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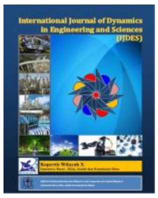

Seismic Hazard Analysis of Surface Level in Tasikmalaya City

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Abstract

Learning from Tasikmalaya earthquakes on December 15, 2017 and September 2, 2009, seismic hazard analysis of surface level in Tasikmalaya City become important to do. This study presents seismic hazard estimation of Tasikmalaya City in terms of maximum ground acceleration (PGA) and spectral acceleration at surface level. The latest seismicity data were used to evaluate seismic hazards. There were three seismic source types considered to model seismic sources in the region, including megathrust, shallow crustal, and background source zones. Several Ground Motion Prediction Equations (GMPE) were used to characterize the properties of attenuation. The average shear wave velocity for 30 m depth (Vs30) for site classification were estimated using Multichannel Analysis of Surface wave (MASW). Furthermore, Probabilistic Seismic Hazard Analysis (PSHA) correspond to an exceeded 2% probability within 50 years were carried out to map seismic hazards at surface level by considering the site classification. The analysis showed that the highest seismic hazard at surface level in the Districts of Kawalu, Tamansari, Cibeureum, Mangkubumi, and Purbaratu. This area needs attention because it also has a large population.

Keywords: PGA, PSHA, Vs30, seismic hazard, Tasikmalaya.

1. Introduction

Tasikmalaya, a city located in the southeastern part of West Java Province, covers about 183.85 km² (Figure 1). It is located between 108^{0}08’38”-108^{0}24’02” E and 7^{0}10’-7^{0}26’32” S, which is one of the cities that is prone to earthquake disasters due to its proximity to the Indo-Australian and Eurasian plate collision [1]. Many strong earthquake events in southern Java occur due to the convergence of the Indo-Australian plate which moves to the Eurasian plate. The subduction zone which stretches from the southern part of Banda Island to the western part of Andaman Island is one of the most active seismotectonic regions in the world [2].

There were at least two earthquakes causing damages in the City of Tasikmalaya in 2009–2019, the earthquake that occurred on December 15, 2017 (Mw 6.5) and September 2, 2009 (Mw 7.5). The former caused a lot of damage in the City of Tasikmalaya and so did the later, which caused heavy damage (1,260 houses) and light damage (5,784) [3]. The damages caused by these earthquakes were caused by the earthquake shocks in addition to the poor quality of the buildings to resist the earthquake loads.An earthquake, in addition to causing structural collapse, can also have implications for fires, liquefaction, and landslides. Therefore, it is very crucial to estimate the earthquake hazard to reduce the risks associated with an earthquake.

Earthquake hazard analysis is an effective analysis in predicting potentially damaging earthquake phenomena [4]. Earthquake hazard assessment is an important component in earthquake hazard analysis, mitigation, and emergency management.

Several studies had been made to estimate the future earthquake hazard in the City of Tasikmalaya. National Standardization Agency of the Republic of Indonesia has issued earthquake zone maps for the Indonesia territory, among others, in 2002 [5] and revised it in 2012 [6] and 2019[7]. The map is applicable to all regions of Indonesia and has not been based on analysis for the surface level. Sunardi et al. (2019) evaluated the earthquake hazard in the City of Tasikmalaya using a probabilistic approach suitable for the exceedance probability of 2% in 50 years, but the study was carried out at the bedrock level [1].

The National Earthquake Center (PusGen) issued a 2017 earthquake hazard and source map of Indonesia for the bedrock level. One of the recommendations is to develop a surface level shaking map by considering the local site conditions or VS30 (average shear wave velocity to a depth of 30 m) [8]. The regional earthquake hazard map of the Java region has also been estimated probabilistically which is suitable for the exceedance probability of 10% in 50 years, but it is still at the bedrock level [9].

The content of earthquake vibration frequency will affect the ground motion. Spectral acceleration at surface level, including the PGA (Peak Ground Acceleration), provides important information for earthquake resistant design [10]. Spectral acceleration is extensively used in seismic engineering practice to indicate the frequency content of earthquake vibrations. The spectral acceleration parameter is more interesting since it can directly be used to design the structures.

Earthquake waves that propagate from bedrock to ground surface will experience modification due to contrast impedance which is commonly referred to as local site effects. Accordingly, local geology and soil conditions have a significant effect on the shaking intensity on the ground due to the earthquake. In most cases, where the building foundation is not continuous to the bedrock, this local site effect is very important and becomes a supporting factor for building damage [11]. Therefore, getting an earthquake hazard map at the surface level is very crucial.

This paper describes an approach to estimate the earthquake hazard at the surface level in TasikmalayaCity for the hazard exceedance probability of 2% in 50 years, corresponding to a return period of 2475 years. An earthquake hazard is represented on the PGA and spectral acceleration maps at the surface level. The PSHA (Probabilistic Seismic Hazard Analysis) approach was carried out by considering the existing site classification. It is the most widely adopted approach to describe earthquake hazards in terms of the exposure period. It can calculate all potential earthquake sources by including the uncertainty generated from the magnitude, location, and time of the earthquake [12]. Estimation of earthquake hazard at the surface level was performed by considering site classification. The site classification was estimated using the MASW (Multichannel Analysis of Surface wave) method, which is a non-invasive method for estimating the shear wave velocity profile. It is successfully used in many studies [13-20].

The results of the study can be used for the design and assessment of existing infrastructure, the consideration for planning earthquake-resistant buildings, the analysis of structural dynamics, and other needs, such as vulnerability and risk assessment of buildings in the City of Tasikmalaya.

2. Methodology

Geologically, the constituent rocks in the study area are dominated by Miocene sedimentary rocks. The constituent rocks in the City of Tasikmalaya include Alluvium (Qa) deposits, young volcanoes (Qv), Galunggung volcanic breccia (Qvb), old volcanoes (QTv), Kalipucang formation (Tmkl), and Bentang formation (Tmb), see Figure 2.

