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GIS Based Evaluation in Earthquake Hazard Micro-Zonation - A Case Study of Madang and Morobe Province, Papua New Guinea

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Abstract— *Tectonism induced liquefaction, landslide, Tsunami, fire, etc. are the common earthquake hazards that cause immense destruction of infrastructure, life, properties of people. Areas vulnerable to tectonism related hazard warrant appropriate emphasis in any infrastructure development planning. Various procedures and methods are applied throughout the world to identify levels of earthquake risk within a site of interest. The output results are used as tools for site selection and finding viability of funding in infrastructure development, the former could also be an instrument for the insurance companies for fixing premium of the insured infrastructure. The output aids in devising appropriate building codes for civil construction, judicious selection of sites to preclude future loss of life and property owing to infrastructure collapse by earthquake induced hazard. Earthquake hazard micro-zonation has been a recently adopted technique throughout the world for site selection and investment in infrastructure developments. It is the way forward in analyzing and integrating several linked factors in a GIS environment to delineate specific areas of hazard zones. For any earthquake disaster the fatalities mostly happen depending on the ferocity, depth of the epicenter / focus and distance of the infrastructure from the epicenter, along with its shaking intensity conditioned by geomorphology and geological factors of the terrain. The present study aims at assessing the historical seismicity databases with liquefaction potential zones that house the geological and geomorphological factors into demarcation of levels of earthquake hazard zones within the study region with the knowledge of multi-criteria evaluation and Analytical Hierarchy Process (AHP) appraisal in GIS and Remote sensing technologies. The main data layers that are chosen for carrying out the assessment consist in available seismicity data layers and geomorphological and geological databases. Several thematic layers were prepared and the weightage and ranking was assigned followed by normalization using Saaty's analytical hierarchy process. The final seismic hazard zones map was prepared using the raster calculated tool from ArcGIS 10. The output hazard zones were then reclassified into five categories such as 'very high', 'high', 'moderate', 'low' and 'very low' levels of hazard.*

Keywords— Tectonism, Liquefaction, Hazard microzonation, Analytical Hierarchy Process.

I. INTRODUCTION

Earthquake hazard micro-zonation has been a recently adopted technique to decide the risk levels due to earthquake within a region. Assessment and monitoring of any natural Hazards like cyclone, flood, earthquake, landslide, etc. in a region are of vital importance for the governing bodies and the general public as a whole. Such studies provide fixed tools that help in better infrastructure development planning, mitigation measures and also foster in developing early warning preparatory system. The paper here essentially deals with the hazards emanating from earthquakes, the contributing factors to earthquake hazard, and the source and cause of earthquake hazard within the study region.

Earthquake is one of the natural disasters that are common around the world triggering widespread damage and destruction. Earthquakes normally occur due to plate motions owing to specific geological and tectonic settings of the earth. The tremor induced devastation can be understood from the study by Statista (2016) that global total estimated death toll due to earthquake from year 2000 to 2012 had been 493, 736.

In the Last decades for PNG region, many earthquakes have caused deaths and destructions.

A tragic example of 1998 when a 7.0 magnitude earthquake struck the north coast region near Aitape triggering a large undersea landslide that caused a devastating tsunami with almost 2,200 fatalities and 50 million USD in economic. This figure proves how damaging or terrible is the event of earthquakes if it is to occur any time anywhere at a specific magnitude and depth. (Davies Hugh, 1998)

Papua New Guinea is one of the countries in the Pacific region that lies within the 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. Within this collision zone in PNG there are also several smaller micro plates each moving at differing speed and direction adding complexity of the tectonic setting. It is plausible that an earthquake of any magnitude may happen in an area having multiple of fault structures (plate boundary).

Earthquake hazard is simply any hazard that is related to the earthquake event of certain magnitude at certain depth. According to UPSeis (2016), the first main earthquake hazard (danger) is the effect of ground shaking, where Buildings can be damaged by the shaking itself. The follow up of the shaking hazard during earthquake, can be liquefaction, landslide, flood, Tsunami and fire. These are all hazards related to earthquake and are termed as earthquake hazards. Thus for the case of doing earthquake hazard micro-zonation it is simply an approach to identify zones of vulnerability so as to adopt safety measures during an earthquake event (Mohanty. W. K et al, 2006).

Seismic micro-zonation is the subdivision of a seismic zone into smaller zones that have relatively similar exposures to various earthquake effects. It is also the process of estimating response of soil layers under earthquake excitation and thus the variation of earthquake ground motion, magnitude and depth characteristic on the ground surface (Sitharam. T. G and Anbazhagan. P, 2016). According to Pal, et al (2006) the earthquake hazard zonation in Sikim Himalaya was prepared from analysing 8 thematic layers within the GIS platform.

Pal et al (2006) have integrated several environmental and seismic data layers namely: Geology (GE), Soil Site Class (SO), Slope (SL), Landslide (LS), Rock Outcrop (RO), Frequency Wave number (F–K) simulated Peak Ground Acceleration (PGA), Predominant Frequency (PF), and Site Response (SR) at predominant frequencies using Geographic Information System (GIS).

