Seismic Hazard Analysis using AHP-GIS

Zin Zin Nwe#1, Kay Thwe Tun#2

***Abstract*—**Myanmar, lying in the Alpide earthquake belt, indeed is an earthquake-prone and is vulnerable to hazards from moderate and large magnitude earthquakes. There is a real need for creditable seismic zoning of the Mandalay city, which lies near the active Sagaing fault, to mitigate its earthquake hazards because it is not only very dense population but also urbanized city. Many researchers had been developed the seismic hazard map for Mandalay city based on the seismological data. In this paper, seismic hazard of the Mandalay City is microzoned by integrating seismological, geological and geotechnical themes in GIS. The potential seismic hazard microzonation (SHM) map is further classified into five categories: Very High, High, Moderate, Low and Very Low hazard zones. The most dangerous area is the western part of Mandalay city which is near the Sagaing fault. Near the Mandalay hill and the right portion of Pyi Gyi Ta Gon township suffer very low seismic hazard. Liquefaction effect should consider carefully along the Ayeyarwaddy river bank. This SHM map will be very useful for calculating seismic risk assessment and also making disaster mitigation plans to reduce the seismic risk for Mandalay city.

***Keywords*—**Sagaing fault, seismic hazard, Mandalay city, GIS.

I. Introduction

Hazard is a probability of occurrence within a specified period of time and within a given area, and has a given intensity. Hazards can induce latent conditions that may present future threats. When the hazard materializes, the earthquake actually takes place, causing the losses and casualties to the vulnerable society, and creating the disaster.

Risk results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk. Therefore, seismic hazard assessment is very important for investigation of earthquake risk assessment. There are two approaches for seismic hazard assessment such as deterministic and probabilistic approaches which is based on seismological data.

Recently the qualitative method based on the combination of analytic hierarchy process (AHP) and geographic information system (GIS) technique has been used successfully to map seismic hazard zonation in different parts of the world. This method is considered the multi conditions such as seismological, geological and geotechnical conditions.

Myanmar, lying in the Alpide earthquake belt, indeed is an earthquake-prone and is vulnerable to hazards from moderate and large magnitude earthquakes. There is a real need for creditable seismic zoning of the Mandalay city, which lies near the active Sagaing fault, to mitigate its earthquake hazards because it is not only very dense population but also urbanized city. Many researchers had been developed the seismic hazard map for Mandalay city based on the seismological data. In this paper, seismic hazard of the Mandalay City is microzoned by integrating seismological, geological and geotechnical themes in Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) model are applied to map seismic hazard zonation qualitatively. The main inputs for data integration in this study are peak ground acceleration (PGA), liquefaction potential index (LPI), site condition, soil condition, slope condition and geology condition.

II. Description of Study Area

Mandalay is the second largest city in the Republic of the Union of Myanmar. It is situated between Longitude E 95˚ 58´ and E 96˚ 22´, and Latitude N 21˚45´ and N 22˚10´. Its population has about 1.3 million according to the 2014 census record and the population growth rate is 3% in average from 2000 to 2014. There are 7 townships in Mandalay city divided from Mandalay City Development Committee (MCDC) as of 2012. In this study, only the 5 townships as shown in Fig.1 are included because these townships are very dense population and downtown area of this city.

Mandalay lies near Sagaing fault, a tectonic plate boundary between the India and Sunda plates. The well-known and seismologically very active Sagaing fault, trending roughly north-south, has been an originator of a large proportion of destructive earthquakes in Myanmar. It has experienced many destructive earthquakes because it lies much closed to the Sagaing fault. The most destructive events are Innwa (23 March 1839) and Sagaing (16 July 1956) earthquake. In the historical records, many earthquakes happened in and around Mandalay area. Table I shows the historical earthquakes of Mandalay area.

Zin Zin New is with Mandalay Technological University, The Republic of the Union of Myanmar.

Kay Thwe Tun is with Mandalay Technological University, The Republic of the Union of Myanmar.

