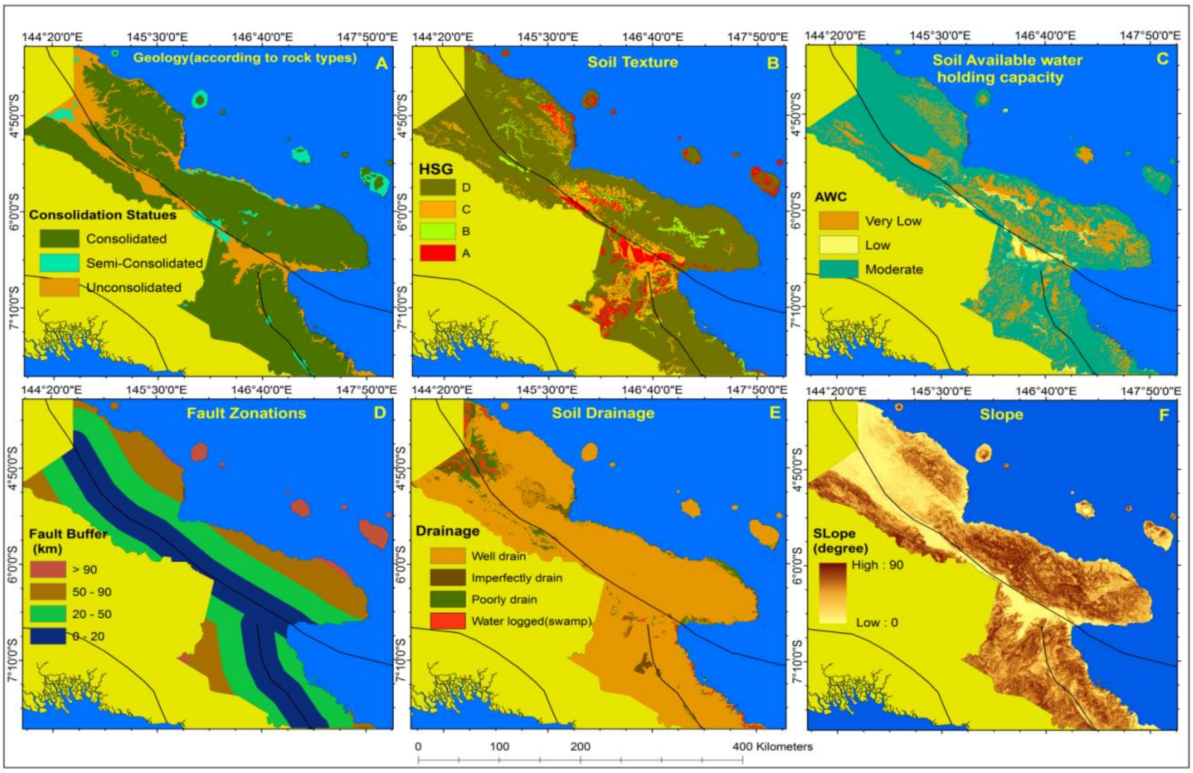

Figure 4: Thematic layers of different parameter use for evaluation of Liquefaction potential

Table 6: Weightage and rankings of each factor

Theme	Weight	Classes	Ratings	Normalized Rate	Area(km^2)	Area (%)
Geology (According to rock types) (GE)	0.383	Consolidated	1	0.11	49777.87	79.68
		Semi-Consolidated	3	0.19	2637.67	4.22
		Unconsolidated	4	0.7	10057.07	16.1
Soil Texture (ST)	0.225	D	1	0.07	50104.16	79.95
		C	2	0.12	5972.44	9.53
		B	3	0.3	2235.33	3.58
		A	4	0.5	4353.85	6.95
Soil AWC (SA)	0.18	Very low	1	0.11	13673.13	21.82
		Low	3	0.19	2002.92	3.2
		Moderate	4	0.7	46990.79	74.99
Fault Buffer (km) (FB)	0.103	> 90	1	0.03	2421.28	3.86
		50-90	2	0.1	14547.94	23.2
		20-50	3	0.31	25083.57	40
		0-20	4	0.61	20655.43	32.94
Soil Drainage (SD)	0.066	Well drain	1	0.07	56355.7	89.93
		Imperfectly drain	2	0.1	1591.46	2.54

