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Identification of Seismic Vulnerability Zones based on Land Use Condition

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Abstract

Due to urbanization, the vulnerability is increased in cities and the scale of disaster from earthquake is increased in major cities. Therefore, developing seismic vulnerability map for urbanized cities is very important. Mandalay city is not only one of the most earthquake-prone regions but also the most urbanized and dense population in the Republic of the Union of Myanmar. This study examines the seismic vulnerability assessment of Mandalay city based on the land use conditions by utilizing analytic hierarchy process (AHP) and Geographic Information System (GIS). The land use data was collected by doing field survey and classified into 20 types of study area regarding to the Myanmar National Building Code (MNBC) and field condition. The importance of each criterion (land use types) are determined by using subjective opinion made by authorized persons from Mandalay City Development Committee (MCDC) because the seismic vulnerability levels may be different based on land use conditions. The consistency ratios (CR) are also checked for reliability of weighted criteria. The final seismic vulnerability map is developed by overlapping the weighted land use map with building density and population density map by using aggregation method in GIS. It will be very useful for making a national emergency plan for earthquakes to mitigate the seismic risk due to the future earthquakes.

Keywords: analytic hierarchy process; GIS; land use; vulnerability.

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1. Introduction

Myanmar is located at a very active tectonic area, which includes the subduction zone and the active Sagaing fault. Sagaing fault extending more than 1,000 km across entire Myanmar in N-S direction forms the transcurrent N-E boundary of the Indian Plate accommodating its northerly motion between the Burma and Sunda microplates. It is a typical continental dextral strike-slip fault with a slip-rate of 18 mm/year and is comparable to other well-known faults such as the San Andreas Fault in California, U.S., North Anatolian Fault in Turkey and the Great Sumatra Fault in Indonesia. Historically and within the instrumental period, the Sagaing fault has produced a number of large earthquakes some of which has caused significant damage [1]. Historical earthquakes occurring along Sagaing fault with notable magnitudes are shown in Figure 1.

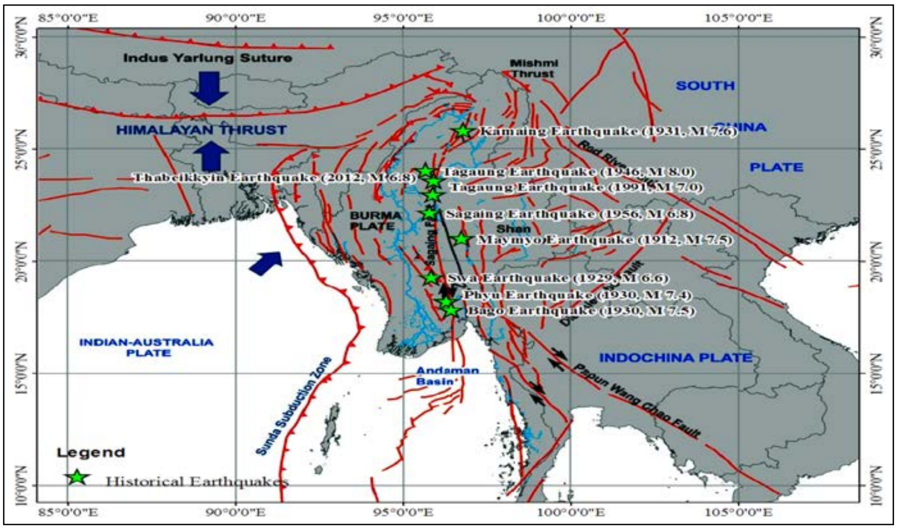

Figure 1: map of historical earthquakes after the year 1906

Mandalay lies very closed to the dextral Sagaing fault (about 7 km in the west), a tectonic plate boundary between the India and Sunda plates. In the historical records, many earthquakes happened in and around Mandalay area. The most distinct events near Mandalay area are Innwa earthquake (March 23, 1839) and Sagaing earthquake (July 16, 1956). Due to Innwa earthquake (maximum intensity of MMI IX), about three to four hundred casualties were resulted in Mandalay area and many buildings including pagodas were severely damaged. The Sagaing earthquake with (Mw=7.0) magnitude also caused some considerable damage and casualties [9]. Therefore, developing seismic vulnerability assessment for Mandalay city is very crucial. This study examines the seismic vulnerability assessment based on the actual land use conditions by using AHP-GIS to minimize the losses due to the future earthquakes.