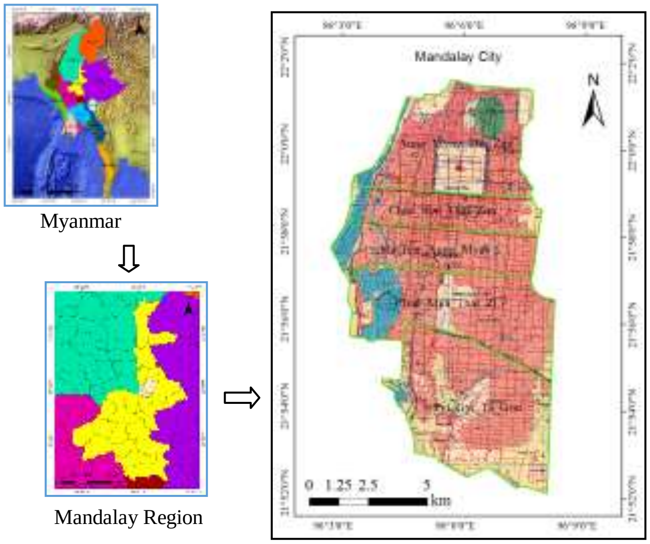

Fig. 1 Map of study area

TABLE I
HISTORICAL EARTHQUAKES OF MANDALAY AREA

No.	Date	Location	Remarks
1	1429	Innwa	Collapse of buildings
2	1469	Innwa	Collapse of pagodas and temples; liquefaction
3	24-7-1485	Sagaing	Collapse of famous pagodas
4	1501	Innwa	Collapse of buildings and pagodas; many monks killed
5	23-6-1620	Innwa	
6	18-8-1644	Innwa	Liquefaction; floating of fish in Myitngae River
7	10-9-1646	Innwa	
8	11-6-1648	Innwa	
9	1-9-1688	Innwa	Collapse of pagodas and temples; loss of many lives
10	3-4-1690	Innwa	
11	15-9-1696	Innwa	
12	8-8-1714	Innwa	Collapse of pagodas and temples; flooding
13	15-7-1771	Innwa	
14	9-6-1776	Innwa	Collapse of pagodas and temples
15	26-4-1830	Innwa	
16	21-3-1839	Innwa/ Amarapura	
17	23-3-1839	Innwa	(300-400), liquefaction; River flow was reversed)
18	16-7-1956	Sagaing	(7.0 M) (40-50), Sagaing Bridge moved about 3″ at Mandalay Site

Source: Dr. Myo Thant (Geology Department, University of Mandalay)

III. METHODS AND MATERIALS

In this study, Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) model are applied to map seismic hazard zonation qualitatively. The main inputs for data integration in this study are peak ground acceleration (PGA), liquefaction potential index (LPI), site condition, soil condition, slope condition and geology condition. The PGA map is based on the probabilistic seismic hazard map of Mandalay for 10% of probability of exceedance in 50 years by means of PGA (g), considering site condition developed by Myo Thant et al. The LPI map is developed by summarizing the factor of safety (FS) proposed by Luna and Frost (1998). The factor of safety against liquefaction is calculated by simplified procedure.

The average shear wave velocity to upper 30 m, Vs30 of Mandalay city developed by Myo Thant et al is used to classify the site condition. The slope condition is calculated from Digital Elevation Model (DEM) evaluated from the topographic maps. The required data for geology and soil condition is collected from Myanmar Geoscience Society. The importance of criteria is evaluated based on the analytic hierarchy process (AHP) method. After assigning the criteria weights and sub-criteria ranks, the final seismic hazard microzonation (SHM) map is developed qualitatively by using aggregation method in GIS.

IV. DATA PREPARATION

The main parameters for developing the seismic hazard microzonaiton (SHM) map are peak ground acceleration (PGA), liquefaction potential index (LPI), site condition, soil condition, slope condition and geology condition.