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		Poorly drain	3	0.3	3409.76	5.44
		Water logged (swamp)	4	0.5	1308.35	2.09
Slope (degree) (SP)	0.044	0-13	1	0.09	26929.92	42.68
		13-29	2	0.13	25720.35	40.76
		29-44	3	0.28	10228.93	16.21
		44-90	4	0.49	224.12	0.36

Table 6 shows the weightage and ratings assigned for each theme with their classes. The normalized weights were calculated using AHP techniques and finally were assigned (Table 6) for each themes. For the theme that contributes more to Liquefaction hazard was assigned high weightage and low weightage was assigned to theme that contributes less. As regards ratings for each class of factors the ratings were assigned and again were normalized using AHP techniques. The value 1 was assigned to classes that contribute least to liquefaction potential and value 4 was assigned to classes that contribute most to liquefaction potential. The table also shows the area in kilometre square (km2) and percentages (%) for each classes.

5. Delineation of Final Output map

After assigning all the weightage and ratings, the spatial analyse tool; Raster Calculator in ArcGIS 10 was employed in calculating and producing the final Liquefaction potential zonation map (figure 5). The final map derived was based on weightage and ratings assigned. The formula highlighted by Pal et al (2007) was used to calculate the Liquefaction potential zone for a study region.

For the present study the formula employed was:

$$GHI = [(GEw . GEr) + (STw . STr) + (SAw . SAr) + (FBw . EBr) + (SDw . SDr) + (SPw . SPr)] / \Sigma w$$

GHI = Geohazards Index. Table 7 highlights the GHI value that was generated and was reclassified into each potential zones of liquefaction from very low to very high. The Liquefaction potential map generated is shown in figure 5.

Table 7: Liquefaction Potential zones re-classification according to Geohazards intensity numbers that was generated during integration of thematic layers In ArcGIS 10

Geohazards Index Value	Liquefaction Potential Zones	Area (km^2)	Area (%)
1 – 1.51	Very low potential zone	10812.487	17.36
1.51 – 2.08	Low Potential zone	35337.016	56.73
2.08 – 2.71	Moderate Potential zone	6131.145	9.84
2.71 – 3.26	High Potential Zone	7503.160	12.05
3.26 - 3.95	Very High Potential Zone	2507.347	4.03

The Table 7 presents the areas in square km (km2) and percentage (%) for each liquefaction potential zones. The very low and low potential zone indicates that there is no risk of liquefaction at all; the moderate potential zone indicates liquefaction may or may not occur; however high or very high potential zone indicates actual possibilities of liquefaction in the study area. From the calculation, it was found out that ‘Very low’ potential zone has 17.36% of area coverage, Low potential zone has 56.73% of area coverage, moderate potential zone has 9.84% of area coverage, high potential zone has 12.05% of area coverage and very high potential zone has 4.03% of area coverage.