Alluvium deposits consist of mud, clay, silt, sand, gravel, crust, and lumps of igneous rock. These deposits are not fully consolidated or loose and easily eroded. The products of young volcanoes consist of volcanic breccia, lava, and tuffs composed of andesite to basalt from Mt. Galunggung. Galunggung volcano breccia was formed from the results of landslides from the lava flow of Mount Galunggung which consists of chunks of the andesite lava forming mounds with several meters to kilometers heigh. The products of old volcanoes consist of volcanic breccias, flow breccias, tuffs, and lava from andesite to basalt. The Kalipucang formation consists of coral limestone, light gray-white, solid, hard, and hollow with a layered structure. Bentang formation consists of limestone sandstone, tuffaceous sandstones, shale inserts, and contains limestone lenses [21].

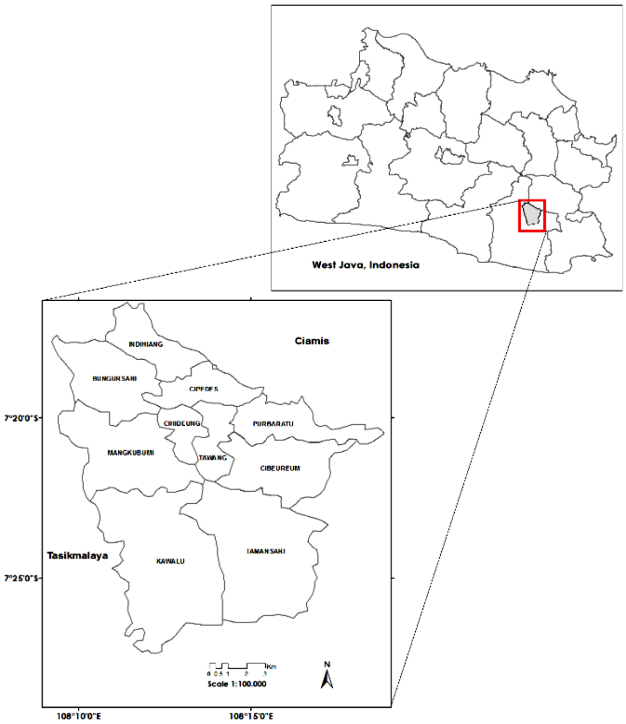

Figure 1. The study area, which is located in the southeast of West Java Province

The methods used in this work include collecting and analyzing seismicity data, identifying and modeling earthquake sources, characterizing earthquake sources, determining attenuation, and managing uncertainty using a logic tree. The PSHA was used to estimate the earthquake hazards. The last, PGA and spectral acceleration were estimated at the surface level, which had been adjusted to the classification of sites in the City of Tasikmalaya.

Current seismicity data were obtained from some institutions, including the BMKG and United States Geological Survey (USGS). The duplication of earthquake events was eliminated and the magnitude was different on the Mw (moment magnitude) scale using the Scordilis equation [22]. This process used a valid global empirical relationship that allows the conversion of various magnitudes into Mw. The earthquake data were then clustered using an algorithm proposed by Gardner and Knopoff[23] and modified by Uhrhammer[24].

To estimate the earthquake hazard in an area, it is necessary to divide it into a seismically homogeneous sub regional system called the seismic source [25]. Seismogenic zones, active fault maps, focal mechanisms, and earthquake catalogs were the main data for earthquake source modeling. Three types of seismic sources were considered in modeling earthquake sources including interface subduction model source, shallow crustal model source, and background source zones. Figure 3 shows the distribution of earthquake events and earthquake sources around the City of Tasikmalaya.

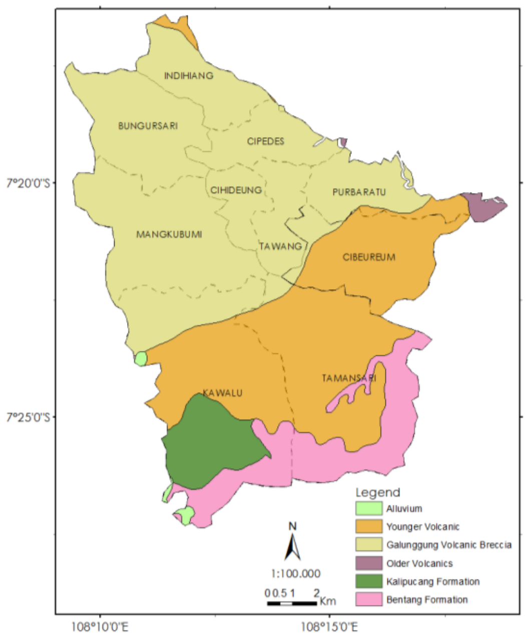

Figure 2. Regional geology of Tasikmalaya City

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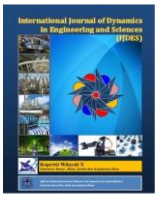

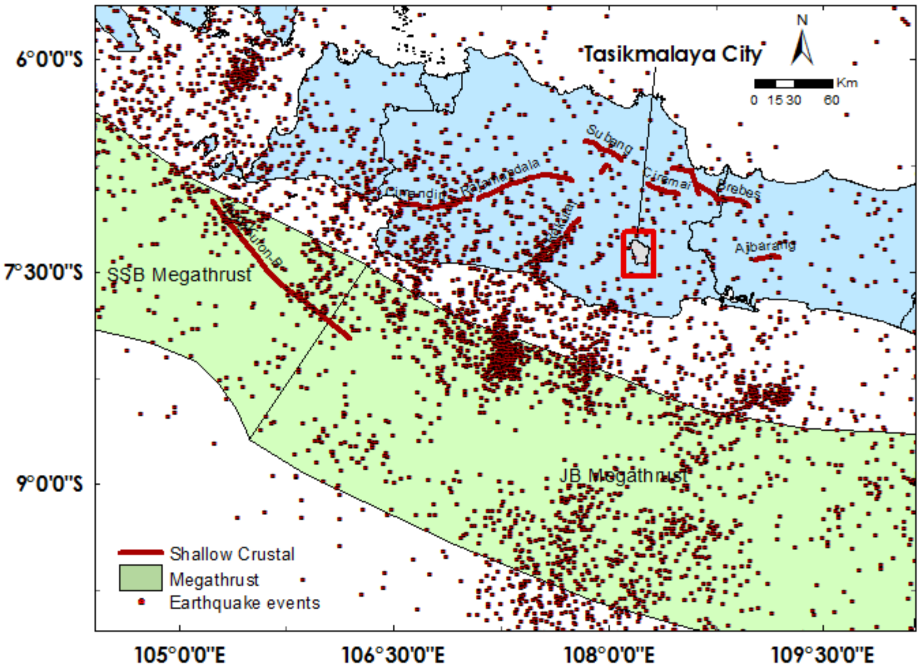

Figure 3. Distributionof earthquake events and seismic sources around Tasikmalaya City