2. Description on Study Area

Mandalay, the second largest city and third capital of the Republic of the Union of Myanmar, is located in the central dry zone of Myanmar by the Ayeyarwaddy River at 21.98° North, 96.08° East, 80 meters (260 feet) above sea level. Mandalay features noticeably warmer and cooler periods of the year.

The highest reliably recorded temperature in Mandalay is 45.6 °C (114.1 °F) and the lowest is 5.6 °C (42.1 °F). [5] Its population has about 1.3 million for five townships and several fields, e.g. urban development and industrialisation, rapidly increased. As of 2012, Mandalay City Development Committee (MCDC) divided Mandalay City into 7 townships which are Amarapura, Aung Myay Tha Zan, Chan Aye Tha Zan, Chan Mya Tha Zi, Maha Aung Myay, Pyi Gyi Ta Gon, and Patheingyi townships.

Only the 5 central townships as shown in Figure 2 are included in this study because the left townships, Amarapura and Patheingyi, were added recently into the city area. Table 1 shows some information of Mandalay city such as population, number of buildings and area of each township, etc.

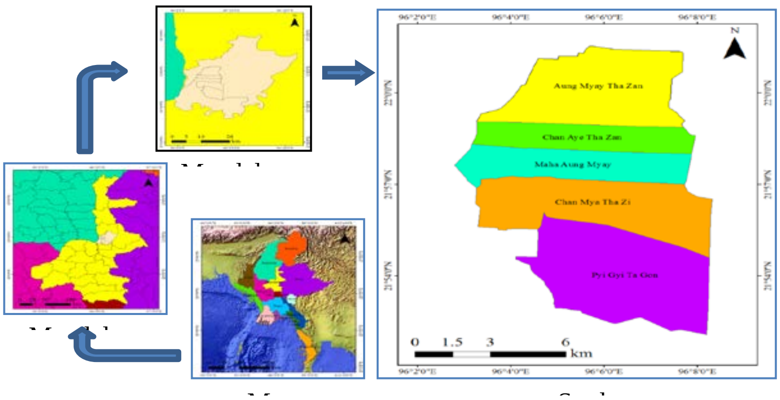

Figure 2: map of study area

Table 1: Mandalay city information

Townships	Area (km^2)	No. of Quarters	Households	No. of Buildings	Population		
					Male	Female	Both Sex
Aung Myay Thar Zan	25.81	18	38 907	49 233	130 162	136 203	266 365
Chan Aye Thar Zan	11.70	20	28 785	24 452	93 216	104 096	197 312
Maha Aung Myay	14.45	18	37 385	43 231	116 802	123 954	240 756
Chan Mya Tharzi	26.13	14	43 520	66 318	136 811	146 494	283 305
Pyi Gyi Ta Gon	33.18	16	36 492	49 948	120 756	116 639	237 395
Total	112.27	86	185 089	233 182	597 747	627 386	1 225 133

3. Methodology

In this study, Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) are used to make the earthquake vulnerability assessment. To determine the importance of criteria and sub-criteria, analytic hierarchy process (AHP) model, one of multi criteria decision making method that was originally developed by Prof. Thomas L. Saaty, is used. AHP is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement or from subjective opinion [6]. The weight of each factor is determined regarding its level of importance as shown in Table 2 and introduced by Saaty (1977). Some small inconsistency in judgment is allowed because human is not always consistent. If the value of Consistency Ratio (CR) is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, the subjective judgments need to revise. The Consistency Ratio is a comparison between Consistency Index (CI) and Random Consistency Index (RI). The Consistency Index (CI) is defined by Saaty (2000) as follows:

$$CI = (\lambda\_max - N)/(N - 1) \qquad (1)$$

where λ_{max} is the largest or principal eigenvalue of the pairwise comparison matrix and N is the order of the matrix. Saaty (1980) has identified the average random consistency index (RI) as shown in Table 3.