A. Peak Ground Acceleration (PGA)

The seismic hazard map of Mandalay city developed by Eyn Keey and Maung Thein et al (2011) is the first map for that city, in which the seismic hazards are calculated by using the deterministic way. After that, Myo Thant et al (2012) evaluated the seismic hazard map for that city by using both probabilistic and deterministic approaches, representing peak ground acceleration (PGA) in g, peak ground velocity (PGV) cm/s and spectral acceleration (SA) in g at the period of 0.3 s and 1.0 s. The probabilistic seismic hazard analysis is performed for 2% probability of exceedance in 50 years and 10% probability of exceedance in 50 years, while the deterministic seismic hazard analysis is carried out by utilizing the two distinct fault specific seismic sources: Sagaing and Kyaukkyan fault. While developing the seismic hazard maps, the site condition was not considered, it is calculated only for rock condition. In 2014, Myo Thant et al calculated the seismic hazards for 2% probability of exceedance in 50 years and 10% probability of exceedance in 50 years by considering the site condition. The hazards are presented by means of peak ground acceleration (PGA) in g and spectral acceleration (SA) in g at the period of 0.2 s and 1.0 s. In this study, PGA map shown in Fig. 2 is the latest peak ground acceleration (g) map developed by Myo Thant et al.

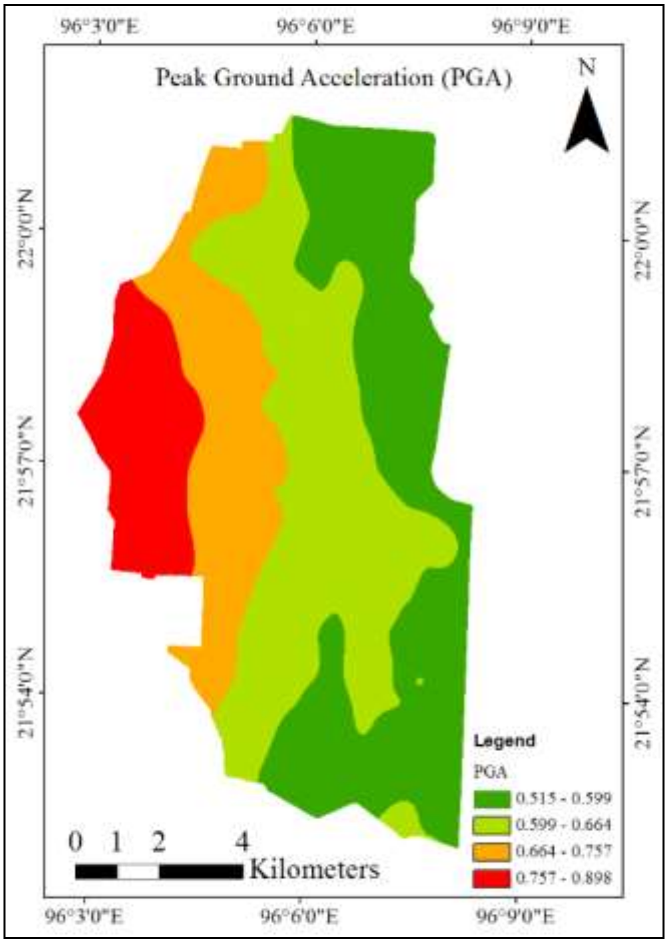

Fig. 2. Peak ground acceleration (PGA) map

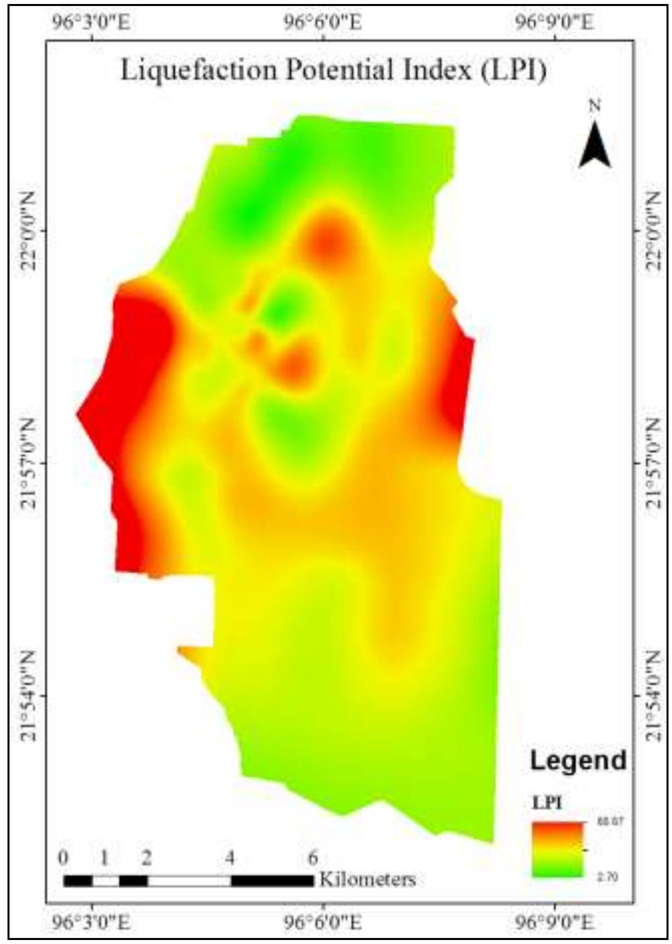

Fig. 3. Liquefaction potential index (LPI)

B. Liquefaction Potential Index (LPI)

Evaluation of liquefaction is one of the most important and commonly encountered problems in civil engineering. Soil liquefaction and related ground failures are commonly associated with large earthquakes. Therefore, the liquefaction potential index (LPI) is very crucial for assessing seismic hazard analysis.

Several approaches have been developed to evaluate the liquefaction potential. The most widely used are cyclic stress approach and cyclic strain approach to characterize the liquefaction resistance of soils both the laboratory and field tests. Some other approaches are probabilistic approaches, energy dissipation and effective stress based response analysis, etc. During the past two decades, several procedures have been proposed to estimate liquefaction resistance based on V_S.