The megathrust zone under consideration includes the SSB Megathrust (Sunda Banten Strait Megathrust) and JB Megathrust (West Java Strait Megathrust). The source of the shallow crustal earthquake in this study includes the Ciremai, Subang, Cirebon, Cirebon-1, Cirebon-2, Tampomas, Rakutai, Kencana, Cimandiri, Nyalindung-Cibeber, Rajamandala, Lembang, Brebes, Ajibarang, and UjungKulon B fault segment. The earthquake sources that had not been identified and quantified properly were considered as the background sources zone.

The characterization of each earthquake source had been based on the results of the current studies. The source of the megathrust earthquake was obtained from seismotectonic data. The parameters of this model include the location, rate, and a-b-value, as well as the depth limit of the megathrust area. The megathrust movement rate can be a recurrence rate, Mmax. SSB Megathrust has a length and width of about 280x200 km and can cause earthquakes with a maximum magnitude (Mmax) of up to Mw 8.8. a-b values of the Gutenberg-Richter relation for this megathrust zone are 5.59 and 1.15, respectively. JB Megathrust has dimensions of 320x200 km and can cause earthquakes of Mmax Mw 8.8. The a and b values for this zone are 5.5 and 1.08, respectively [8].

The source of the shallow crustal earthquake in this study was 15 fault segments, ranging from Banten to Central Java. The calculated model parameters refer to current research as shown in Table 1.The model of the background source zone was used to estimate the rate of future small to moderate earthquakes in the fault area and random earthquakes outside the fault. This model predicts that greater earthquake events may occur in areas around small to moderate earthquakes that have occurred before [26]. The background sources zone in this study were divided into five types, shallow background (0-50 km), deep 1 background (50-100 km), deep 2 background (100-150 km), deep 3 background (150-200 km), and deep 4 background (200-300 km).

Tabel 1. Parameters of shallow crustal sources

Segment Fault	Mechanism	Mmax	Slip Rate
Ciremai	Strike Slip	6.5	0.1
Subang	Reverse	6.5	0.1
Cirebon	Strike Slip	6.2	0.5
Cirebon-1	Reverse	6.5	0.1
Cirebon-2	Reverse	6.5	0.1

Tampomas	Normal	5.6	0.5
Rakutai	Normal	6	0.1
Kencana	Strike Slip	6.2	0.1
Cimandiri	Reverse	6.7	0.55
Nyalindung-Cibeber	Reverse	6.5	0.4
Rajamandala	Strike Slip	6.6	0.1
Lembang	Strike Slip	6.8	2
Brebes	Reverse	6.5	0.1
Ajibarang	Strike Slip	6.5	0.1
UjungKulon B	Strike Slip	7.6	10

One of the important factors in earthquake hazard analysis is to choose the right GMPE (Ground Motion Prediction Equations), which is a mathematical model that connects the ground motion parameter to the earthquake source parameter. The most common method for obtaining the above relationship is to use empirical methods based on historical earthquake data. The relationship between the earthquake source parameter and the ground motion parameter is statistically obtained using several methods, such as single or multiple regression analysis. This method requires a lot of data to get statistically reliable results [27].

The used GMPE was adjusted to each earthquake source model. In this study, the GMPE proposed by Zhao et al. [28], BCHYDRO12 [29], and rock and global source subduction Atkinson-Boore BC [30], were used to estimate ground motion for megathrust earthquake events, while the GMPE of Boore-Atkinson NGA [31], Campbell-Bozorgnia NGA [32], and Chiou-Youngs NGA [33], were used for earthquakes from shallow crustal and shallow background sources. The deep background model used the GMPE of AB intraslab seismicity of the BC-rock condition Cascadia region [30], Geomatrix slab seismicity rock [34], and AB 2003 intraslab seismicity worldwide BC-rock condition region data [30].

There are two types of uncertainty in an earthquake hazard analysis; aleatory and epistemic. Aleatory uncertainty represents natural randomness in a process, whereas epistemic uncertainty is the lack of knowledge introduced in models attempting to represent actual behavior [12]. The PSHA aims to estimate earthquake risk with probability, which incorporates uncertainty in the model. The PSHA uncertainty involves the uncertainty of earthquake magnitude, location, fault characteristics (maximum possible magnitude and slip rate), and the potential for future earthquakes. The basic approach uses the logic tree methodology to deal with this uncertainty [35].

The estimation of the earthquake hazard in bedrock was carried out using the PSHA. The PSHA map is a fairly effective method to determine the distribution of potential shocks as well as a reliable basis for estimating the earthquake hazard in a residential area or existing infrastructure [36-39]. PSHA is a standard method used in earthquake engineering. The main basis for compiling the PSHA map is that earthquake events can be modeled as a time-independent Poisson process phenomenon. The occurrence and estimation of ground shaking by the earthquake source is also a Poisson process if the earthquake event follows the Poisson process and the probability of each earthquake event producing ground shaking at one point for a certain level is an independent event of other earthquake events at the same observation point [8]. The process of calculating the earthquakehazard using the PSHA method developed by Cornell [40] was followed by Merz and Cornell [41]. EERI Committee on Seismic Risk continued to develop its analytical models and calculation techniques [42]. In this study, the PSHA was carried out for the exceedance probability of 2% in 50 years. The results obtained from the PSHA will show the variation of the mean PGA and spectral acceleration with respect to annual exceedances.