Table 2: Scale of preference between two parameters in AHP (Saaty, 1977)

Intensity of importance	Degree of preference	Explanation
1	Equally	Two factors contribute equally to the objective
3	Moderately	Experience and judgment slightly to moderately favor one factor over another
5	Strongly	Experience and judgment strongly or essentially favor one factor over another
7	Very strongly	A factor is strongly favored over another and its dominance is showed in practice
9	Extremely	The evidence of favoring one factor over another is of the highest degree possible
2, 4, 6, 8	Intermediate	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9
Reciprocals	Opposites	Used for inverse comparison

Table 3: Random inconsistency indices (RI) for n=1, 2, 3… 12 (Saaty, 1980, 2000)

N	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54

4. Identification of Seismic Vulnerability Zones based on Land Use Condition

4.1. Generation of Land Use Map

The 2014 satellite image was used to digitize the land use data and Myanmar National Building Code (MNBC) was used to classify the land use condition. Firstly, polygons are drawn based on visual interpretation of land use. Secondly, field survey was done to collect the actual information for detail land use types. This survey was done with the help of remote sensing department from Mandalay Technological University for six months.

Finally, land use was classified as 20 types (Table 4) such as residential, commercial, education, and hotel, etc. After making the field survey, land use types were assigned to attribute table and combined the polygons in the same land use types. Figure 3 and 4 show the main and detail land use conditions of Mandalay city based on field survey and MNBC.

Table 4: Land use classifications based on field survey and MNBC

Items	Main Group	Land Use Details	Remarks
I	Residential	Only Resident	Public houses, government service's houses
		Mixed	Resident + Store, Entertainment, Cinema
II	Commercial	Market	Shopping mall, Private Bank, Restaurant, Wedding hall, Car show room
		Private Hospital	Private hospitals and clinics
		Private School	Private Pre-school, Primary and High school, Training center
		Hotel	Hotel
III	Governmental	Education	Basic Education Primary, Middle and High School, Institute, University, Cripple, Training
		Office	Police station, Bank, Audit, Township Admin,
		Government Hospital	Public hospital, Sangha hospital, Workers' hospital, Central women hospital, Children hospital etc.
		Military	Military
IV	Industrial	Home industry	Oil, car workshop, trucker industry, peanut mill, ware house, purified water plant, Timber plant, Juice, detergent, soap
		Hazardous industry	Paper industry, sugar, iron, candle, leather, gas, Plastic, alcohol, concrete, textile, fertilizer
V	Religious	Monastery	Monastery
		Pagoda	Pagoda
		Community hall	Church, Chinese temple, Dhamma hall, etc.
VI	Public and Social	Station	Express station, Railway station
		Stadium	Sport stadium
		Museum	Museum
		Recreational zones	Playground, park, Golf, Skate
VII	Open spaces	Waterbody, field, etc.	Waterbody, field, etc.

4.2. Making the Criteria to develop vulnerable zones

To find the different vulnerability level based on land use changes, analytic hierarchy process (AHP) model under multi criteria decision making (MCDM) is used. Waterbody and open space are not considered in assessing vulnerability. Firstly, pairwise comparison matrixes are developed for criteria weights and then sub-criteria weights are calculated based on the expert judgements by the authorized persons from Mandalay City Development Committee (MCDC). Finally, the total weights are estimated by multiplying the criteria weights and sub-criteria weights respectively. Pairwise comparison matrix, weighted values, and consistency ratio for criteria and sub-criteria are shown in Table 5 and Table 6 respectively. All CR values for all criteria and sub-criteria are less than 0.1 hence it can be said weight assigning is reasonable. Table 7 shows the total weights for assigning the attribute table.

