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RESEARCH

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Regional zonation based on seismic vulnerability using local site effect analysis and potential damage to the city of Medan (North Sumatra, Indonesia) due to earthquake

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Abstract

Background: Microzonation becomes important for big cities like Medan (North Sumatra, Indonesia) as population agglomeration increases in urban areas resulting in rapid and unplanned construction. Mitigation efforts must be carried out to minimize losses arising from earthquakes, such as loss of life and environmental damage, and it can be done by analyzing seismic susceptibility and local site effects.

Purpose: This study analyzes the potential for environmental damage caused by seismic hazards in the city of Medan, North Sumatra, Indonesia. The purpose of this study is to provide an overview of the definition and methodology of seismic–geotechnical hazard zoning and the methodology used for making seismic hazard maps with the case study of Medan City.

Methods: While determining the zoning, microzonation measurements and environmental data parameters are involved. To obtain comprehensive results, microzonation measurements were carried out using three methods, namely the Multichannel Seismic Analysis Surface Wave (MASW), Spatial Autocorrelation (SPAC), and Horizontal-To-Vertical Spectral Ratio (HVSR) with 200 measuring points spread throughout the city of Medan. Parameter weighting values such as population, site class, seismic susceptibility, dominant period, land cover, slope, and weather class were obtained using the analytic hierarchy process (AHP) method.

Results: We presented the result of the survey, including the MASW, SPAC, and HVSR results. In general, medium soil and soft soil dominate almost all areas of Medan city. The estimated depth of engineering bedrock is at a depth of about 291.33 – 735.87 meters from the ground surface. The dominant period values ranged from 0.0907 s to 8.30723 s.

Conclusions: We classified Medan City (North Sumatra) into several zones, based on their seismic vulnerability using local site effect analysis and potential damage due to earthquakes. This study is necessary for future seismic hazard assessment.

Keywords: Microzonation, Environmental parameter, Regional zonation of potential damage

Introduction

Medan is the capital city of North Sumatra Province, Indonesia, which is surrounded by active faults (Natawidjaja 2018; Sieh and Natawidjaja 2000). Based on the United States Geological Survey (USGS) catalog, the distribution of earthquakes in the area concentrated on