In this paper, the simplified procedure is used to calculate the factor of safety against liquefaction. The liquefaction potential index (LPI) is evaluated by summarizing the factor of safety (FS) proposed by Luna and Frost (1998). The required soil information is collected from Mandalay City Development Committee (MCDC) and Civil Engineering Service Group. There are 64 bore holes that cover the study area. The soil deposits in Mandalay area mainly consist of clayey silt, clayey sand, soft clay. The estimated liquefaction potential index (LPI) map for study area is shown in Fig. 3.

C. Site Condition (SiC)

Based on the existing borehole data and the microtremor survey, Myo Thant et al (2014) developed the average V_s^{30} map for Mandalay city shown in Fig 4. The range of average shear wave velocity, V_s^{30} is between 210 and 390 m/s, therefore the soil condition is mostly stiff soil. The lateral changes of the soil properties, in terms of V_s^{30} values are in North-South direction. The minimum V_s^{30} range, 210 – 280 m/s, constitutes in the middle part of the city, comprising Chan Aye Tha Zan, Maha Aung Myay and Chan Mya Tha Zi townships. The maximum V_s^{30} values can be observed in the northern-most and southern-most part of the city, with the range of 280 – 370 m/s.

Regarding to the average shear wave velocity, site condition is classified into four groups such as 210 - 260 m/s (D1), 260-310 m/s (D2),310-360 m/s (D3), 360-380 m/s (C). The site condition is one of the most important parameters in calculating the seismic hazards.

D. Slope Condition (SlC)

Slope map is produced from Digital Elevation Model (DEM) with the help of spatial analyst tools and classified into four groups based on percent rise (Fig. 5). Digital Elevation Model (DEM) is generated with 10 m resolution by Spline interpolation method based on the spatial analyst tools of GIS and topographic maps. Firstly, elevation points are digitized from existing topographic maps, and then polylines with 10 m interval are constructed. Secondly, these feature data are converted into contour lines together with boundary of the study area. Finally, the contour shape file is changed into raster file to develop the DEM by interpolation in spatial analyst tools.