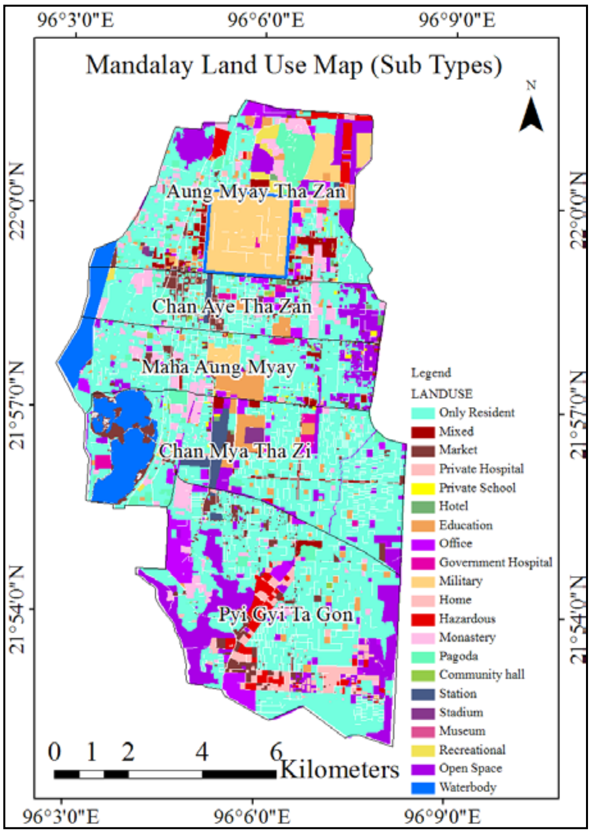

Figure 3: detail land use map

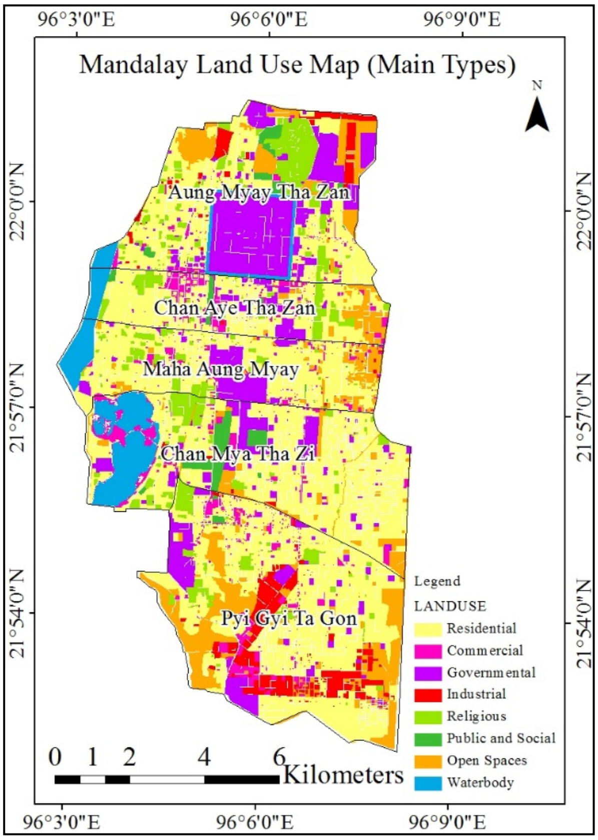

Figure 4: main land use map

Table 5: Pairwise comparison matrix, criteria weights

Criteria	C1	C2	C3	C4	C5	C6	Weighted values
Residential	1	2	3	4	5	6	0.379
Commercial	1/2	1	2	3	4	5	0.249
Governmental	1/3	1/2	1	2	3	4	0.160
Industrial zones	1/4	1/3	1/2	1	2	3	0.102
Religious	1/5	1/4	1/3	1/2	1	2	0.065
Public and Social	1/6	1/5	1/4	1/3	1/2	1	0.043
Consistency Ratio (CR): 0.027 < 0.1 ⇒ Acceptable							