The study was carried through assigning ranking and weightage and then normalizing the weightage and rankings using Satty's analytical hierarchy process. The final output was a geohazards and a seismic hazard zones of Sikim Himalaya.

In order to plan any infrastructure development, status of earthquake hazard levels in a region is to be known. Earthquake hazard is the main reason behind the collapse of a lot of potential infrastructures due to shaking, especially when the proper adherence to building codes is not observed. If a building, bridge, road or any infrastructure that is built on unconsolidated or saturated soils and sediments, such an infrastructure is prone to collapse during earthquake events of larger magnitude at shallow depth. Adequate understanding of the levels of each hazard zone will assist in better planning for infrastructure development and hence will aid in maintaining and improving economic growth of the country. For the present study, the application of GIS and remote sensing technology was utilized to investigate and analyse several seismicity data layers that is; magnitude, depth, Peak Ground Acceleration (PGA) and Liquefaction zones (geological and Geomorphological factors) through multi-criteria and Analytical hierarchy process introduced by Saaty (1980, 1992).

1.1 IMPORTANCE OF THE STUDY

The study is particularly important since multitude of active fault lines pass through the study region making it even more susceptible to earthquake events and this can be confirmed by analyzing the data of historical earthquakes in the area. Furthermore the importance of seismic micro-zonation of study region is that: the study region plays an important role in maintaining as well as boosting the economy of the country. Also Lae city being the second largest and most industrialized city in PNG is located within the study region. Hence this makes the present study much more relevant in the context of country's general welfare. According to Global facility for disaster reduction and recovery (2014) PNG is ranked top 6 of 26 Asia-Pacific region countries as having the highest percentage of population exposed to earthquake hazard. The country as a whole is a seismic active region and home to multiple tectonic plates and their boundaries (fault lines) that make PNG very interesting for earthquake hazard zonation exercise. It is all the more important to carry out such research study to evaluate and assess earthquake hazard for PNG through utilizing background knowledge of GIS and Remote Sensing. Thus result generated can be used as 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 can facilitate decision making processes by Governing bodies. General public and governing bodies can be more aware of earthquake risk areas in the study region.

1.2 RESEARCH QUESTIONS AND CONTRIBUTIONS TO KNOWLEDGE

To move forward with the study, the following three (3) questions will form the pivot of this investigation.

1. What are the main types of environmental and seismicity factors that can contribute to earthquake hazard?

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2. How can earthquake hazard micro-zonation assessment 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 earthquake hazard?

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

1.3 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 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. The several mountain range found in the study region are; Adelbet range, Schrader range, Finistere range, Bismark range, Sarowaget range and Owen Stanley Range. The two major valleys within the study region are Markham and Ramu valley flanking on both sides guided by mountain ranges. Figure 1 illustrates the study region and figure 2 illustrates the major physiographic units of the study region.

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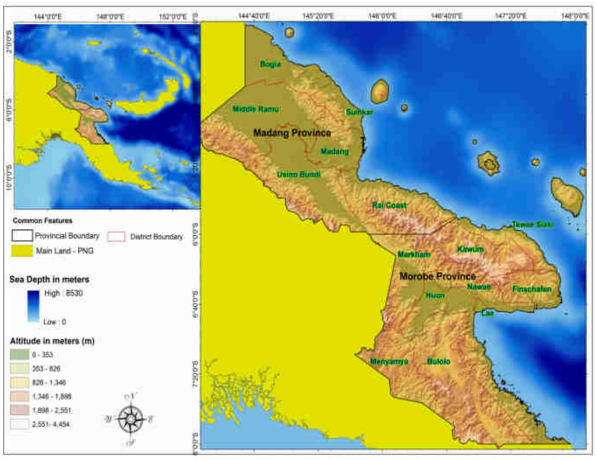

Fig.1: Study area locality map

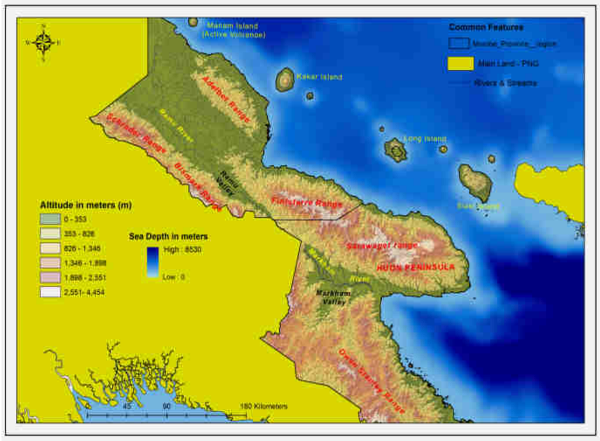

Fig.2: Study area physiographical units

II. DATA USED AND METHODOLOGY

2.1 DATA COLLECTION AND THEMATIC LAYERS PREPARATION

The main data used in this study were seismicity, geological and geomorphological data layers. For the case of geomorphological and geological; the soil attributes and geology according to rock types were extracted from PNGRIS and Geobook Meta data, which were integrated in GIS environment and the geohazards factor in the form of liquefaction potential was delineated.