The estimation of ground shaking at the surface level requires characteristics of local soil conditions. The characteristics of local soil conditions have significance in earthquake micro zonation studies. The characteristics of local soil conditions can amplify ground shaking, so it will exacerbate the potential for earthquake damage. In modern seismic micro zonation practices, shear wave velocity which is a dynamic geotechnical property has been accepted for characterizing local soil conditions. Most codes, such as Eurocode-8 [43], NEHRP [44], International Building Code [45], etc., determine site classification based on the average shear wave velocity to a depth of 30 m (Vs30).

Geotechnical and geophysical tests are commonly performed to obtain a value of Vs30. The distribution of the Vs30 values in this study was obtained from the Multichannel Analysis of Surface Waves (MASW) data. The MASW measurement techniques include the process of ground roll (Rayleigh) data acquisition, dispersion curve reconstruction, and inversion process to obtain shear wave velocity [46]. The 1D MASW data acquisition process was carried out by measuring the geometry of the distance between the geophones of 2 m, offset distance of 5 m, and a recording time of 1000 ms. Furthermore, the results of the shear wave velocity were used to determine the site classification by referring to the provisions in the Indonesia National Standard SNI 1726:2019 [7]. To estimate the earthquake hazard at the surface level which had been adjusted to the site classification, the PGA and spectral acceleration at the bedrock level as the result of the PSHA analysis were then multiplied by the amplification factor listed in the Indonesia National Standard SNI 1726:2019 [7].

3. Results and Discussion

A set of earthquake hazard maps at the bedrock level of the TasikmalayaCity was estimated using USGS software [47]. It was developed not only for estimating PGA (Peak Ground Acceleration) but also for SA (Spectral Acceleration) at the natural period of 0.2 and 1 second, the critical damping ratio of 5%, and the exceedance probability of 2% in 50 years, corresponding to a return period of 2475 years. The earthquake hazard map at the bedrock level is illustrated in Figure 4 – 6.

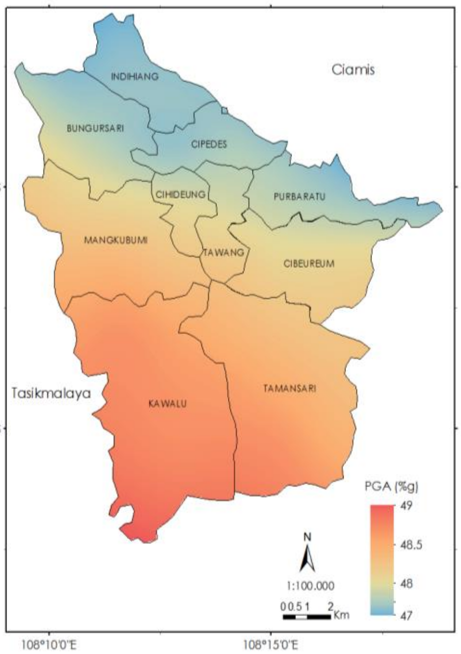

Figure 4. The PGA at bedrock level corresponding to 2% probability of exceedance in 50 years

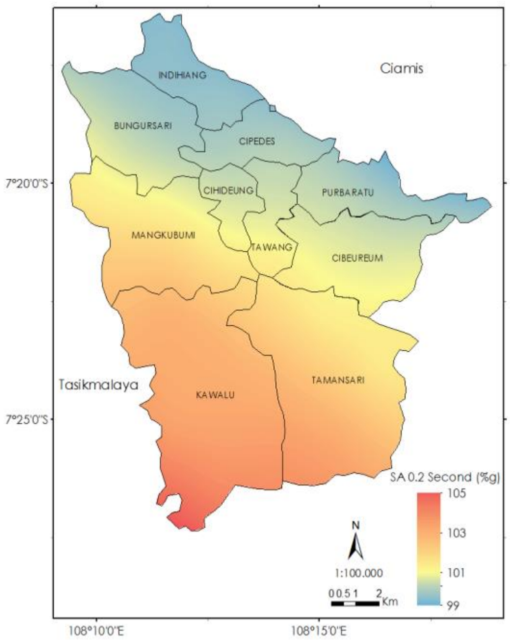

Figure 5. The spectral acceleration for 0.2 second period at bedrock level corresponding to 2% probability of exceedance in 50 years

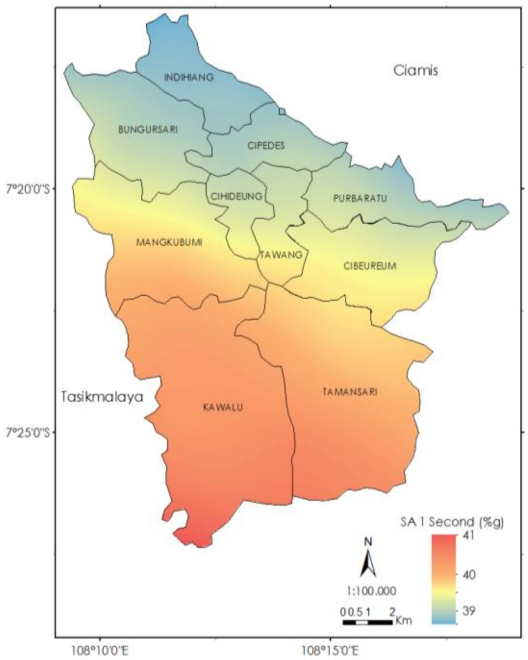

Figure 6. The spectral acceleration for 1 second period at bedrock level corresponding to 2% probability of exceedance in 50 years

The earthquake hazard map at the bedrock level for PGA had a value of 46.3-49.6% g (see Figure 4). The earthquake hazard level shows an increasing trend from north to south. The highest PGA value was found in the southern part of the City of Tasikmalaya, especially in the Kawalu Sub-district. Meanwhile, the lowest PGA was found in the northern part, especially in Indihiang Subdistrict. It was estimated that the spectral acceleration value in the natural period of 0.2 seconds was in the range 96.9-105.4% g (see Figure 5). The highest spectral acceleration value for the 0.2 second period was in Kawalu Subdistrict, declining to the north, and the lowest one was found in Indihiang Subdistrict. It correlates with the location of seismogenic sources and their orientation. This map has a similar pattern to the PGA map in bedrock. Likewise, the highest spectral acceleration value in the natural period of 1 second was found in Kawalu Subdistrict, while the lowest one was found in Indihiang Subdistrict. The spectral acceleration value in the natural period of 1 second was found in the range of 37.9-41.4% g (see Figure 6).