Table 6: Pairwise comparison matrix, sub-indicator weights

Sub-indicator	1	2	3	4	Weighted values
Residential					
Only Residents	1	1/3			0.250
Mixed	3	1			0.750
Consistency Ratio : 0.093 < 0.1 ⇒ Acceptable					
Commercial					
Market	1	2	3	4	0.466
Private Hospital	1/2	1	2	3	0.277
Private School	1/3	1/2	1	2	0.161
Hotel	1/4	1/3	1/2	1	0.096
Consistency Ratio : 0.015 < 0.1 ⇒ Acceptable					
Governmental					
Education	1	2	3	4	0.466
Office	1/2	1	2	3	0.277
Government Hospital	1/3	1/2	1	2	0.161
Military	1/4	1/3	1/2	1	0.096
Consistency Ratio : 0.015 < 0.1 ⇒ Acceptable					
Industrial zones					
Home industry	1	1/4			0.200
Hazardous industry	4	1			0.800
Consistency Ratio : 0 < 0.1 ⇒ Acceptable					
Religious					
Monastery	1	2	3		0.539
Pagoda	1/2	1	2		0.297
Community hall	1/3	1/2	1		0.164
Consistency Ratio : 0.01 < 0.1 ⇒ Acceptable					
Public and Social					
Station	1	3	5	3	0.512
Stadium	1/3	1	3	2	0.238
Museum	1/5	1/3	1	1/3	0.078
Recreational zones	1/3	1/2	3	1	0.172
Consistency Ratio : 0.049 < 0.1 ⇒ Acceptable					

4.3. Identification of Seismic Vulnerability Zones

The final seismic vulnerability map based on the actual land use condition is shown in Figure 7. To develop the final seismic vulnerability map, the weighted land use map is integrated with population density map (Figure 5) and building density map (Figure 6).

The importance of criteria is evaluated based on the analytic hierarchy process (AHP) method developed by Thomas L Saaty. The weighted values of each thematic layer are shown in Table 8.

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:

$$R\_nrm = (R\_i - R\_min)/(R\_max - R\_min) \qquad (2)$$

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

Table 7: Assigning total weights by using AHP model

No.	Criteria	Criteria Weights	Sub-criteria	Sub-indicator Weights	Total Weights
1	Residential	0.379	Residential	0.250	0.095
			Mixed	0.750	0.284
2	Commercial	0.249	Market	0.466	0.116
			Private Hospital	0.277	0.069
			Private School	0.161	0.040
			Hotel	0.096	0.024
3	Government	0.160	Education	0.466	0.075
			Office	0.277	0.044
			Government Hospital	0.161	0.026
			Military	0.096	0.015
4	Industrial zones	0.102	Home industry	0.200	0.021
			Hazardous industry	0.800	0.082
5	Religious	0.065	Monastery	0.539	0.036
			Pagoda	0.297	0.020
			Community hall	0.164	0.011
6	Public and Social	0.043	Station	0.512	0.022
			Stadium	0.238	0.010
			Museum	0.078	0.003
			Recreational zones	0.172	0.007
7	Open Spaces				0