From the previous study the liquefaction potential zones of same study region currently under investigation for delineation of earthquake hazard was prepared. Thus this was used as one of the contributing factors or a thematic layer to be integrated with seismicity data layers for final demarcation of earthquake hazard zones for the current study.

For the case of seismicity data layer, it was the magnitude, depth and PGA of each earthquake event from year 2000 up to 2016 was considered. The seismicity data layers were collected from USGS earthquake catalogue centre in a excel spread sheet format and then followed by editing, converting and exporting to ArcGIS format. The entire seismicity database recorded from year 2000 up to 2016 related to magnitude, depth and date are all present in charts and graph below. The total number of earthquake events recorded from year 2000 up to 2016 was 2830.

Figure 3 illustrates the earthquake magnitude against earthquake depth, figure 4 illustrates the earthquake magnitude recorded each year and figure 5 illustrates the number of earthquakes recorded each year. After the edition, conversion and exporting of seismicity datasets to ArcGIS format, the thematic layer or factor was prepared. The seismicity datasets once exported to ArcGIS format are all in Point features. Mainly for this analysis, interpolation technique that is inverse distance weighting (IDW), a ArcGIS 10 spatial analysed tool was employed to prepare the factors. This is simply to interpolate raster surface from points since all seismicity data are in point format once open in ArcGIS 10. The three factors prepared through interpolation techniques are earthquake depth distribution, earthquake magnitude distribution and PGA. The earthquake depth distribution was prepared based on how deep or shallow the earthquake was. It was then reclassified according to the idea that, shallower the earthquake depth, greater the hazard while deeper the earthquake depth less the hazard. The other raster surface prepared from interpolation technique was earthquake magnitude distribution. It was reclassified based on how bigger or smaller the earthquake magnitude, ie; smaller the magnitude, lesser the hazard while bigger the magnitude, greater the hazard. Finally the raster surface for levels of shaking intensity within a study region was prepared. Purposely for the preparation of PGA raster surface, only the shaking intensity level for major earthquake events above 5 magnitudes was considered. It was reclassified based on how bigger or smaller the shaking hazard, i.e.; smaller the shaking lesser the hazard while greater the shaking bigger the hazard in the aftermath.

After the preparation of four thematic layers, multi-criteria evaluation and AHP techniques were employed to generate levels of earthquake hazard in the study region. Thus each factor was ranked according to its potential contribution to earthquake hazard. Also the class of each factor was assigned weightage according to its potentiality in earthquake 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 normalize 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 each factor with their classes are then integrated in GIS environment using raster calculator spatial analysed tool in ArcGIS 10. The overall view of methodology followed is presented in figure 6 and the data used are present in table 1.