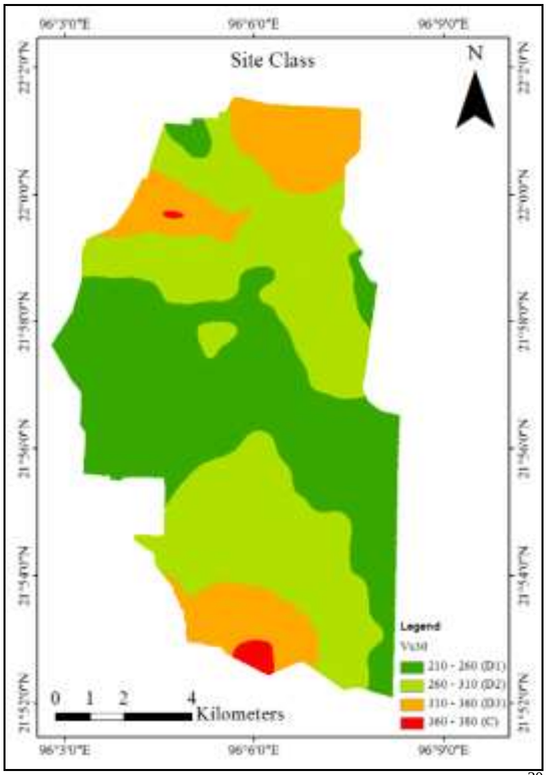

Fig. 4 Average shear wave velocity to upper 30 m, V_s^{30} of Mandalay city

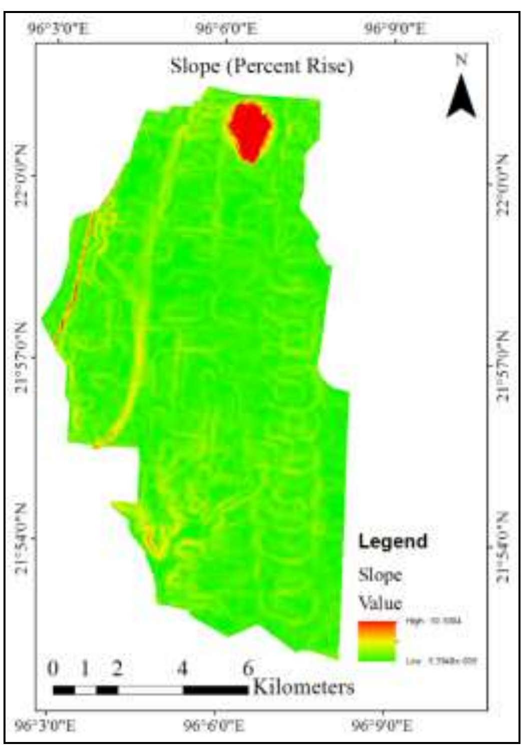

Fig. 5 Slope (Percent rise) of Mandalay

E. Geology Condition (GC) and Soil Condition (SoC)

The geology condition and soil data for study area is collected from the Myanmar Geoscience Society. According to this data, geological condition for that area is classified into 3 types and also 6 types for soil condition. The geology and soil map of Mandalay city shown in Fig. 6 and Fig. 7 is developed by digitizing in GIS.

