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First Order Seismic Microzonation of Miri district of Sarawak Malaysia using AHP-GIS Platform

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Abstract

This investigation is dealing with the seismic microzonation index of Miri district of Sarawak Malaysia using Analytical Hierarchy Process (AHP) by utilizing Geographical Information System (GIS), Miri is the coastal city situated in the Sarawak state of Malaysia. This study is timely for the prevention of havoc since, Peninsular Malaysia lies in the vicinity of regions (Sumatra, Indonesia) that have experienced strong earthquakes in the past. The state of Sarawak and Sabah, also lie in Malaysia are nearby to the seismic tremor zone of South Philippines and North Sulawesi. However, the chances of being vibrated by at least moderate local earthquakes are highly possible from the previous earthquake records of Malaysia. The highest PGA for Sarawak is 0.09g (which is in Miri) and the lowest is 0.01g in terms of 10% probability of exceedance of an event in 50 years. The hazard themes consist of peak ground acceleration (PGA), shear wave velocity (Vs30), liquefaction potential index (LPI), amplification ratio AR, lithology (LTGY) and predominant frequency (PF), which were developed for the Miri district. All the hazard themes were integrated in the GIS environment using AHP, in order to produce the seismic microzonation index map. From the results, the Miri district has been classified into three zones viz, Low, Moderate and High hazard zone. The current study predominantly reports issues to develop the seismic microzonation map of Miri city and the results of this study can be used as direct data in choosing the proper land use planning in order to reduce the adverse effects of earthquakes in the Miri district of Sarawak, Malaysia.

Keywords; *Analytical Hierarchy Process AHP, earthquake, geographical information system GIS, Miri, seismic microzonation.*

I. INTRODUCTION

Seismic tremors are standout amongst the riskiest, dangerous and eccentric regular perils, which can surrender everything over to a couple of hundred kilometers in entire pulverization right away. Catastrophic events are progressively undermining human lives, framework, and monetary and social exercises. Seismic hazard zonation for urban territories, mostly denoted to as seismic microzonation, is the first and most vital advance towards a seismic hazard investigation and alleviation strategy in thickly populated locales. Cataclysmic events are one of the reasons for human suffering.

Earthquake is a natural disaster that is unpredictable that creates a huge amount of damage, which affects the communities and their surroundings [1]. The first and most essential step towards seismically risk analysis and reduction approach in heavily populated communities is the earthquake hazard zoning of urban areas, often called seismic microzonation [2]. However, it has been reported from several earthquake events that the critical damage to man-made structures and buildings is

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mostly found in those regions, where the soft sediments are predominant [3]. This can also lead to huge socio-economic disasters with even relatively minor incidents of earthquakes. Egypt was struck with an earthquake on 12 October 1992 with a moderate earthquake of magnitude 5.4, resulting in an estimated loss of 1 billion US dollars, 20000 people wounded and 554 deaths [4][5]. For the present study area, two earthquakes were found in the Miri district having magnitude 4.2 and 5.2 on Richter scale, which occurred on 19/04/2005 and 01/05/2004 respectively and also felt earthquakes from far and near sources of earthquakes since 19th century [6] (USGS). On the other hand, an earthquake of magnitude 4.8 of 2/05/2004 in the vicinity of Miri, Sarawak, also damaged non-reinforced concrete buildings and created ground breakage [7].

The definition of Seismic microzonation is subdividing a territory into small zones having the diverse potential for the dangerous seismic tremor effects. The site response, peak ground acceleration (PGA), landslide, and liquefaction caused by earthquakes are the essential attributes of seismology to develop a microzonation map for earthquakes. Seismic microzonation is used as an instrument to enhance the condition of land use planning and to reduce the devastating threat of earthquakes in the future [8]. Generally, Seismic microzonation has been considered as the most essential instrument in hazard assessment and it may be defined as the division of a region into small regions with respect to site-specific conditions, ground motion characteristics (PGA, SA) [9] (TC4-ISSMGE, 1999). So, as to build up appropriate management plans for the reduction of the earthquake disaster, it is basic that the planners of the city have a clear understanding of the degree of conceivable harm to their city in case of a future seismic tremor. In against a natural disaster earthquake, the initial step to ensure the safety of the region is to have a comprehension of the susceptibility of that region under thought to future seismic tremors [10].