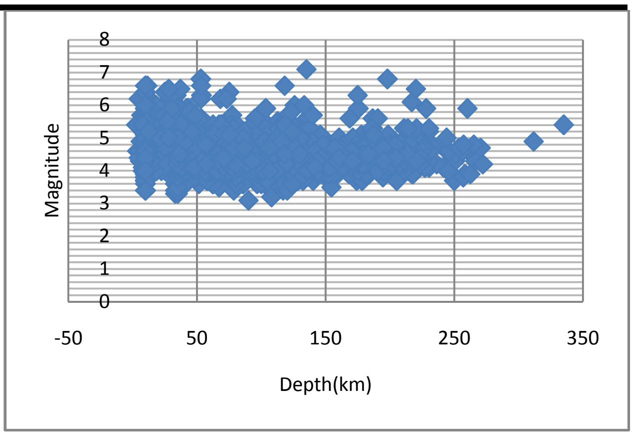

Fig.3: Earthquake magnitude against earthquake dept

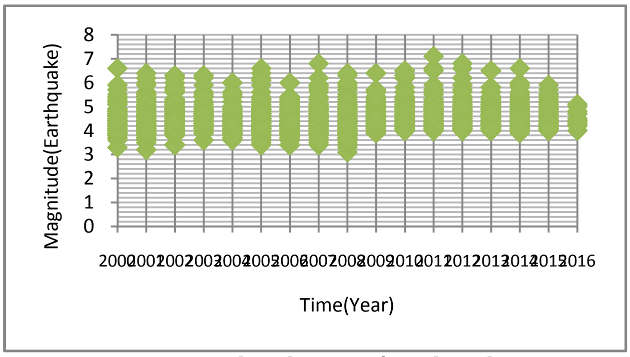

Fig.4: Year wise distribution of earthquake events

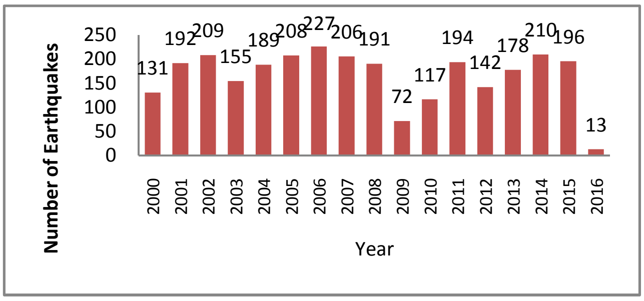

Fig.5: Number of earthquake events per year

Table 1: Data layers used

Data layers	Description	Source
Slope factor	Extracted from PNG SRTM DEM	PNG University of Technology
Soil Attributes	Derived from Geobook and PNGRIS Meta data.	PNG University of Technology
Geology (rock types & Fault line)	Derived from PNGRIS metadata and PNM geological metadata	PNG University of Technology
Magnitude	Downloaded from USGS websites	USGS Earthquake Catalogue centre
Depth	Downloaded from USGS websites	USGS Earthquake Catalogue centre

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Peak Ground Acceleration (PGA)	Downloaded from USGS websites	USGS Earthquake Catalogue centre

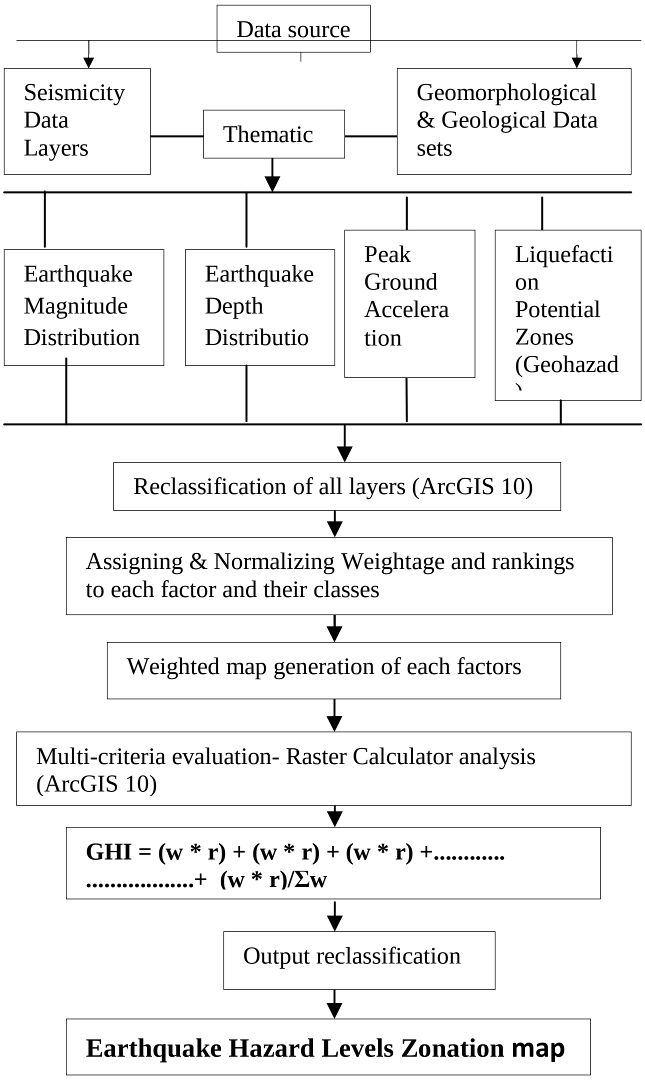

Fig.6: Methodological flow chart

2.2 ASSIGNING OF WEIGHTAGE 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.

For the present study, the AHP technique was adopted as a decision aiding method to finalize the weights and ranks assigned to different thematic layers with their classes that were employed to do Earthquake hazard micro-zonation. After preparing all the factors as discussed above, their individual classes were reclassified using "reclassify" tool in ArcGIS 10 according to the weights scale range of 1 to 5. The weights were assigned to each class depending on their relative importance in contribution to earthquake hazard level. Weight 1 indicates "low" whereas weight 5 indicates "high". For example, the class "3.1 – 4.1 which was classified as class of lower magnitude" in the factor Magnitude was given the weight of value "1" because this class corresponds to minimal contribution to earthquake hazard. On the other hand, the class "6.1 – 7.1 which was classified as class of higher magnitude" is given the weight of"5" which is the highest value because it is the factor that can contribute to more earthquake hazard. Same principle was applied to other factors as well.

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 normalized by Saaty's AHP. 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.

The normalized weights and assigned weights for 4 factors that was used to generate earthquake hazard levels are shown in Table 3. With respect to weightage assignment to each factor, the liquefaction factor (Geohazard) was ranked the highest with a normalized weight of 0466 while earthquake depth distribution raster surface was considered as least with a normalized weight of 0.096. The assigned weights were normalized and consistency ratio was calculated. Pair-wise comparison matrix for 4 factors assessed for the delineation of earthquake hazard levels is shown in Table 2.