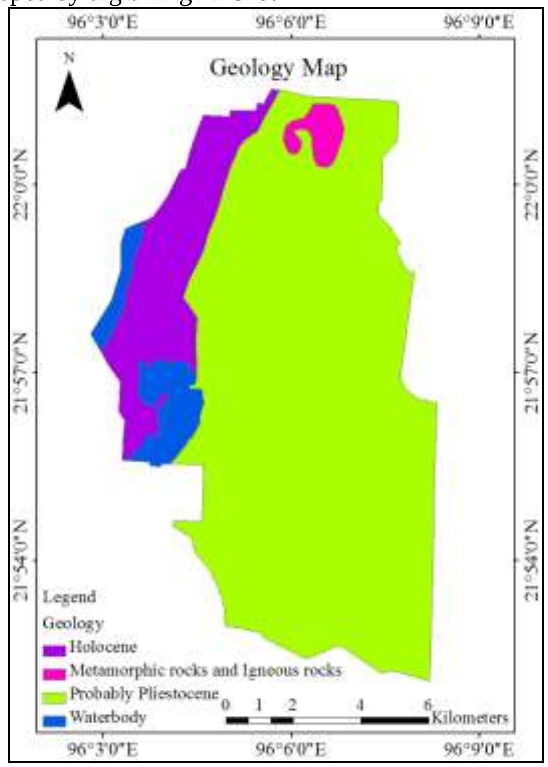

Fig. 6 Geology condition of study area

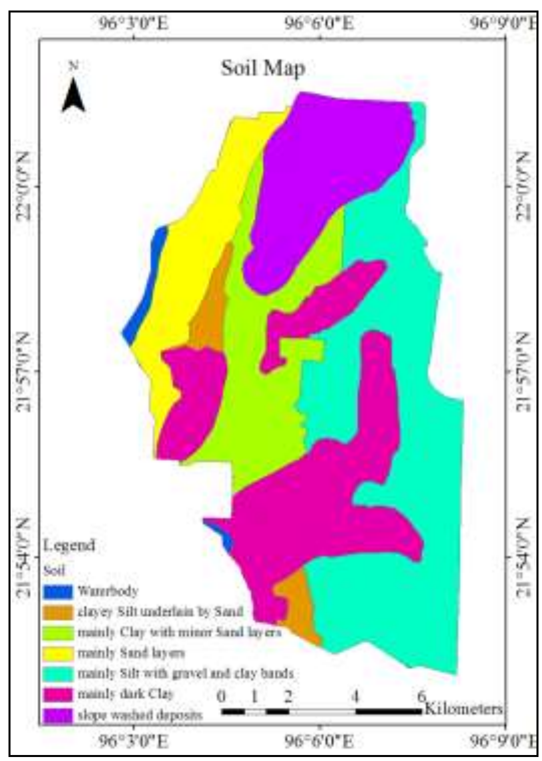

Fig. 7 Soil condition of study area

V. RESULTS AND DISCUSSIONS

The Analytic Hierarchy Process (AHP), a multi-criteria decision-making approach introduced by Thomas L. Saaty is used to calculate the weight of criteria. To derive the individual normalized weights of each criterion, a matrix of pair-wise comparisons (ratio) between the criteria is built. The pair-wise comparison is performed by calculating the principal Eigen vector of the matrix and the elements of the matrix are in the range of 0 to 1 summing to '1' in each column. The weights for each theme are calculated by averaging the values in each row of the matrix. These weights were used in deriving the weighted sum of rating of each region of cells or polygon of the mapped layers. Table II shows pair-wise comparison matrix of themes and their normalized weights for calculating the seismic hazard analysis.

TABLE II
PAIR-WISE COMPARISON MATRIX OF THEMES AND THEIR NORMALIZED WEIGHTS

Themes	PGA	LPI	SiC	SlC	SoC	GC	Weights
PGA	1	6/5	6/4	6/3	6/2	6/1	0.284
LPI	5/6	1	5/4	5/3	5/2	5/1	0.236
SiC	4/6	4/5	1	4/3	4/2	4/1	0.189
SlC	3/6	3/5	3/4	1	3/2	3/1	0.142
SoC	2/6	2/5	2/4	2/3	1	2/1	0.102
GC	1/6	1/5	1/4	1/3	1/2	1	0.047

The features of each thematic map are also normalized between 0 and 1 to ensure that no layer exerts an influence beyond its determined weight. Normalization is carried out for the features using the relation:

$$R_{nrm} = \frac{R_i - R_{\min}}{R_{\max} - R_{\min}}$$

where R_{nrm}, R_{min} and R_{max} denotes the, normalized, assigned minimum and maximum ranks respectively.