The pattern of damage in Mexico during the 1985 Michoacan earthquake unequivocally showed the significant effect of local site conditions. Ground shaking amplification has the effect of destroying buildings with a period approaching the site period. It is important to characterize the local site conditions to ascertain the effect of earthquake shaking at surface level.

Complete characteristics of local site conditions are important factors in determining site classification. The Vs30 was used for site classification within the IBC (International Building Code) classification [18, 48], also in the Indonesian National Standard SNI 1726: 2019 provisions [7]. The Vs30 value for site class A (> 1500 m/s), site class B (750–1500 m/s), site class C (350-750 m/s), and site class D (175-350 m/s had been considered in this study.

In this study, the MASW measurements were used to estimate the Vs30 distribution in the City of Tasikmalaya. Figure 7 presents the Vs30 distribution map of the City of Tasikmalaya. The red dots are the location of the MASW measurement. The measurement results indicated that the Vs30 interval in the City of Tasikmalaya is 286-665 m/s. Figure 7 indicates that Vs30 is relatively low (yellow color) in the Kawalu Sub-district, Tamansari Sub-district, Cibeureum Sub-district, Purbaratu Sub-district, and Mangkubumi Sub-district, as well as a small part of Cihideung Sub-district, Tawang Sub-district, and Cipedes Sub-district. These areas were categorized as site class D and the other areas (green color) were categorized as site class C according to the recommendation in the Indonesian National Standard SNI 1726: 2019 provisions [7]. Two site classes were considered to estimate the earthquake hazard at the surface level of the City of Tasikmalaya. Further geotechnical and geophysical investigations are recommended to correlate the MASW data with other geotechnical data.

The PGA and spectral acceleration at the surface level, which had been adjusted to the classification of the SC and SD sites in the City of Tasikmalaya, were estimated and mapped for the exceedance probability of 2% in 50 years. Based on the site classification, the PGA and spectral acceleration at the surface level for short periods of T 0.2 and T 1 second could differ from the conditions in bedrock. They were modified as shown in Figure 8-10 due to the local site conditions. Figure 8 shows the lowest value of 47.3% g and the highest value of around 49.6 g. In general, the PGA value at the surface level slightly increased compared to the PGA value in the bedrock. The PGA value at the surface level increased mainly in the Kawalu Sub-district, Tamansari Sub-district, Cibeureum Sub-district, Purbaratu Sub-district, Mangkubumi Sub-district and parts of Cipedes Sub-district.

By using a probabilistic approach and adapting to the classification of the SC and SD sites, the spectral acceleration value at the surface level was predicted to last both a short and a long period. The results confirmed that the high spectral acceleration value was found in the period of 0.2 seconds and the lower spectral acceleration were found in the period of 1 second. Although in most codes, e.g. IBC, the lower amplification is recommended over a longer period (as compared to a shorter period). There are reports in the literature where the soil is amplified over a long period. The reason may be due to the soft sedimentation and high groundwater level in the study area [49].

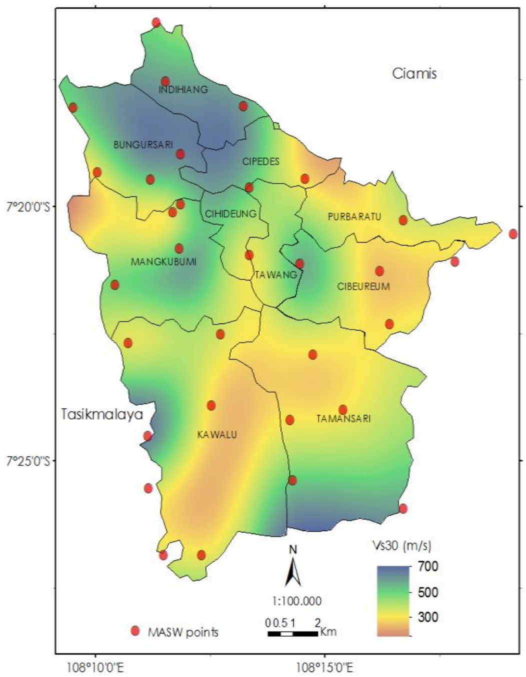

Figure 7. The Vs30 distribution map of Tasikmalaya City

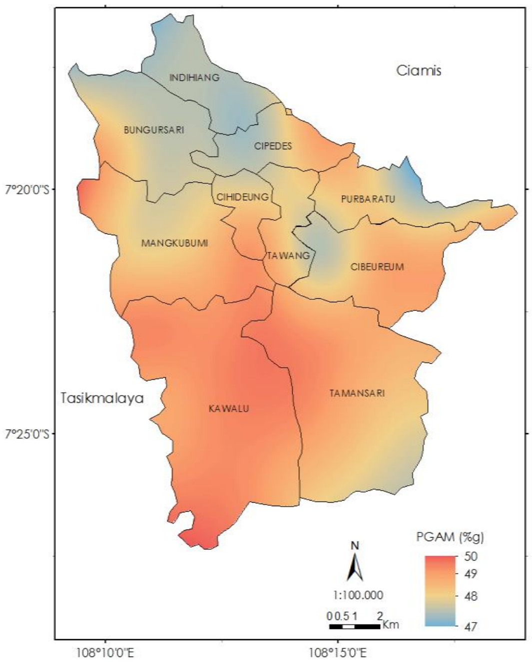

Figure 8. The PGA at the surface level corresponding to 2% probability of exceedance in 50 years