After normalizing to restore consistency about the weight assigned for each factor and class, the spatial analysis

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tool; raster calculator in ArcGIS 10 was employed to derive the final thematic map for Earthquake hazard levels for the study region through employing the formula adopted from Pal et al (2006).

Table 2: Pair-wise comparison matrix of 4 factors used for the delineation of Earthquake hazard levels

Themes	Themes			
	LPZ	**PGA**	**Depth**	**Magnitude**
LPZ	1			
PGA	1/2	1		
Magnitude	1/3	1/2	1	
Depth	1/4	1/3	1/2	1

Table 3: Assigned and normalized weights of 4 factors used for the delineation of Earthquake hazard levels

Factors	**Assigned weights**	**Normalized weights**
Liquefaction factor	4	0.4658194
PGA	3	0.27714047
Magnitude	2	0.16107023
Depth	1	0.0959699
Total		1
CR		**0.01**

III. RESULTS AND DISCUSSION

The principal aim of preparation of earthquake hazard zonation was to highlight the sites within a study region that are highly vulnerable to linked hazards, where greater damages are to be expected during any major earthquake event. Thus MCE and AHP techniques were mainly employed in GIS environment to assess and analyze each contributing factors into demarcation of earthquake hazard levels. Multi-criteria evaluation or analysis technique is applied in various themes, like flood hazard assessment, ground water potential investigation, malaria hazard risk investigation, and so forth. The technique consists of processing and overlaying several environmental factors in the GIS environment. Multi-criteria evaluation works well with AHP to synthesize and normalize the decision made. For the present study the spatial analysis tool; weighted overlay raster calculator and reclassify tool in ArcGIS 10 were mainly used for the preparation of earthquake hazard levels. Thus four (4) factors were processed and assessed. These four (4) factors are explained in details below. Their effectiveness or importance in contributing to Liquefaction is discussed in the next section. For those factors selected to do earthquake hazard micro-zonation are all related to each other in contributing hazard.

3.1 LIQUEFACTION POTENTIAL ZONES

The combination or the integration of six (6) geological and geomorphological parameters that is; rock types based on consolidation status, available water holding capacity of soils, soil drainage, soil texture, slope factor and fault structure were used a input in delineation of liquefaction potential zones (LPZ) based on ranking and weightage assigned. The factors integrated are shown in figure 6. The liquefaction potential, also a geohazard was prepared and is shown in figure 8 (A) and it was used as one of the main contributing factor into delineation of earthquake hazard levels. The geohazard levels were then reclassified to five (5) classes, as very high, high, moderate, low and very low. The hazard levels were then assigned weightage and rankings. Very high zones were assigned higher weightage based on the idea that during any earthquake events, the areas are more prone to liquefaction, which eventually could lead to graver earthquake hazards. Hence from the analysis, it was found out that the very high liquefaction potential zones are the indication of the areas consisting of soft, saturated and unconsolidated sediments, soil or rock. The areas with low potential zones were assigned lower weightage. Liquefaction factor alone cannot fully and perfectly decide each earthquake hazard levels; it needs some other factors as well to be integrated with, in order to finally delineate earthquake hazard zones. Therefore the three (3) seismicity data layers were combined and integrated with liquefaction factor which house or holds the factors related to geology and geomorphology in to delineation of levels of earthquake hazard zones. According to Organization of American State (1991), possibility of liquefaction is simply a geohazards within a region related to earthquake, thus assessment of geological and geomorphological features are vital here to prepare liquefaction potential zones.

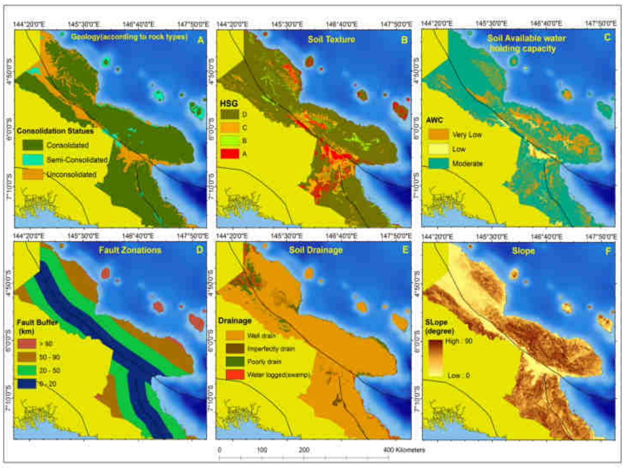

Fig.7: Thematic Layers evaluated for preparing LPZ (Geohazard)

3.2 PEAK GROUND ACCELERATION (PGA)

PGA raster surface was one of the factors that was employed into preparation of Earthquake hazard levels of the study region. PGA can also be termed peak horizontal acceleration which is contoured in units of percent- g; g = acceleration due to the force of gravity. Mostly the peak value of the horizontal acceleration was used to construct a PGA raster surface thematic layer. Once the earthquake strikes at the focus, the wave is generated and propagates to the surface. The intensity of shaking felt at each sites are measured in %gal at nearby recording stations.