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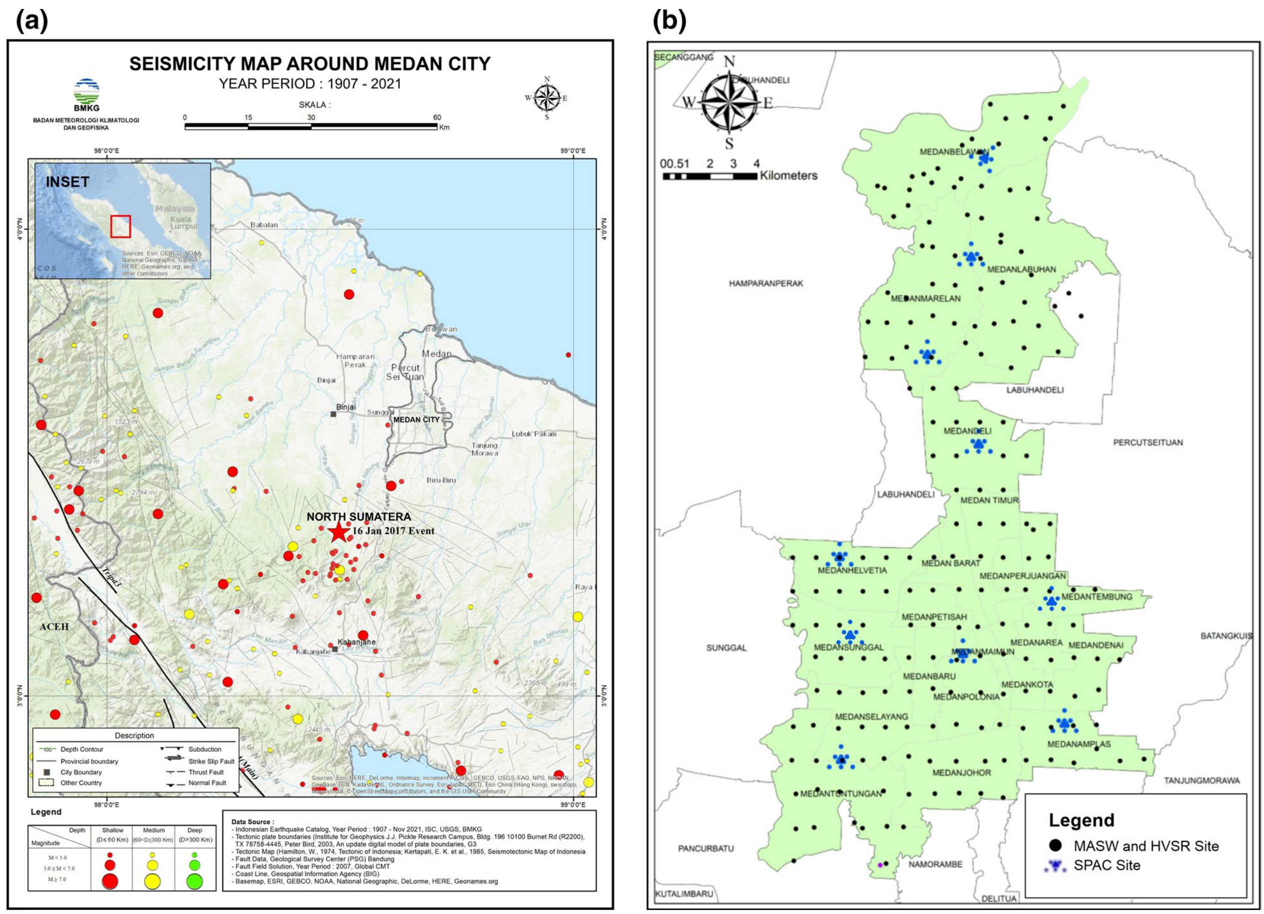

Fig. 1 Study area and the measurement locations. **a** Seismicity map of Medan City, North Sumatra, Indonesia for the period of 1907–March 2020. Circles represent earthquake epicenters with magnitudes and scales with circle sizes. Color represents earthquake depths (see legend). The red star depicts the epicenter of the 16 January 2017 M5.2 earthquake. Black lines indicate active tectonic structure. The inset shows the location of Northern Sumatra. **b** The location of site measurements in Medan City, North Sumatra. Black dots are for MASW (multichannel seismic analysis surface wave), while blue inverted triangles are for SPAC (spatial autocorrelation) analysis

land scattered around Medan with various depths from 1 to 421 km and magnitudes of M1.3–M6.6 (Fig. 1a). During the period, several earthquakes on land were felt in the area, including the Deli Serdang Earthquake (M 5.2) on January 16, 2017, which was felt up to the III-IV on Modified Mercalli Intensity (MMI) scale.

Microzonation becomes important for big cities like Medan as population agglomeration increases in urban areas resulting in rapid and unplanned construction (Molnar et al. 2020; Celikbilek and Sapmaz 2016; Navarro et al. 2014; Anbazhagan and Sitharam 2008; Mirzaoglu and Dýkmen 2003). Urban areas are more dangerous and high risk even for medium earthquakes (Celikbilek and Sapmaz 2016). So, mitigation efforts must be carried out to minimize losses arising from earthquakes, such as loss of life and environmental damage; it can be done by analyzing seismic susceptibility and local site effects (Molnar et al. 2020; Daniell et al. 2017; Navarro et al. 2014).