The seismic activity in East Malaysia has been increased since 1900, fortunately, devastating earthquakes are very rare in Eastern Malaysia. However, on 26th July 1976 and 05 June 2015, this region was struck by devastating earthquakes with a moment magnitude of 5.8 and 6.0 having epicenter in Lahad Datu and Ranau respectively. The seismicity rate around East Malaysia comes from isolated sources either from Kalimantan, Sulawesi, and Southern Philippines and local sources that appear to be linked with some local faults and weak zones producing the low-to-moderate magnitude of earthquakes [11]. In this study, seismic microzonation of the Miri city of Sarawak Malaysia is presented. Miri is a coastal area situated on the island of Borneo near the border of Brunei

Lots of lessons to be learned are left from the past records of earthquakes throughout the world therefore, immediate procedures must be taken to mitigate such disastrous earthquakes in the future. The first attempt of seismic microzonation was carried out in Yokohama city, Japan in the year of 1954 [12] (National Institute of Disaster Management, 2011). Nowadays, the seismic microzonation is the world-wide essential tool to eliminate the seismic risk [8][13]. However, seismic microzonation is distinguishing proof of areas having distinctive seismic risk potentials which will essentially serve for land use planning and urban planning [14]. The main phases towards the seismic risk analysis and the reduction of seismic risk are Site characteristics, site-specific analysis and seismic microzonation [15]. Although, seismic microzonation maps can be developed inexpensively and rapidly which explains the ground shaking parameters, and these maps are useful to engineers and can be used as guidance for the structural engineers in designing and constructing the earthquake resistant structures so as to eliminate the loss of property and loss of life [16]. Also, according

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to [17] seismic microzonation maps present the amplification and the surface acceleration which are plotted to generate a comprehensive microzonation model to categorize the areas as, high-risk earthquake area, moderate risk earthquake area and low-risk earthquake area for land use planning. Seismic microzonation maps are the zonation maps which include the site soil properties and the geology of the site [18]. In Boshehr (the southern cities of Iran) site-specific analyses, site characteristics, and seismic microzonation were conducted to mitigate the risk of earthquakes [15] the earthquake response spectrum is the most popular tool use in seismic hazard analysis [19]. The data collected from the bedrock motion and boreholes obtained were computed by Nonlinear Earthquake Site Response Analysis (NERA), to generate the amplification and surface acceleration required for mapping [17]. Seismic microzonation was used as a tool in turkey to enhance the quality of land use planning to reduce the risk of earthquakes in the upcoming, after the 1999 earthquake of Kocaeli, the project of microzonation was started. In this project, all the data was converted to GIS format and the computed results were calculated to get a microzonation map along with landslide hazard, liquefaction susceptibility and site amplification [8]. Seismological and geological data has been used to obtain seismic hazard analysis and seismic microzonation in Sikkim Himalaya. While as in Guwahati city seismic microzonation was done which was based on geomorphology, geology, soil characteristics, seismotectonics, peak ground acceleration, predominant frequencies and seismic hazard. Also, the first order seismic microzonation of Haldia has been prepared which is based on peak ground acceleration, elevation map and predominant frequencies. And in the city of Dehradun, a seismic microzonation map has been developed on the basis of shear wave velocity with site response analysis [20].

II. GEOLOGY AND TECTONIC SETTINGS

Borneo is found far from boundaries of major tectonic plates, there are signs of continuing deformations [21], as appeared by the event of seismic tremors in the area, for the most part on the NW portion [22] [23]. Miri is a coastal city in northeast Sarawak, Malaysia, situated on the island of Borneo, near the border of Brunei. Borneo is a fragment of the Sunda plate, and it is caged by the indo-Australian and Philippine Sea plate [24] [23]. Miri is at a distance of 330 Km from Sabah State. Sabah is situated very close to most seismically active plate boundaries between Eurasian Plate and Indo-Australian Plate in the western and between Philippine Plate in the east. The movement of Peninsular Malaysia for the north component towards south-east is at a normal speed of -0.89 ±0.01 cm/yr and for the east component is 1.70 ±0.02 cm/yr, while East Malaysia moves south-east as well, for the north component at a normal speed of -1.06 ±0.01 cm/yr and 2.50 ±0.02 cm/yr for the east component [25].