For the present study, the recorded PGA of higher earthquake magnitude of 5 and above from year 2000 up to 2016 was assessed and analysed to prepare PGA raster surface with the premise whenever a specific site had experienced greater shaking intensity in the past earthquake episodes, the same site also stands vulnerable for greater shaking in the future earthquake events. All recorded PGA for each major earthquake events were acquired in point format and then were interpolated to prepare one single raster surface of PGA that is shown in figure 8 (B). From the integration of all recorded PGA values, it was found out that the highest shaking intensity experience within the study region was 35 %gal and the lowest was 1%gal.

After the preparation of PGA raster surface, it was reclassified into 5 classes based on its intensity values. The higher PGA values were given higher weightage based on the facts that higher the intensity of ground shaking more will be the likelihood of damage. The effects of PGA intensity at each site are determined or controlled by size and depth of the earthquake, greater the earthquake magnitude more will be the shaking intensity. Also shallower the earthquake depth more will be the shaking intensity. However, it is paramount to note that the levels of shaking intensity are immensely influenced by sub and site surface conditions. As the wave propagates from the earthquake focus, it is the side and sub surface geology and geomorphological factors that will determine whether the waves will be amplified or attenuated. According to McPherson (2005), once the waves propagate towards soft or saturated and unconsolidated sediments, soil or rock, the seismic waves tend to amplify and hence cause more damage with the invigorated shaking intensity. Eventually soft or saturated and unconsolidated sediments, soil or rock with sufficient moisture are susceptible to liquefaction posing high risk of collapse to overlying infrastructures. All these facts and factors are related and connected to each other that led to delineation of earthquake hazard zones of the study region.

3.3 EARTHQUAKE DEPTH

Earthquake depth distribution is one of the common features that were considered for delineation of earthquake hazard zones. Keeping in mind that the sites have experienced shallower depth earthquake in the past, the same sites are more vulnerable for shallower depth earthquake in the future too.

The raster surface of earthquake depth distribution was prepared from interpolation techniques using ArcGIS 10. It is obvious that the shallower the earthquake event, there’s higher possibility for earthquake damage to life and properties. However, the extent of damage will be determined by site and sub surface features. Deeper the earthquake events, lesser will be the possibility of damage, due to the fact that the waves from the earthquake focus have to travel long distance and face attenuation posed by different layers. However on the other hand the strength of the waves can be amplified if it comes to areas of soft, saturated and unconsolidated sediments or rocks but can again be reduced when it comes to consolidated sediments or rocks. These all depends on how deep or shallow is the earthquake focus. According to these ideas, the raster surface was reclassified into five (5) classes. Higher weightage was assigned to shallower earthquake depth and low weightage was assigned to classes of deeper earthquake. Figure 8 (C) highlights the raster surface of earthquake depth distribution.

3.4 EARTHQUAKE MAGNITUDE

Magnitude raster surface was prepared through interpolation techniques and was used as one of the 4 factors into delineation of earthquake hazard zones. As was discussed earlier, all the historical earthquake magnitudes from year 2000 up till 2016 were acquired in the point format and the interpolation technique in ArcGIS 10 was used to generate the raster surface of magnitude distribution with the precept that if the particular sites have experienced greater earthquake events in the past, then the same sites will also be vulnerable for experiencing greater earthquake magnitude in the future.

The raster surface prepared was then reclassified to five (5) classes based on its levels or magnitude. It was found out that the highest magnitude recorded within the study region was 7.1 in the south of study region around Bulolo and Wau area, while the lowest magnitude was found to be 3.1 in the study region. Evidently higher earthquake magnitudes pose greater damage to the surrounding environment and lower magnitude pose minimal or no damage. With this precept the weightage and rankings were assigned to each class. Although ‘magnitude’ has the gravest influence in earthquake induced damage, this

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factor alone cannot be perfect indicator of damage to a certain site, unless other factors are included or integrated into delineation of final output.

Figure 8 (D) illustrates the magnitude raster surface created from point interpolation