Seismic susceptibility analysis and local site effects were carried out by considering seismicity and geological conditions on a large scale without considering geotechnical aspects (Gurler et al. 2000). Analysis of local soil site effects is generally very useful in seismic hazard assessment and risk evaluation (Hidayat et al. 2017). Seismic vulnerability analysis and local site effects can also be carried out on a smaller scale taking into account regional seismicity, geology, socioeconomic, population, and local site conditions (Hidayat et al. 2017; Fathani and Wilopo 2017; Irsyam et al. 2015). Measurement and analysis of local soil footprint effects of an area produce detailed maps that estimate hazards at a much smaller scale (seismic microzonation) (Irsyam et al. 2015). Seismic microzonation is a geophysical method that divides an area into several zones with their respective geological conditions so that special characteristics of an area can be obtained. Seismic microzonation can determine specific seismic behavior for engineering design, land use, and urban planning (Celikbilek and Sapmaz 2016).

This study analyzed the local soil conditions and their response to seismic waves in Medan City using the microzonation method. Measurements were carried out using three methods, namely the Multichannel Seismic Analysis Surface Wave (MASW), Spatial Autocorrelation (SPAC), and Horizontal-To-Vertical Spectral Ratio (HVSR) methods. The output of this measurement produces information on local soil conditions (Soil Type, depth of bedrock, Frequency, Dominant Period, Seismic Vulnerability) and response to earthquake shocks. This data is then weighted with environmental parameters (Land Cover Data, Slope Data, Weather Data) and Population Density Data to analyze the Potential Level of Environmental Damage Due to Earthquakes in Medan City. This analysis uses the Analytic Hierarchy Process method. This method decomposes a complex multi-factor problem into a hierarchy. The results will be used as the basis for making the Medan City Environmental Damage Zoning Map due to the earthquake.

Therefore, the purpose of this study is to provide an overview of the definition and methodology of seismic-geotechnical hazard zoning and the methodology used for making seismic hazard maps (e.g., Mase and Sugianto 2021; Fathani and Wilopo 2017) with the case study of Medan City.

Data and methodology

Data

Microzonation measurement locations are in the city of Medan as many as 200 points spread across 21 sub-districts (Fig. 1b). The MASW and HVSR measurement locations are simultaneously, and the SPAC measurement location points are 10 points with 50 configurations. MASW measurements use 24 geophone sensors with a frequency of 4.5 Hz and a 10 kg hammer. SPAC measurements use four integrated accelerometers, and HVSR measurements use a single seismograph (three components).

For environmental parameter data, we used demographic data obtained from the Central Statistics Agency of Medan City in 2020; topography was obtained from DEMNAS data obtained by the Geospatial Information Agency of Indonesia (BIG) in 2021; and weather data which is rainfall data obtained through observations from BMKG Station in Medan City.

Demographic data used are population density data per sub-district and settlement data on land cover in the city of Medan. Population density data is classified into several class units with each class length as shown in Additional file 1: Table S1.

The topographic data used in this study has a resolution of 0.27 Arcsecond/8.1 m. The DEMNAS (Digital Elevation Model) data were processed to obtain the slope data with a classification based on Law No. 26 of 2007 concerning Spatial Planning (the Republic of Indonesia, 2007). The classification of soil slope class division is divided into 5 (five) classes, i.e., flat (0–8%), gentle (8–15%), slightly steep (15–25%), steep (25–45%) and very steep (>45%).

Weather data (rainfall) was obtained from the BMKG stations, that is, from Belawan Maritime Meteorological Station, Bawil I Medan, and Sampali Climate Stations. Rainfall data in this study are for nine years in a daily format. Data processing is further divided into two, namely spatial processing and numerical processing. Numerical processing purposes to obtain the average rainfall and spatial processing for rainfall data for all sub-districts in the city of Medan through an interpolation approach. In this paper, all the data are included in the set of Additional file 1: Tables S1–S17.