The Bukit Mersing Fault is seen as strike-slip in nature and is active through Eocene to the central Miocene. The Fault was reactivated a few times and this reactivation alongside different movements prompted extreme deformation of parts of central and northern Sarawak [26]. According to [27], the northern Sarawak referred here as Miri zone covers the region to the north of the Bukit Mersing Fault [28]. The West Baram Fault Line seems to meet the Sarawak shoreline around 40 km more towards Miri [29]. Borneo has been isolated into five zones—Kuching Zone, SW Borneo, Sibu Zone, Miri Zone and East Borneo Zone—by the Lupar Line, Adang Fault, Tatau-Mersing Line, Tinjar Line and Long Aran-Witti-Kinaya Fault, respectively. The Miri Zone imparts a fringe toward the south to the Sibu Zone by the Tatau-Mersing Line. Mainland clastics, post-Eocene carbonates and molasses lacking solid deformation, which is underlain by the pre-strongly

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collapsed deep marine Rajang Group, all these dominate the Miri Zone [22] shown in Figure 1.

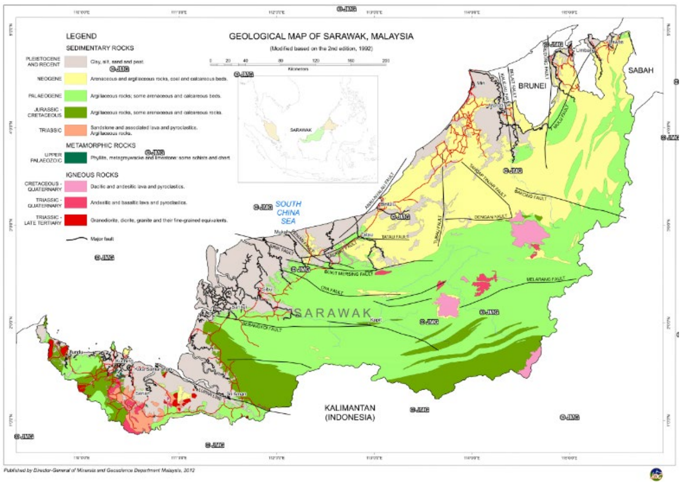

Figure 1 Geology of Sarawak, Malaysia (JMG)

III. SEISMICITY IN MIRI DISTRICT

Borneo is found far from boundaries of major tectonic plates, there are signs of continuing deformations [21], as appeared by the event of seismic tremors in the area, for the most part on the NW portion [22] [23]. From the previous records of earthquakes in East Malaysia, it has encountered several seismic tremors of the local origin of magnitudes “between” 3.6 to 6.5 from 1984 to 2007 [30]. Historical Earthquakes in and around East Malaysia from 01-01-1900 to 20-10-2018 having magnitude from 3.5 to 6.5 is shown in Figure 2. In the past 35 years, 3 earthquakes were recorded ranging from Mw 3.5 to 5.3 in Sarawak by observing the maximum intensity of IV on the Modified Mercalli scale [31]. If compared to other parts of Malaysia, Sabah is prone to the earthquake with moderate magnitude. The seismic activity in East Malaysia has been increased since 1900, while destructive earthquakes are luckily very rare in East Malaysia (Sarawak and Sabah), previously East Malaysia also experienced devastating earthquake which was centered in Lahad Datu on 26th July 1976 with a moment magnitude of MW 5.8 [32]. Recently an earthquake that happened in Sabah, a state situated in the northern piece of Borneo, has shaken the SE Asian public since it was not anticipated to occur. A noteworthy number of specialists were similarly shocked due to the harm it caused. The low-to-moderate magnitude seismic tremor struck Sabah on 5 June 2015 and this incident is viewed as the greatest recorded quake ever of Borneo, and it is accounted for that 18 individuals lost their lives [22] [32] [33]. Miri city in Sarawak is about 342.53 Km distant from the Ranau Sabah. Sabah state has a lot of local earthquakes with moment magnitude up to 6.0 on the Richter scale (United States Geological Survey, [6] (USGS)). For the present study area, two earthquakes were found in the Miri district having magnitude 4.2 and 5.2 on Richter scale, which occurred on 19/04/2005 and 01/05/2004 respectively shown in Figure 2 and in addition, felt earthquakes from far and near sources of earthquakes since 19th century [6] (USGS). On the other hand, an earthquake of magnitude 4.8 of 2/05/2004 in the vicinity of Miri, Sarawak, also damaged non-reinforced concrete buildings and created ground breakage [7].