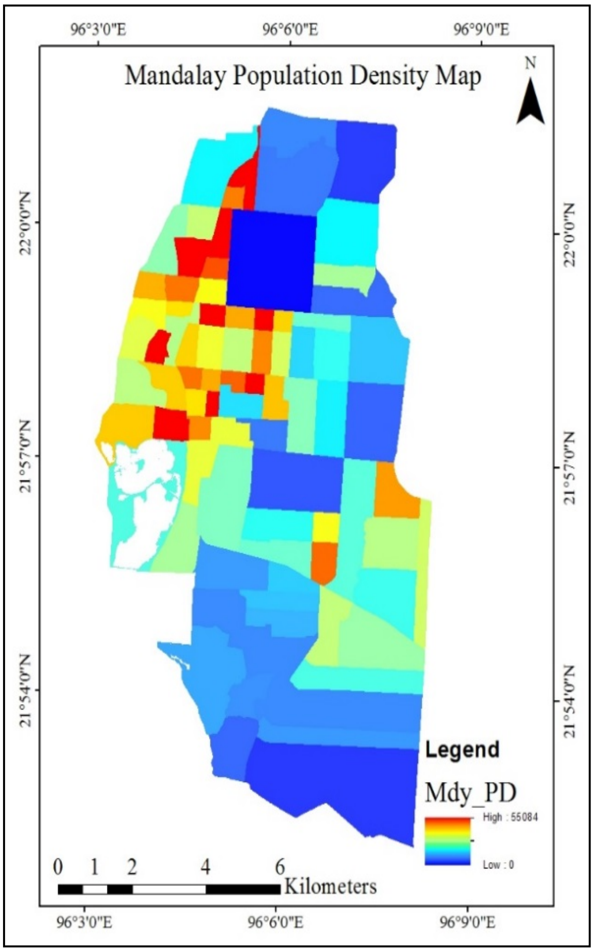

Figure 5: population density (PD) map

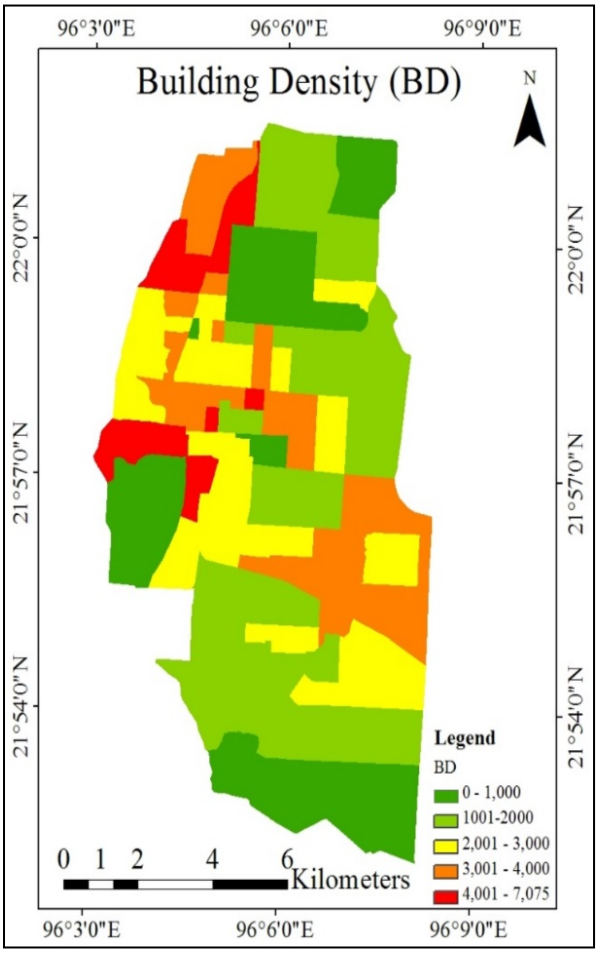

Figure 6: building density (BD) map

Table 9 shows the normalized ranks of each thematic layer for seismic vulnerability assessment. The weighted values of land use condition are considered in calculating the normalized ranks to classify the vulnerable zones of the study area. After defining the weighted values and the normalized ranks of all criteria, all criteria layers are integrated with one another through GIS using weighted aggregation method to identify the seismic vulnerability map (SVM) as

$$SVM = [LU\_w.LU\_r+PD\_w.PD\_r+BD\_w.BD\_r]/\Sigma w \qquad (3)$$

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

Table 8: Weighted values of each thematic layer

	Land Use	Building Density	Population Density	Criteria Weight
Land Use (LU)	1	2	3	0.539
Building Density (BD)	1/2	1	2	0.297
Population Density (PD)	1/3	1/2	1	0.164
Consistency Ratio : 0.01 < 0.1 ⇒ Acceptable				