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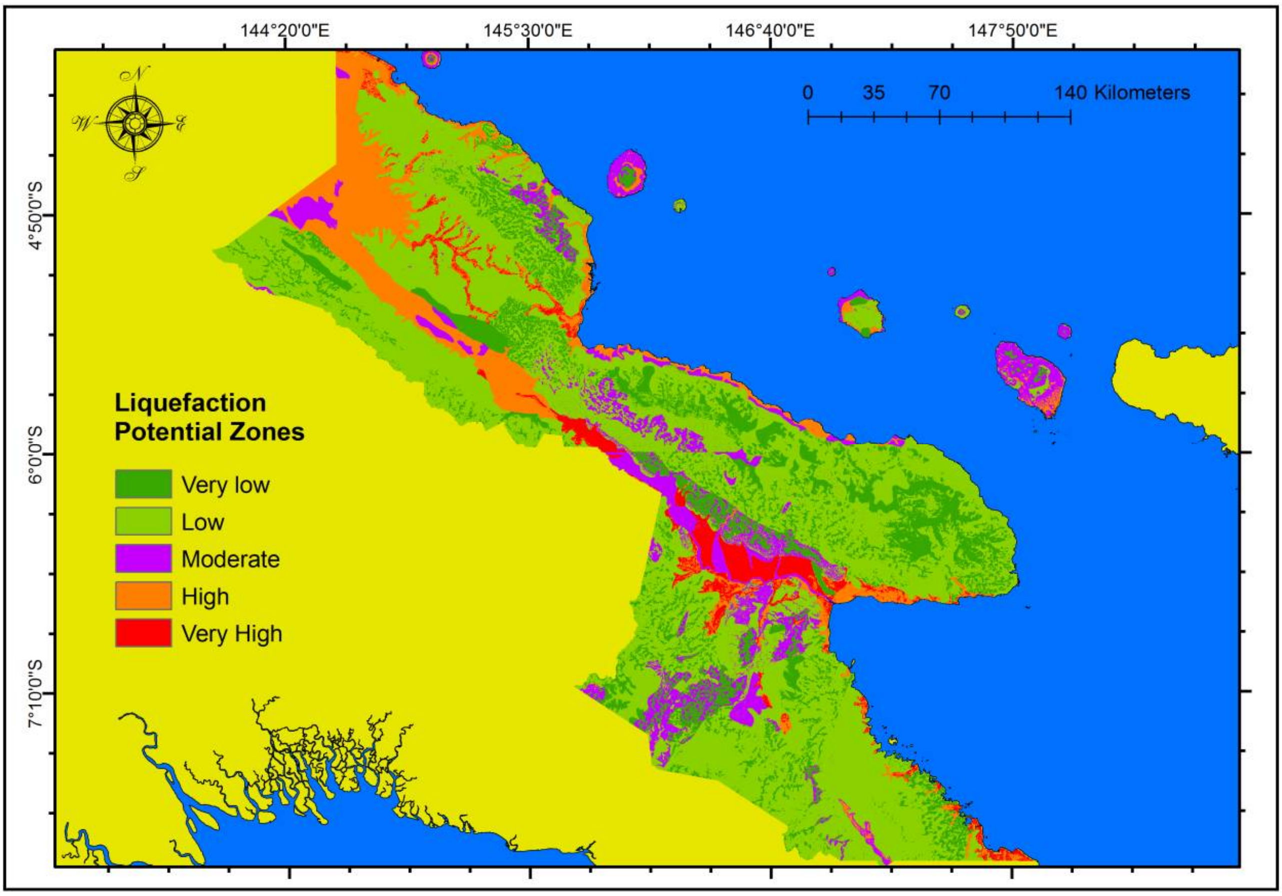

Fig 5: Liquefaction Potential Zones of the Study region

6. Evaluation of features location on the liquefaction potential zones

After the completion of delineation of Liquefaction potential zones, several cultural features like roads, schools, health centres and other important built-up urban infrastructures were selected and overlaid on to Liquefaction potential zones of a study region to evaluate and consider its possible location on potential zones which were created as output of the study. These features are important in terms of maintaining or improving the country's economic growth. These analyses are to let governing bodies and general public as a whole know or figure out their possible locations including locations of each features on potential zones, where this can assist in mitigation planning and awareness. Also it can be a tool to make proper and better future development planning with respect to liquefaction potential zones.

Table 8 highlights the total number and length of each feature on each particular liquefaction potential zones. The table column shows the potential zones from very high to very low and the table rows show each features assessed under each potential zones in terms of counts (number) and lengths (distance). Total length of roads with respect to each potential zone was measured in kilometres through spatial analysis techniques in GIS environment and the value was noted. Also total number of count features like; major towns, health centres and schools were counted with respect to each potential zones and the value was recorded. Figure 6 illustrates the overall map of potential zones and overlaid features.