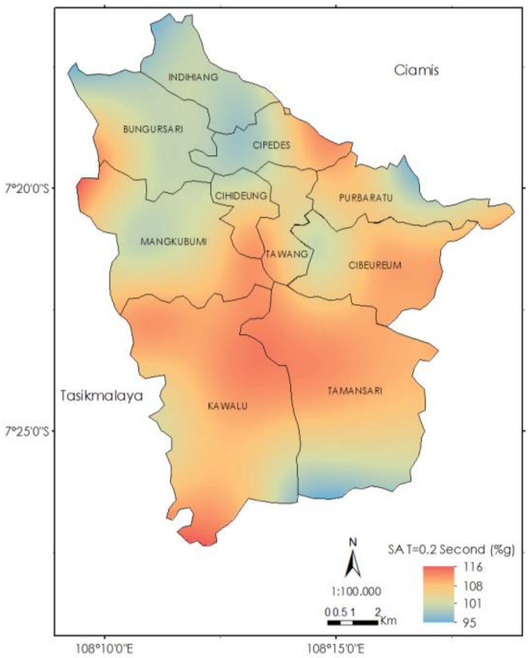

Figure 9. The spectral acceleration for 0.2 second period at the surface level corresponding 2% probability of exceedance in 50 years

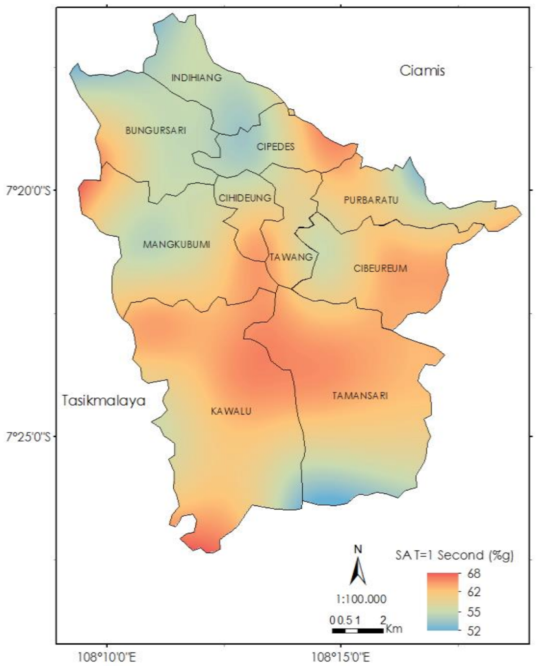

Figure 10. The spectral acceleration for 1 second period at the surface level corresponding 2% probability of exceedance in 50 years

Figure 9 shows the modified spectral acceleration value at the surface level for the period of 0.2 seconds as adjusted for the site classification in the City of Tasikmalaya. The lowest value was around 99.4% g and the highest one was around 112.9% g. The effect of this maximum surface level acceleration could be expected for a 2-story building (the natural period is close to 0.2 seconds). The spectral acceleration value at the surface level increased mainly in Kawalu Sub-district, Tamansari Sub-district, Cibeureum Sub-district, Purbaratu Sub-district, Mangkubumi Sub-district, and parts of Cipedes Sub-district.

The spectral acceleration value at the surface level for the period of 1 second adjusted to site classification in the City of Tasikmalaya shows a more varied value with the lowest value of 54.5% g and the highest value of 65.2% g as shown in Figure 10. The effect of the maximum acceleration of this surface level could be expected for 10 floor- buildings (natural period approaching 1 second). In this condition, several areas in Kawalu Sub-district, Tamansari Sub-district, Cibeureum Sub-district, Purbaratu Sub-district, and Mangkubumi Sub-district had higher spectral acceleration values. The earthquake hazard maps at surface level show improvements due to the characteristics of the local site conditions. Note that some areas in the five sub-districts that have densely populated areas had the higher PGA and spectral acceleration.

This study is expected to give a contribution to the local government of the City of Tasikmalaya in earthquake hazard mitigation. The results of this study are useful for selecting locations and identifying areas that are prone to earthquakes. Thus, it can facilitate planners and technicians in designing earthquake-resistant buildings, especially for new buildings. Besides, it is also useful to strengthen the existing building structures in the City of Tasikmalaya. This scientific information is required for future spatial planning by focusing on the infrastructure and residential buildings. Similar procedures can be applied in other cities.

Recommendations related to future research that can increase the credibility and reliability of this study include the use of the regional GMPE model in the study area. This study adopted the GMPE model from the global strong motion database which can be modified and its accuracy will improve if sufficient strong motion data is available around the study area. The characterization of local soil conditions had been estimated using MASW data, but it was still in a limited number. Additional geophysical and other geotechnical investigation data including boreholes will improve its accuracy in characterizing the local soil conditions.

4. Conclusion

This study indicates that the probability of an earthquake hazard at the surface level of the City of Tasikmalaya increases due to the characteristics of the local site conditions, especially in several sub-districts, i.e. Kawalu, Tamansari, Cibeureum, Purbaratu, and Mangkubumi. These areas need more attention, given that they are important administrative areas and have high populations.

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References

[1] B. Sunardi, S. Rohadi, A. D. Indriyani, Sulastri, D. Karnawati, “Re-Evaluation of Seismic Hazard in Tasikmalata City Using Probabilistic Approach”, *International Journal of GEOMATE*, 17(63), 187-194, 2019.

[2] L. Makrup, H. M. Sodik, S. Winarno, B. Suryo, B. Sunardi, “Soil Surface Seismic Hazard Maps for Yogyakarta, Indonesia Based on Probabilistic Seismic Hazard Analysis, Code, and Global Vs30”, *International Journal of Civil Engineering and Technology*, 9(6), 637–648, 2018.

[3] BNPB (Indonesian Agency for Disater Management), “Peta JumlahRumahRusakBeratAkibatGempabumi di Tasikmalaya”, 2009.