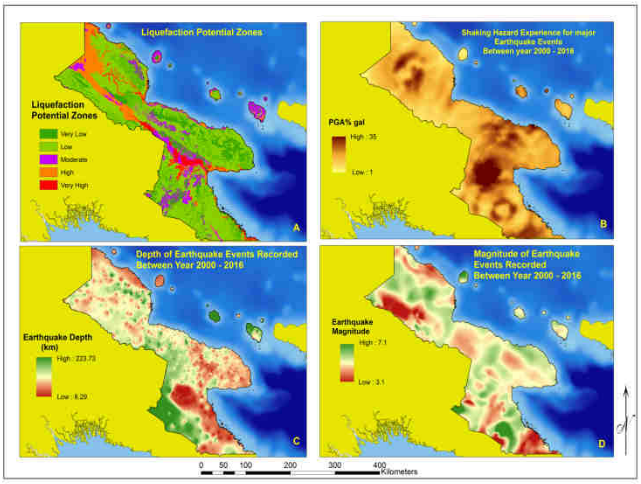

Fig.8: Thematic layers evaluated for Earthquake Hazard Levels preparation

3.5 ASSIGNING OF WEIGHTAGE AND RANKINGS

Through the integration of four (4) factors (A, B, C, D) as discussed above, the earthquake hazard levels were calculated and delineated. Table 4 tabulates the weightage and ratings assigned for each theme with their classes for the delineation of Earthquake hazard zones. The normalized weights were calculated using AHP techniques and finally were assigned for each theme. For the theme that contributes more to earthquake hazard were assigned high weightage and low weightage was assigned to theme that contributes less. As regards each class, ratings were assigned and again were normalized using AHP techniques. The table also shows the area in kilometer square (km2) and percentages (%) for each classes of each team

Theme	**Weight**	**Classes**	**Ratings**	**Normalize Rate**	**Area(km 2)**	**Area (%)**
LPZ	0.466	Very Low	1	0.04	10812.5	17.36
		Low	2	0.09	35337	56.73
		Moderate	3	0.16	6131	9.84
		High	4	0.26	7503.2	12.05
		Very High	5	0.45	2507	4.03
PGA (%gal)	0.277	1 - 7	1	0.04	17232.6	27.57
		7 - 14	2	0.09	21914.9	35.06
		14 - 21	3	0.15	14838.8	23.74
		21 - 28	4	0.31	7302	11.68
		28 - 35	5	0.41	1223	1.96
Earthquake Magnitude (EM)	0.161	3.1 – 4.1	1	0.04	4302.9	6.85
		4.1 – 4.8	2	0.09	13134.6	20.92
		4.8 – 5.4	3	0.16	28109.3	44.77
		5.4 – 6.1	4	0.26	16419	26.15
		6.1 – 7.1	5	0.45	814	1.30
Earthquake Depth (km) (ED)	0.096	180.6 - 223.7	1	0.01	3900.4	6.22
		137.6 – 180.6	2	0.1	9160.9	14.61
		94.5 – 137.6	3	0.20	20662.3	32.95
		51.4 – 94.5	4	0.25	18457.8	29.43
		8.3 – 51.4	5	0.44	10526	16.79

3.6 DELINEATION OF FINAL RESULTS

After assigning all the weightage and ratings, the spatial analyse tool; Raster Calculator in ArcGIS 10 was employed in calculating and producing the final earthquake hazard zonation map (figure 9). The final map derived was based on weightage and ratings assigned. The formula highlighted by Pal et al (2007) was adopted and modified to calculate and prepare earthquake hazard zones for a study region. The formula employed in a GIS environment to calculate and derive earthquake hazard zones was: EHI = [(LPZw . LPZr) + (PGAw. PGAr) + (EMw . EMr) + (EDw . EDr)] /w, where EHI = Earthquake Hazard Index. The EHI value was then assessed and reclassified in order to delineate Earthquake Hazard zones. Table 5 highlights the EHI value that was generated and was reclassified into each zones levels of earthquake hazard from very low to very high

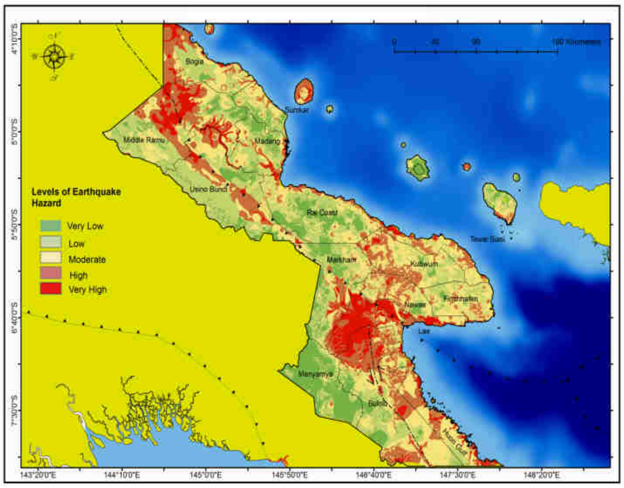

Fig.9: Earthquake hazard Micro-zonation of the Study Region

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Table 5: Earthquake Hazard levels re-classification

Earthquake Hazard Index Value (EHI)	Levels of Earthquake Hazard	Area (km^2)	Area (%)
0.86 – 1.72	Very low	8807.32	14.25
1.72 – 2.14	Low	17463.86	28.26
2.14 – 2.53	Moderate	17189.1	27.81
2.53 – 2.99	High	12905.52	20.88
2.99 – 4.30	Very High	5436.3	8.80

Table 5 presents the re-classification of earthquake hazard levels derived by integration of four (4) thematic layers. The tables also show areas in square kilometre (km2) and percentage (%) for each level of hazard zones. The very low and low zones indicate that there is no risk of earthquake hazard at all; the moderate potential zones indicate earthquake hazard may or may not occur; however high to very high zones indicate real possibilities of hazard to occur in the study area. It was found out from the calculation that 'Very low' potential zone has 14.25 % of area coverage, Low potential zone has 28.26 % of area coverage, moderate potential zone has 27.81 % of area coverage, high potential zone has 20.88 % of area coverage and very high potential zone has 8.80 % of area coverage.