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Table 8: Features assessed under each Liquefaction potential zones

(I) Madang Province	*LIQUEFACTION POTENTIAL ZONES*				
COMMON FEATURS	**Very high**	**High**	**Moderate**	**Low**	**Very Low**
Major Towns	Dumpu	Bogia	…………	……….	…………
		Aiome			
		Madang Town			
		Saidor			
Major Roads (Length in km)	223.34	370	164.12	770.25	380.23
Health Centres (count)	2	21	6	13	3
Academic areas(schools)	1	10	2	2	………….
(II) Morobe Province	*LIQUEFACTION POTENTIAL ZONES*				
COMMON FEATURS	**Very high**	**High**	**Moderate**	**Low**	**Very Low**
Major Towns	Lae Urban	Lae Urban	Kaiapit	Finchhafen	……………
	Bulolo	Wau	Garaina	Morobe	
Major Roads (Length in km)	360.68	168.55	412.47	850.23	584.01
Health Centres(count)	8	8	10	10	9
Academic areas(schools)	6	8	1	7	2

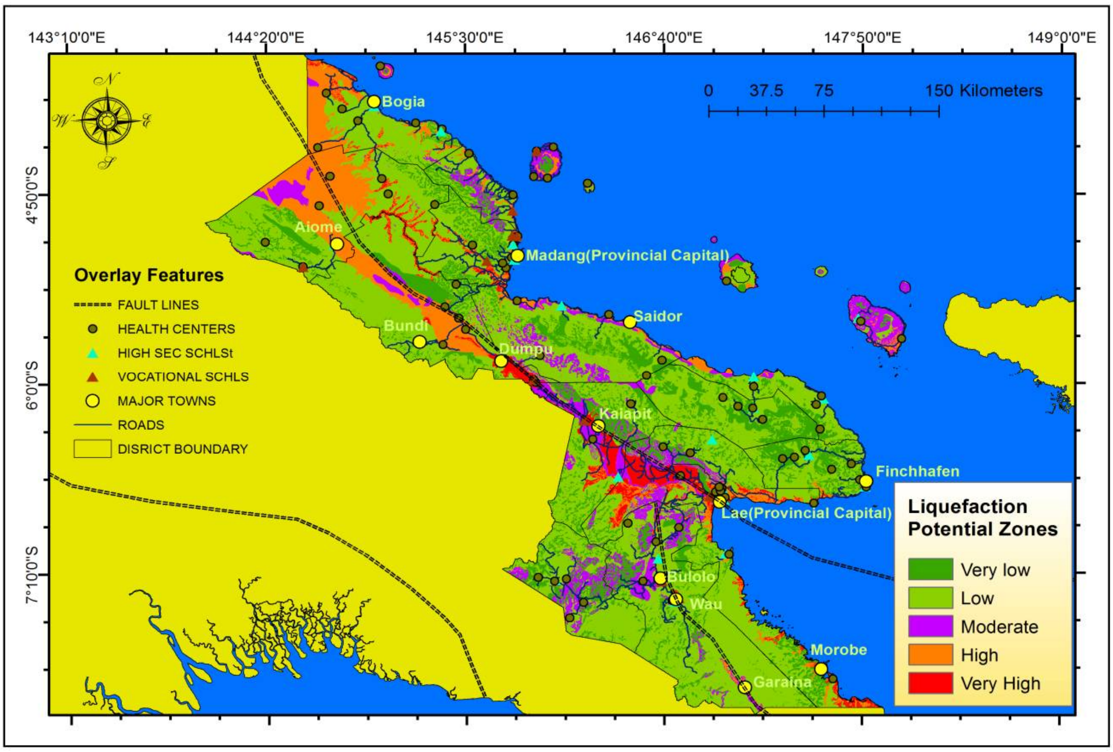

Figure 6: Evaluation of Liquefaction potential sites with common features.