[4] P. Anbazhagan, K. Bajaj, K. Matharu, S. Moustafa, N. Al-Arifi, “Probabilistic Seismic Hazard Analysis Using the Logic Tree Approach – Patna District (India)”, *Nat. Hazards Earth Syst. Sci*., 19, 2097–2115, 2019.

[5] SNI 03-1726-2002, “Tata Cara PerencanaanKetahananUntukBangunan Gedung SNI 03-1726-2002”, Badan Standarisasi Nasional, 2002.

[6] SNI 1726:2012, “Tata Cara PerencanaanKetahananGempaUntukStrukturBangunan Gedung Dan Non Gedung SNI 1726:2012”, Badan Standarisasi Nasional, 2012.

[7] SNI 1726:2019, “Tata Cara PerencanaanKetahananGempaUntukStrukturBangunan Gedung Dan Non Gedung SNI 1726:2019”, Badan Standarisasi Nasional, 2019.

[8] M. Irsyam, S. Widiyantoro, D. Natawidjaja, I. Meilano, A. Rudiyanto, S. Hidayat, W. Triyoso, N. R. Hanifa, D. Djarwadi,Faizal, Sunarjito, “Earthquake Source and Hazard Maps of Indonesia 2017”, National Center for Earthquake Studies (PusGen), Research Center for Housing and Human Settlement, Directorate Generale for Research and Development, Ministry of Public Works and Housing, 2017.

[9] J. Nugraha, G. Pasau, S. Widiyantoro, B. Sunardi, “Seismic Hazard Analysis and Isoseismal for Java-Bali-NTB”, *JurnalMeteorologi dan Geofisika*, 15(1), 1-11, 2014.

[10] R. Mikhail, M. Irsyam, R. Nazir, M. Asrurifak, B. M.Hutapea, S. Rustiani,Munirwansyah, D. S. Harninti, “Development of Nationwide Surface Spectral Acceleration Maps for Earthquake Resistant Design of Bridges Based on National Hazard Maps of

Indonesia 2017”, *J. Eng. Technol. Sci*., 51(4), 501-515, 2019.

[11] T. G. Sitharam, S. Kolathayar, N. James, “Probabilistic Assessment of Surface Level Seismic Hazard in India Using Topographic Gradient as a Proxy for Site Condition”, *Geoscience Frontiers*, 6(2015), 847-859, 2015.

[12] I. Sianko, Z. Ozdemir, S. Khoshkholghi, R. Garcia, I. Hajirasouliha, U. Yazgan, K. Pilakoutas, “A Practical Probabilistic Earthquake Hazard Analysis Tool: Case Study Marmara Region”, *Bulletin of Earthquake Engineering*, 18, 2523–2555, 2020.

[13] J. Xia, R. D. Miller, C. B. Park, “Estimation of Near Surface Shear Wave Velocity by Inversion of Wave”, *Geophysics*, 64(3), 691–700, 1999.

[14] J. Xia, R. D. Miller, C. B. Park, Ivanov, “Construction of 2-D Vertical Shear Wave Velocity Field by The Multichannel Analysis of Surface Wave Technique”, In *Proceedings of The Symposium on The Application of Geophysics to Engineering and Environmental Problems*, 2000.

[15] J. Xia, R. D. Miller, C. B. Park, J. A. Hunter, J. B. Herris,Ivanov, “Comparing Shear Wave Velocity Profiles Inverted from Multichannel Surface Waves with Borehole measurement”, *Soil DynEarthq Eng*., 22(3), 181–190, 2002.

[16] C. B. Park, R. D. Miller, J. Xia, “Multichannel Analysis of Surface Waves”, *Geophysics*, 64(3), 800–808, 1999.

[17] G. Tian, D. W. Steeples, J. Xia, R. D. Miller, “Multichannel Analysis of Surface Wave Method with the Autojuggie”, *Soil DynEarthq Eng*., 23(3), 243–247, 2003.

[18] A. Kanli, P. Tildy, Z. Pronay, A. Pinar, L. Hermann, “Vs30 Mapping and Soil Classification for Seismic Site Effect Evaluation in Dinar Region, SW Turkey”, *Geophysical Journal International*, 65(1), 223–235, 2006.

[19] S. Mahajan, R. Ranjan, R.Sporry, P. K. Champatiray, C. J. V. Westen, “Seismic Microzonation of Dehradun City Using Geophysical and Geotechnical Characteristics in the Upper 30 m of Soil Column”, *J.Seismol*., 11, 355–370, 2007.

[20] P. Anbazhagan, T.Sitharam, “Site Characterization and Site Response Studies Using Shear Wave Velocity”, *J.SeismolEarthq Eng*., 10(2), 53–67, 2009.

[21] A. Widodo, and P. Irawan, “Eksplorasi Air Tanah di KampusUniversitasSiliwangiDalamRangkaPengelolaanSumberDaya Air Berkelanjutan”, *JurnalSiliwangi Seri Sains dan Teknologi*, 5 (2), 56-63, 2019.

[22] E. M. Scordilis, “Empirical Global Relations Converting MS and mb to Moment Magnitude”, *J. Seismol*., 10, 225-236, 2006.

[23] J. K. Gardner, and L. Knopoff, “Is The Sequence of Earthquakes in Southern California with Aftershocks Removed Poissonian?”, *B. Seismol. Soc. Am*., 64(5), 1363–1367, 1974.

[24] R. A. Uhrhammer, “Characteristics of Northern and Central California Seismicity”, *Earthq. Notes*, 57(1), 21–371986, 1986.

[25] S. D. Gregori,and R. Christiansen, “Seismic Hazard Analysis for Central-Western Argentina”, *Geodesy and Geodynamics*, 9(1), 25-33, 2018.

[26] M. D. Petersen, C. S. Mueller, A. D. Frankel, Y. Zeng, “Spatial Seismicity Rates and Maximum Magnitude for Background Earthquakes”, USGS Open-File Report, 2008.