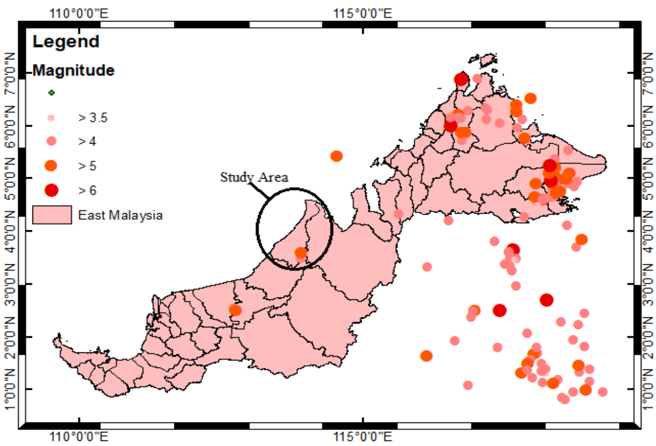

Figure 2 Historical Earthquakes in and around East Malaysia [6] (USGS, accessed on 12/10/2019)

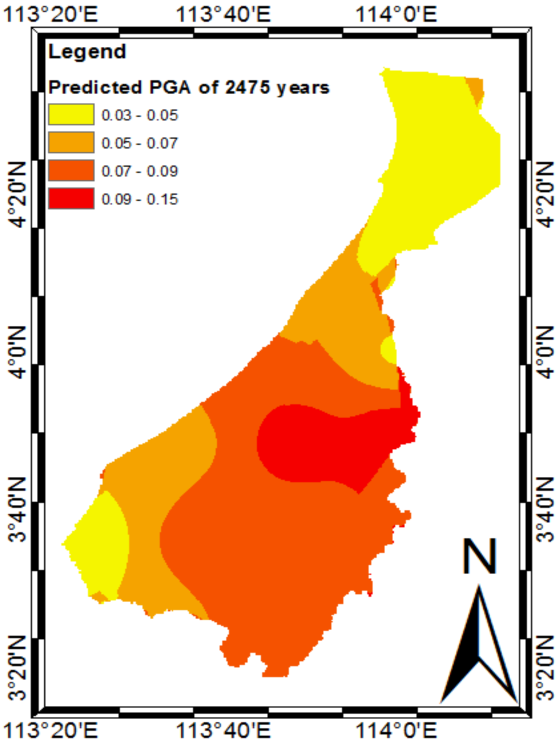

Figure 3 Predicted PGA (g) map of Miri Sarawak, Malaysia, corresponding to 2475 years after [34]

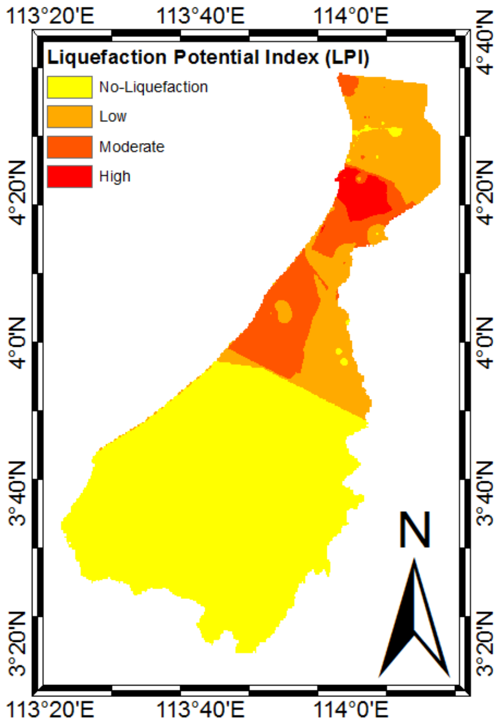

Figure 5 Liquefaction potential index map of Miri district after [36]