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VII. CONCLUSIONS

Liquefactions are one of the naturally occurring Geohazards that can be experienced during earthquake events of high magnitude at low depth. Liquefaction occurs due to certain shaking intensities during earthquakes. It is the process of differential ground subsidence due to underground soils and sediments being unconsolidated and soft, especially saturated with water. Several geological and geomorphological features were integrated in the GIS environment and the Liquefaction potential zones of the study region were delineated. The process of assessing the Geological and Geomorphological factors of the study region can enhance our understanding of how liquefaction actually occurs. Table 6 explains every individual assessment that was carried out to produce liquefaction potential zones. Thus liquefaction potential zonation mapping is an important tool for land use planning in terms of infrastructure development and mitigation measures. It creates easily - read, rapidly accessible charts and maps that facilitate decision making processes by Governing bodies. Armed with the scientific knowledge of each potential zone of liquefactions, future development planning can be done effectively towards site selection for investment decision of major infrastructures.

REFERENCES

[1] Andrew. M (2005). Estimating the influence of sediments on ground shaking. Geosciences Australia issue 82.
[2] Britton R and Britton Consultants Ltd, (2014). Stopbank design and Construction Guidelines. Bay of Plenty Regional Council 5 Quay Street, Whakatāne 3158 NEW ZEALAND
[3] 3. City of Rancho Cordova. (2006). Rancho Cordova Interim General Plan. Draft environment impact report, soil and geology Revised March 4, 2006, California.
[4] 4. County of San Diego low impact development handbook (2009). Geotechnical consideration.
[5] 5. Connecticut Environmental Conditions Online (2010). Soil drainage class. Maps and geospatial data for planning, management, education and research.
[6] 6. Forman, E.H. and Selly, M.A., (2001). Decision by objective and how to convince others that you are right. Singapore: World Scientific
[7] 7. Geobook (2009), The UPNG Geobook set - an interactive mapping atlas for each Province of PNG, Remote Sensing Centre, PO Box 320, University, NCD, Papua New Guinea
[8] 8. Loffler, E., (1974) Geomorphological map of Papua New Guinea, scale 1:1000000, CSIRO Land research series, no 33.
[9] 9. Machiwal, D.., Jha, M.K., Mal, B.C., (2011), Assessment of Groundwater Potential in a Semi-Arid Region of India Using Remote Sensing, GIS and MCDM Techniques, Water Resources Management, 25(5) , 1359-1386
[10] 10. Mid-America Regional Council (2015). Earthquake. Risk and Vulnerability assessment, section4
[11] 11. Nevada Bureau of Mines and Geology (NBMG). 1980. A Preliminary First Stage Study of Nevada Coal Resources. NBMG Open-File Report 80-5. Nevada Bureau of Mines and Geology
[12] 12. National Information Service for Earthquake Engineering(1997) Damage Due to liquefaction. The University of California Bakery, Structural Engineering Slide Library, W. G. Godden, Editor Set J: Earthquake Engineering, V. V. Bertero
[13] 13. Pal. I, Raj. A, Thingbaijam. K. K. S and Bansal. B. K. (2007). Earthquake hazard zonation of Sikkim Himalaya using a GIS platform. Department of Geology and Geophysics, Indian Institute of Technology. Springer Science+Business Media B.V. 2007
[14] 14. Rawat. R. N , Singhat. A (2015). Liquefaction in Soil. Department of Civil Engineering, WIT Dehradun, India. International journal on occupational health & safety, fire & environment – allied science issn 2349-977x
[15] 15. Saaty, T. L., (1977), The analytic hierarchy process: planning, priority setting, and resource allocation. McGraw-Hill, New York, Ed. 1. 17.
[16] 16. Saaty, T. L., (1980), The analytic hierarchy process: planning, priority setting, and resource allocation, McGraw-Hill, New York, Ed. 2. 18.
[17] 17. Saaty, T. L. , (1992), Decision making for leaders, RWS Publications, Pittsburgh 19
[18] 18. Saaty, T. L., (2008), Decision making with the analytic hierarchy process, Int. J. Services Sciences, 1 (1) 83-98.
[19] 19. Stanaway. R (2008). A Dynamic Datum For PNG - Improving PNG94. 42nd Association of Surveyors PNG Congress, Port Moresby, 9th - 12th July 2008
[20] 20. Willige. T. B (2010). Detection of local site conditions influencing earthquake shaking and secondary effects in Southwest - Haiti Using remote sensing and GIS method. TU Berlin, Institute of Applied Geosciences, Berlin