After defining the weights of criteria and the normalized ranks for the features, all thematic layers are integrated step by step using the aggregation method in GIS to generate seismic hazard microzonation (SHM) map as

$$SHM = \frac{PGA_W \cdot PGA_r + LPI_W \cdot LPI_r + SiC_W \cdot SiC_r + SlC_W \cdot SlC_r + SoC_W \cdot SoC_r + GC_W \cdot GC_r}{\sum w}$$

where w represents the normalized weight of a theme and r is the normalized rank of a feature in the theme.

Fig. 8 shows the seismic hazard microzonation (SHM) map for Mandalay city. The integration of the six thematic layers is done by following the weighted sum and overlay operations in ArcGIS. The estimated raster values from seismic hazard microzonation map are between 0.159 to 0.919. Regarding to these values, the potential seismic hazard microzonation map is further classified into five categories: Very High, High, Moderate, Low and Very Low hazard zones.

The most dangerous area is the western part of Mandalay city which is near the Sagaing fault. Near the Mandalay hill and the right portion of Pyi Gyi Ta Gon township suffer very low seismic hazard. Liquefaction effect should consider carefully along the Ayeyarwaddy river bank.

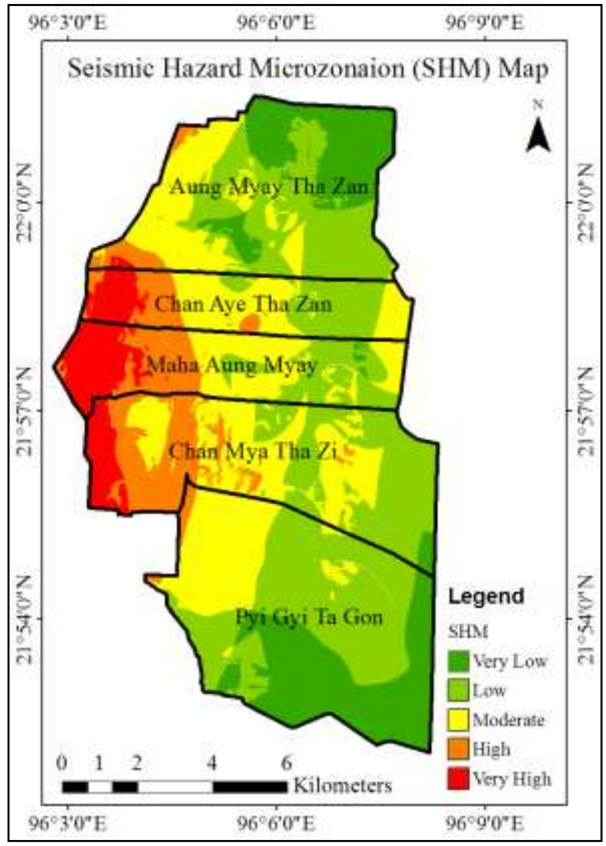

Fig. 8 Seismic Hazard Microzonation (SHM) map

VI. CONCLUSION

An important point of this study is to identify the levels of seismic hazard for Mandalay city. Seismic hazard maps have been generated based on the seismological, geological and geotechnical conditions. Combination of AHP model and GIS tools is very convenient in developing hazardous zones due to earthquake. It can automatically generate the integrated seismic hazard maps for any given region with the presence of the required separate raster maps. This seismic hazard microzonation (SHM) map will be very useful for calculating seismic risk assessment and also making disaster mitigation plans to reduce the seismic risk for Mandalay city.

ACKNOWLEDGMENT

The authors would like to express special thanks to their teachers, Department of Civil Engineering, Mandalay Technological University, for their useful guidance, patience, supervision and giving valuable ideas for this paper. The authors would like to appreciate to Dr. Myo Thant, Associate Professor, Geology Department, University of Mandalay for his useful data and suggestion. The authors wish to acknowledge to all teachers from Remote Sensing Department for their useful data. Finally, the authors would like to thank everyone who assisted this investigation.

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About Author (s):

Ms. Zin Zin Nwe
Ph.D. Student
Department of Civil Engineering
Mandalay Technological University
The Union of Republic of Myanmar

Dr. Kay Thwe Tun
Associate Professor
Department of Civil Engineering
Mandalay Technological University
The Union of Republic of Myanmar