3.7 EVALUATION OF INFRASTRUCTURES WITH HAZARD ZONES

After the completion of delineation of Earthquake hazard zones, several known and available built up infrastructure like roads, schools, health centers and other important built-up urban infrastructures were selected and overlaid on earthquake hazard zones of a study region to evaluate and consider its possible location on each potential zone. These infrastructures are crucial in terms of maintaining and improving the country's civic amenities as well as socioeconomic prosperity. These analyses are to let governing bodies and general public as a whole know or figure out the possible threats to each built-up infrastructure, where this can assist in proper development planning and awareness. Also it can assist in proper and better future development planning. Table 6 highlights the total number and length of each built-up infrastructure on each zone of earthquake hazard levels. The table 'columns' indicates the hazard levels from very high to very low and the 'rows' indicates each built-up infrastructure assessed under each hazard levels or zones in terms of counts (number) and lengths (distance). Total length of roads with respect to each potential zone was measured in kilometers through spatial analysis techniques in GIS environment and the value was noted. Also total number of count features like; major towns, health centers and schools were counted with respect to each potential zones and the value was recorded. Figure 10 illustrates the overall map of earthquake hazard levels with its overlaid features.

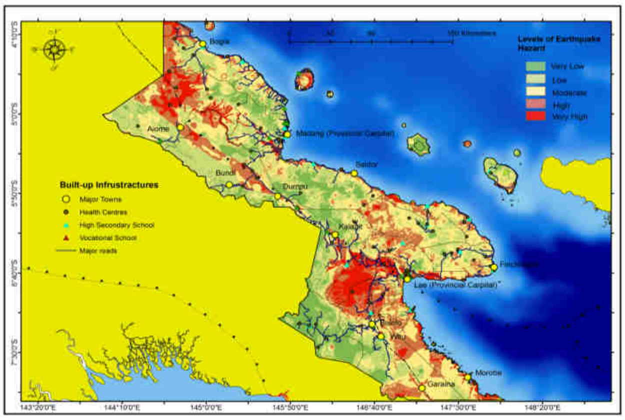

Fig.10: Evaluation of infrastructures on the earthquake hazard zones

Table 6: Built-up infrastructure assessed under each earthquake hazard zone

(I) Madang Province	*EARTHQUAKE HAZARD ZONES*				
BUILT-UP INFRUSTRACTURES	**Very high**	**High**	**Moderate**	**Low**	**Very Low**
Major Towns	Madang Town	Aiome	Bogia	Bundi	
		Madang Town	Dumpu		
		Saidor			
Major Roads (Length in km)	160.35	590.14	450.51	510.15	201.65
Health Centers(count)	6	19	9	11	4
Academic areas(schools)	3	10	2		
(II) Morobe Province	*EARTHQUAKE HAZARD ZONES*				
BUILT-UP INFRUSTRACTURES	**Very high**	**High**	**Moderate**	**Low**	**Very Low**
Major Towns	Lae Urban	Lae Urban	Finchhafen	Kaiapit	
	Bulolo	Wau	Morobe		
		Garaina			
Major Roads (Length in km)	380.82	620.33	490.41	420.92	469.61
Health	11	14	10	5	7

Centers(count)					
Academic areas(schools)	7	11	3	2	1

IV. CONCLUSION

Earthquake hazards are common throughout the world and they are often accompanied with great loss of lives and infrastructural assets. The wide spread damage and death depends on the magnitude, depth of focus and distance of major human built-up infrastructure from the epicenter, the shaking intensity and the ambient geology and geomorphology. Thus assessing the historical earthquake seismicity data layers coupled with geology and geomorphology can assist in identifying possible levels of hazard in each site. There is always a possibility that if the particular sites that have experienced big earthquake events in the past, then the sites remains vulnerable for greater earthquake magnitude in the future. If the sites have experienced great shaking intensity, then the sites are always vulnerable for greater shaking in the future earthquake event. If the sites have experienced shallow depth earthquake in the past, then the sites can expect shallow depth earthquake focus in the future too with more devastating consequences. In the event of a high magnitude earthquake triggered at shallow depth at a site where the sediments, rock or soil are unconsolidated and saturated, then there is higher possibility of experiencing greater damage due to intense shaking. These are the ideas that could be integrated in a GIS platform to produce a meaningful delineation of various earthquake hazard zones. These maps can prove very useful to the administrators.

Earthquake hazard micro-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 earthquake hazard levels, future development planning can be done effectively towards site selection for investment decision of major infrastructures.

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