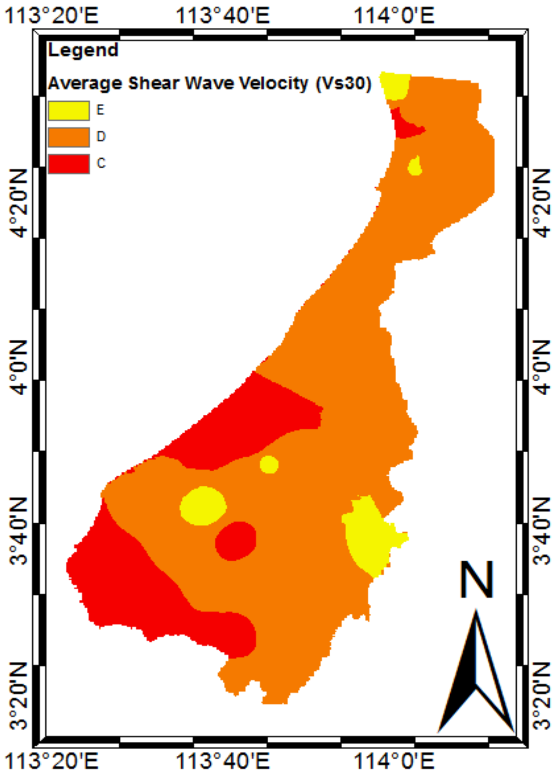

Figure 4 Distribution of Vs30 in Miri district after [35]

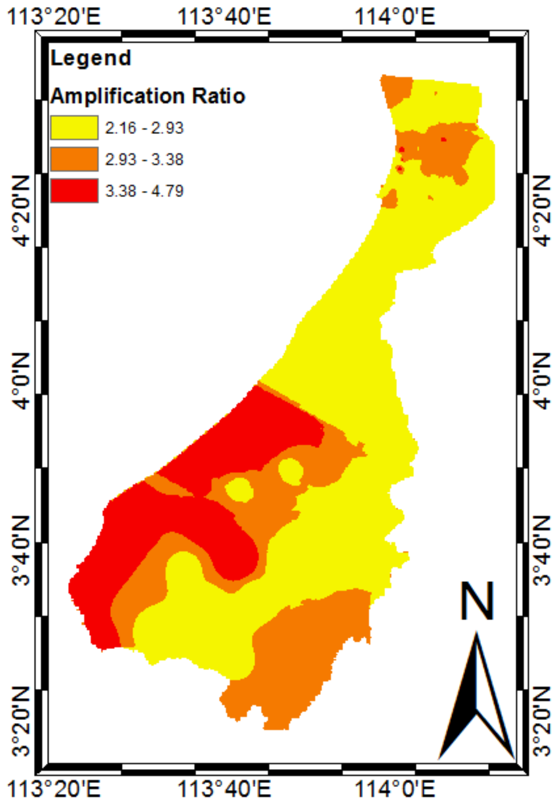

Figure 6 Amplification ratio map of the Miri district after [35]

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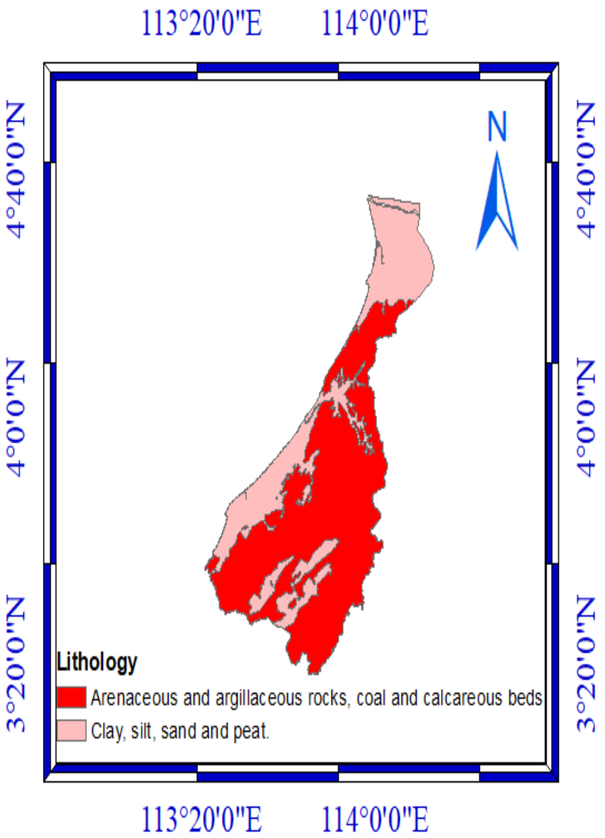