[27] A. Adnan, Hendriyawan, A. Marto, M. Irsyam, “Seismic Hazard Assesment for Peninsular Malaysia Using Gumbel Distribution Method”, *JurnalTeknologi*, 42(B), 57-73, 2005.

[28] J. X. Zhao, J. Zhang, A. Asano, Y. Ohno, T. Oouchi, T.Takahashi, H. Ogawa, K. Irikura, H. Thio, P. Somerville, “Attenuation Relations of Strong Motion in Japan Using Site Classification Based on Predominant Period”, *Bulletin of the Seismological Society of America*, 96 (3), 898-913, 2006.

[29] N. Abrahamson, N. Gregor, and K. Addo, “BC Hydro Ground Motion Prediction Equations for Subduction Earthquakes”, *Earthquake Spectra*, 32(1), 23-44, 2016.

[30] G. M. Atkinson, and D. M. Boore, “Empirical Ground-Motion Relations for The Subduction-Zone Earthquakes and Their Application to Cascadia and Other Regions”, *Bulletin of the Seismological Society of America*, 93(4), 1703-1729, 2003.

[31] J. X. Zhao, J. Zhang, A. Asano, Y. Ohno, D. M. Boore, J. P. Stewart, E. Seyhan,and G. M. Atkinson, “NGA-West

2 Equations for Predicting PGA, PGV, and 5% Damped PSA for Shallow Crustal Earthquakes", *Earthquake Spectra*, 30(3), 1057-1085, 2014.

[32] K. W. Campbell, and Y. Bozorgnia, "NGA-West2 Ground Motion Model for the Average Horizontal Components of PGA, PGV and 5% Damped Linear Acceleration Response Spectra", *Earthquake Spectra*, 30(3), 1087-1115, 2014.

[33] B. Chiou, and R. Youngs, "Update of the Chiou and Youngs NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra", *Earthquake Spectra*, 30(3), 1117-1153, 2014.

[34] R. R. Youngs, S. J. Chiou, W. J. Silva, and J. R. Humphrey, "Strong Ground Motion Attenuation Relationships for Subduction Zone Earthquakes", *Seismological Research Letters*, 68, 58-73, 1997.

[35] P. Foytong, Ornthammarath, R. Arjwech, A. Janpila, N. Areemit, A. Ruangrassamee, P. Chindaprasirt, "Probabilistic Seismic Hazard Assessment of North-Eastern Thailand", *KSCE J Civ Eng*., 24(6), 1845–1857, 2020.

[36] S. T. Algermissen, D. M. Perkins, P. C. Thenhaus, S. L. Hanson, B. L. Bender, "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in The Contiguous United States", US Geological Survey Open-File Report, 82-1033. 107 p, 1982.

[37] A. Frankel, C. Mueller, T. Barnhard, D. Perkins, E.Leyendecker, N. Dickman, S. Hanson, M.Hopper, "National Seismic Hazard Maps: Documentation June 1996", U.S. Geological Survey Open-File Report, 96-532. 110 p, 1996.

[38] A. D. Frankel, M. D. Petersen, C. S. Mueller, K. M. Haller, R. L. Wheeler, E. V. Leyendecker, R. L. Wesson, S. C. Harmsen, C. H. Cramer, D. M. Perkins, K. S. Rukstales, "Documentation for the 2002 Update of The National Seismic Hazard Maps", U.S. Geological Survey Open-File Report, 2002-420, 33 p, 2002.

[39] M. D. Petersen, W. A. Bryant, C. H. Cramer, T. Cao, M. S. Reichle, A. D. Frankel, J. J. Lienkaemper, P. A. McCrory, D. P. Schwartz, "Probabilistic Seismic Hazard Assessment for The State of California", U.S. Geological Survey Open-File Report, 96-706. 33, 1996.

[40] C. A. Cornel, "Engineering Seismic Risk Analysis", *Bulletin of the Seismological Society of America*, 58(5), 1583-1606, 1968.

[41] H. A. Merz, and C. A. Cornell, "Seismic Risk Based on a Quadratic Magnitude-Frequency Law", *Bulletin of the Seismological Society of America*, 63(6), 1999–2006, 1973.

[42] EERI Committee on Seismic Risk, "The Basic of Seismic Risk Analysis", *Earthquake Spectra*, 5(4), 675, 1989.

[43] Eurocode-8, "BS-EN 1998-1, Design of structures for Earthquake Resistance - Part 1: General Rules, Seismic Actions and Rules for Buildings", European Committee for Standardization, Brussels, 2003.

[44] BSSC, "The 2003 NEHRP Recommended Provisions for New Buildings and Other Structures, Part 2: Commentary (FEMA 450)", Building Seismic Safety Council, National Institute of Building Sciences, Washington, DC, U.S.A, 2003.

[45] IBC-International Building Code. International Code Council, Washington, 2009.

[46] P. Susilanto, D. Ngadmanto, B. Sunardi, and S. Rohadi, "AnalisisKecepatanGelombangGeser (Vs) SebagaiUpayaMitigasiBencanaGempabumi di Kulonprogo, Daerah Istimewa Yogyakarta", *JurnalLingkungan dan BencanaGeologi*, 10(2), 41-50, 2019.

[47] S. Harmsen, "USGS Software for Probabilistic Seismic Hazard Analysis (PSHA) Draft Document", United States Geological Survey, Reston, VA, USA. 1-51, 2007.

[48] R. Dobry, R. D. Borcherdt, C. B. Crouse, I. M. Idriss, W. B. Joyner, G. R. Martin, M. S. Power, E. E. Rinne, R. B. Seed, "Newsite Coefficients and Site Classification System Used in Recent Building Seismic Code Provisions", *Earthquake Spectra*, 16(1), 41–67, 2000.

[49] K. Pallav, "Seismic Microzonation of Imphal City and Probabilistic Seismic Hazard Assesment of Manipur State", Doctor of Philosophy Thesis, Department of Civil Engineering, Indian Institute of Technology Guwahati, 2010.