Table 9: Normalized ranks for seismic vulnerability assessment

Themes	Attributes		Rank	Normalized ranks
	Land Use Types	**Weighted values**		
Land Use Condition	Waterbody, field, etc.	0	1	0.000
	Museum	0.003	2	0.053
	Recreational	0.007	3	0.105
	Stadium	0.010	4	0.158
	Community hall	0.011	5	0.211
	Military	0.015	6	0.263
	Pagoda	0.020	7	0.316
	Home industry	0.021	8	0.368
	Station	0.022	9	0.421
	Hotel	0.024	10	0.474
	Government Hospital	0.026	11	0.526
	Monastery	0.036	12	0.579
	Private School	0.040	13	0.632
	Office	0.044	14	0.684
	Private Hospital	0.069	15	0.737
	Education	0.075	16	0.789
	Hazardous industry	0.082	17	0.842
	Only Resident	0.095	18	0.895
	Market	0.116	19	0.947
	Mixed (Resident + Store)	0.284	20	1.000
Population Density	0 - 500		1	0
	500 - 5000		2	0.20
	5000 - 10000		3	0.40
	10000 - 15000		4	0.60
	15000 - 25000		5	0.80
	25000 - 55084		6	1.00
Building Density	1 - 1000		1	0
	1001 - 2000		2	0.25
	2001 - 3000		3	0.50
	3001 - 4000		4	0.75
	4001 - 7075		5	1.00

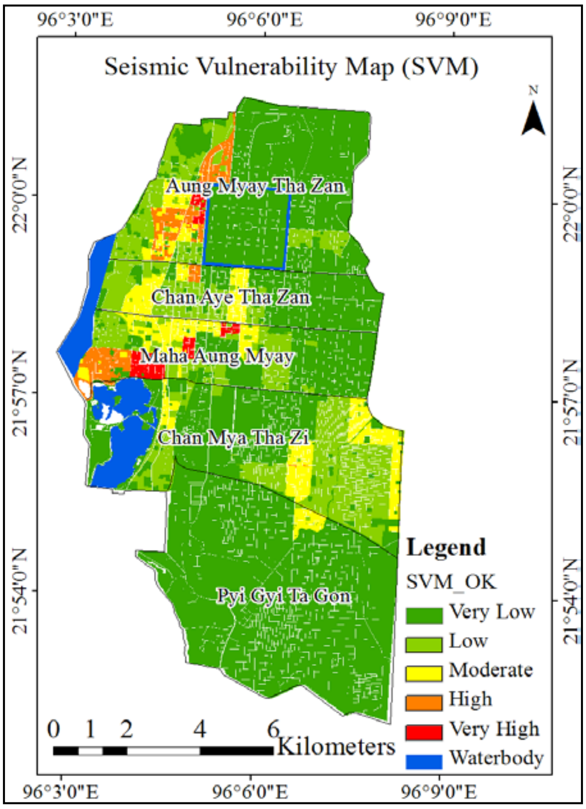

Figure 7: seismic vulnerability zones map of Mandalay city

5. Discussion and Conclusion

The seismic vulnerability is different depending on the land use changes. To estimate the different vulnerability levels based on land use changes, analytic hierarchy process (AHP) model under multi criteria decision making (MCDM) was used by combining with Geographic Information System (GIS). Land use map was developed by doing the actual field survey depending on the 2014 satellite image. Land use conditions were classified regarding to the Myanmar National Building Code (MNBC) and field condition of the study area. The importance of criteria weights was defined by the authorized persons from Mandalay City Development Committee (MCDC). The weighted values of land use condition were used in calculating the normalized ranks to classify the vulnerable zones of the study area. The population density map was developed from the 2014 census data based on each quarter. The number of buildings was counted depending on the 2014 satellite image and the building density was estimated by dividing the total number of buildings into each area.

The seismic vulnerability map was developed by integrating the weighted land use map, building density map and population density map in GIS. Combination of AHP model and GIS tools is very convenient in developing vulnerable zones due to earthquake. This seismic vulnerability map is very useful for estimating the seismic risk and also making disaster mitigation plans to reduce the seismic risk for Mandalay city. As land use condition was in 2014-2015, the future vulnerability should be calculated by using future land use condition and future population data to update the information. Depending on these results, the detail investigation should be done in the most vulnerable areas to mitigate the seismic risk due to the future earthquakes.

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