Figure 7Lithology of Miri district

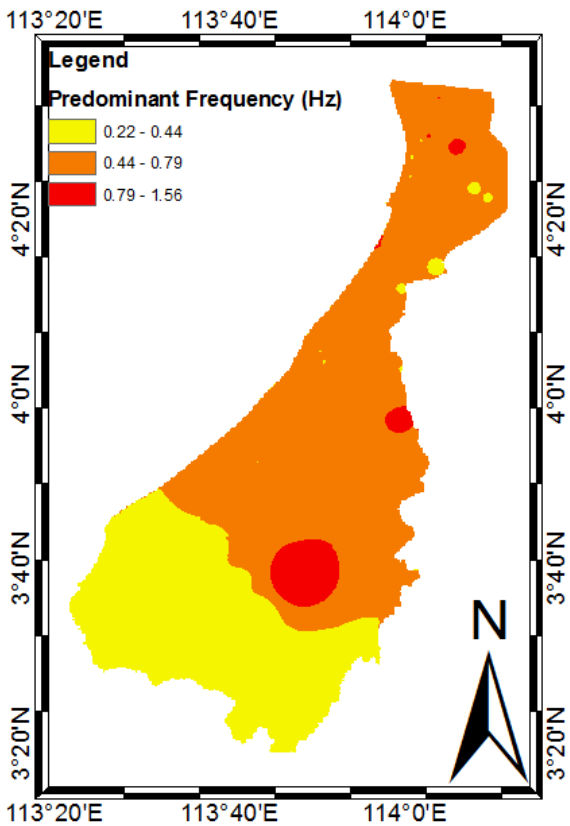

Figure 8 Predominant frequency (Hz) map of the Miri district after [35]

IV. METHODOLOGY

In this research, point-by-point probabilistic seismic hazard investigation completed by [34] for the whole Sarawak state has been utilized, also, detailed site-specific ground response analysis on selected boreholes for the Miri city carried out by [35] has been used. In addition, computational analysis of liquefaction in the district of Miri carried out by [36] (Fig 8) has been used. The hazard themes comprise of predicted peak ground acceleration (PGA) from probabilistic seismic hazard analysis, shear wave velocity (Vs30), lithology (LTGY), amplification ratio (AR), predominant frequency (PF) [35] from site response analysis and liquefaction potential index (LPI) [36] for the Miri district of Sarawak Malaysia, all the themes are shown in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8 respectively.

All the themes were developed for the entire study region and plotted as hazard maps by utilizing the geographical information system (ArcGIS). Based on parameters of seismicity, the probabilistic seismic hazard assessment of the study area at the bedrock must be accomplished. The geotechnical information comprises of standard penetration test values (SPT-N values). 114 SPT boreholes were used by [35] [36] for the assessment of site effects and for the assessment of liquefaction potential index. This geotechnical data is analyzed by using the software DEEPSOIL by using ground motion from pacific earthquake engineering research (PEER) [37] (because of unavailability of ground motions in Sarawak) compatible with target response spectrum of Sarawak malaysia, that have been transmitted through each SPT boreholes to evaluate the site effects. The Vs30 functions are categorized according to the classification of the NEHRP site shown in Table 1.

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Table 1 classification of site according to NEHRP on the basis of Vs30 upto the depth of 30m [38]

NEHRP site class	Rock/soil type	Vs30 (m/s)
A	Hard rock	>1500
B	Rock	760-1500
C	Dense soil/soft soil	360-760
D	Stiff soil	180-360
E	Soft soil	<180

The obtained results from DEEPSOIL software were then integrated with the geographical information system (GIS environment) to develop the different themes of seismic microzonation map by using the Saaty's [39] (the 1980) analytical hierarchy process (AHP).

Table 2 Formation of matrix of themes

Themes	PGA	Vs30	LPI	AF	LTGY	PF
PGA	1	6/5	6/4	6/3	6/2	6/1
Vs30	5/6	1	5/4	5/3	5/2	5/1
LPI	4/6	4/5	1	4/3	4/2	4/1
AF	3/6	3/5	3/4	1	3/2	3/1
LTGY	2/6	2/5	2/4	2/3	1	2/1
PF	1/6	1/5	1/4	1/3	1/2	1

AHP is a multi-theme decision-making tool that assigns a weight to each theme based on hierarchical structuring and comparison of ratios. Finally, for each theme, standardized weights are obtained. AHP's second phase is to group the values into classes within a theme, generally referred to as each theme's characteristics. Then, according to the relationship outlined below, each function is ranked. The assigned ranks and weights are shown in Table 2 and the normalized weightage is shown in Table 3.

$$Rnorm = \frac{Ri - Rmin}{Rmax - Rmin}$$

Where Rnorm is normalized rank, Ri is initial integral, Rmin is assigned minimum rank and Rmax is assigned maximum rank. Finally, thematic integration to calculate the Seismic Hazard Index (SHI) is performed in the GIS.

$$SHI = \frac{\begin{array}{c} PGA_W.PGA_R + Vs30_W.Vs30_R + LPI_W.LPI_R \\ +AF_W.AF_R + LTGY_W.LTGY_R + PF_W.PF_R \end{array}}{\sum w}$$

Where, PGA, Vs30, LPI, AF, LTGY and PF are the themes, R and W represent Rank and weight of theme respectively.

[40] also used this strategy effectively for comparable microzonation research. Also, the characteristics of each thematic map are standardized from 0 to 1 [41] to guarantee that no layer exerts impact beyond its determined weight. The calculated weight factor for each layer is based on the choice of expert. For this case study, the combined correlation matrix is set up for the six themes (PGA, Vs30, LPI, AF,)

GIS environment is then used to integrate all the hazard themes by allocating the weightages to each theme by using the aggregate tool under spatial analyst tool also [40] to deliver the seismic microzonation map of Miri district.

Table 3 Normalized weights assigned to each theme

Themes	PGA	Vs30	LPI	AF	LTGY	PF	Weightage
PGA	1	1.2	1.5	2	3	6	**0.28**
Vs30	0.83	1	1.25	1.67	2.5	5	**0.24**
LPI	0.67	0.8	1	1.33	2	4	**0.19**
AF	0.5	0.6	0.75	1	1.5	3	**0.14**
LTGY	0.33	0.4	0.5	0.67	1	2	**0.09**
PF	0.167	0.2	0.25	0.33	0.5	1	**0.05**
$\sum$	**3.5**	**4.2**	**5.25**	**7**	**10.5**	**21**	**1**

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VI. RESULTS AND DISCUSSION

Miri is the district in East Malaysia with low-to-moderate seismicity. For seismic microzonation, all the themes are classified as; predicted peak ground acceleration (PGA), shear wave velocity (Vs30), lithology (LTGY), amplification factor (AF), liquefaction potential index (LPI) and predominant frequency (PF). Each theme has assigned a weight by using analytical hierarchy process (AHP) of Saaty, which was used by [42] [5] [43] [40]. The themes in decreasing order are shown in Table 3. The highest weight is given to PGA as 0.28, and then the decreasing order is as Vs30 as 0.24, LPI as 0.19, AF as 0.14, LTGY as 0.09 and PF as 0.05 followed by [41] [44]. All the six themes were integrated in ArcGIS by using the weighted and overlay operations under spatial analysis tool, this tool was also used by [43] [41].

All the used hazard themes are geotechnical in character except PGA. These hazard themes are significant from the site response perspective, which assumes a significant job in building harm and pulverization. The first to note is the distribution of shear wave velocity (Vs30) from the site's geotechnical parameters. Classes C, D and E are dominant in the district of Miri [35] shown in Fig 5.Liquefaction susceptibility was found by [36] and it was found that overall Miri district is having low to moderate liquefaction potential.

Fig 9 shows the seismic microzonation map of Miri district corresponding to 2475 years, based on seismic hazard analysis and geotechnical dataset. The seismic microzonation map is classified into three zones: low, moderate and high hazard zones. The northern part of Miri district is under low hazard and the majority of southern and central part is under moderate hazard, only a few areas in Miri district are showing the high hazard shown in Figure 9.

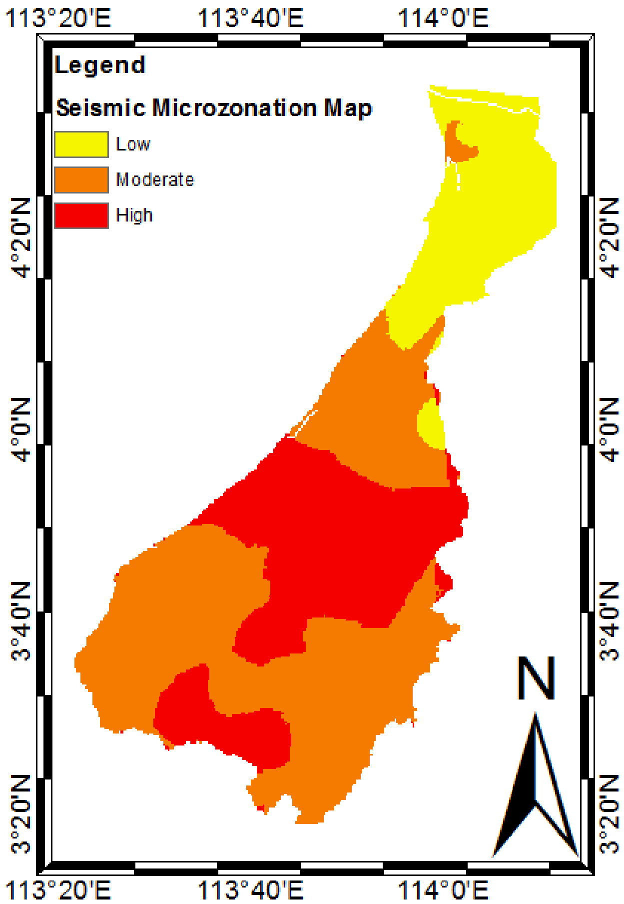

Figure 9 Seismic microzonation map of Miri district of Sarawak Malaysia corresponding to 2475 years

Following the above methodology and investigation, the subsequent seismic microzonation map of the Miri district of Sarawak is appeared in Fig 9. The seismic microzonation map of Miri district corresponding to 2475 yearsis expressed in terms of seismic hazard index by following [40] and is classified into three classes: low, moderate and high hazard zone. In this way, overall of Miri district of Sarawak is susceptible to low-to-moderate seismic hazard.

VI. CONCLUSIONS

A significant purpose of this examination is to recognize the degrees of seismic danger for the Miri district. Seismic microzonation can be considered as being made out of three fundamental stages. In the primary stage, the quake source feature for the investigation region should be resolved all the more

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precisely in a probabilistic way to fulfill the necessities of the structural designing and land use planning. The subsequent stage is the examination of the geographical and geotechnical site conditions, thinking about all the applicable elements (topographic, site conditions and soil classifications). This data is a fundamental element for the evaluation of site-specific ground response analysis. The third stage is the investigation and elucidation of the gathered information in the initial two stages to set up suitable and appropriate microzonation parameters that could be used for land-use planning and therefore can result in mitigation of seismic hazard. By utilizing GIS, it is conceivable to create a seismic microzonation map that examinations seismic danger (risks) and therefore gives help to land use planning.

In cataclysm vulnerable locales, the capability to recognize and stay away from severely risky regions is appropriate to limit losses and harms. For this study, a first level seismic microzonation map of Miri district has been created dependent on weighted parameters of seismological, site response, geological and Liquefaction analysis. With the microzonation map it is trusted that future advancement will have the option to stay away from exceptionally dangerous regions of related risks and encouraging more secure building standards and practices of land use planning.

The reason for this study is to carry out the seismic microzonation of the Miri area of Sarawak. This seismic microzonation index (SHI) map will be exceptionally valuable for computing seismic hazard and furthermore making disaster mitigation arrangements (land use planning) to decrease the risk of earthquakes in Miri district.

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