Multichannel seismic analysis surface wave (MASW)

The principle of the MASW survey is based on Rayleigh's theory of surface wave propagation, where the waves are generated from the interaction of shear waves with the surface soil layer. By measuring the velocity of the Rayleigh surface wave, the Vs30 profile can be estimated. The advantage of the dispersive properties of Rayleigh waves is used to identify the thickness of the layer corresponding to the shear wave velocity so that the Vs30 profile can be obtained.

The location is selected on a surface with a flat contour; the geophone is installed in an inline configuration with a distance of 2 m. Measurements were made using the fixed spread method (the location of the geophone sensor does not move). The data that has been obtained is then processed by adjusting the input geometry; then, the Fourier transform is performed on the signal data. The transformed signal is then selected for a dispersion curve, which will then be inverted repeatedly until it reaches the desired minimum RMS error. The shear wave velocity profile (Vs) concerning depth will be displayed based on the processed data and then classified according to ASCE 2010 and SNI 1726:2002.

Spatial autocorrelation (SPAC)

SPAC is a Microtremor Array (MA) survey method that is based on the Rayleigh surface wave propagation theory, where the waves are generated from the interaction of shear waves with the surface soil layer (Kita et al. 2011). The SPAC method uses a sensor that has a wide frequency range, and the source used is passive vibration with varying frequencies so that the penetration of waves that can be reached is deep and can estimate the depth of engineering bedrock which is generally at a depth of more than 30 m. In this SPAC method, the surface wave vibration recording is obtained from the sensor configuration (array) to record the microwave tremor. The configuration is made isotropically, such as a triangular shape, so that the phase velocity of the wave from all directions to form a dispersion curve can be calculated.

The selection of the triangular size design of the microtremor placement array is adjusted to the desired depth profile target. For very deep depth profile targets (deep layers) using Microtremor Array data with a stretch/distance of 1000 m, 500 m, and 250 m. As for the shallow depth profile (shallow layers) using Microtremor Array data with a stretch/distance of 125 m and 62.5 m. 2. Microtremor recording data used a sampling interval of 0.01 s and 16,384 sample blocks. The data that has been opened is then transformed into a phase velocity-frequency curve, and the next step is to combine the wave phases with other configurations. The results of this merger will be compared with the initial model, which then produces a depth profile of the S wave velocity. The software used in this processing is McSeisImager.

Horizontal-to-vertical spectral ratio (HVSR)

HVSR is a method used to calculate the spectrum ratio of the horizontal component to the vertical component of the microtremor wave (Pranata et al. 2018). From the HVSR curve in the frequency domain, it can be seen that the maximum response spectra value is the value of the soil amplification factor (Ao), while the frequency value of the maximum response spectra is the soil dominant frequency value (fo). Analysis of the data from the microtremor survey to obtain T_{DOM} was carried out with the help of the Geopsy computer program. In the analysis, windowing, filtering, and smoothing processes were carried out with the criteria of adjusting the recorded microtremor. Furthermore, the reading of the dominant period will be compared with the value of Vs30 based on the empirical equation (Zhao et al. 2006) to obtain the type of soil according to the SNI 1726:2019 standard (Irsyam et al. 2020). The empirical equation and the relationship between the dominant period and Vs30 can be seen in Additional file 1: Table S2. The data that has been obtained is then processed by performing a signal filter and calculating the HVSR method. The resulting output is then converted into a period value so that the average HVSR color spectrum and standard deviation of the resulting value can be seen.

Analytic hierarchy process (AHP)

The Analytic Hierarchy Process (AHP) is a general theory of measurement developed by Saaty (1987). AHP is used to derive the ratio scale from discrete and continuous pair comparisons. In its general form, AHP is a nonlinear framework for carrying out deductive and inductive thinking without using a syllogism by considering several factors simultaneously and allowing assistance and feedback-making numerical exchanges to arrive at a synthesis or conclusion (Saaty 1988). The solution using the AHP system has four basic principles, i.e., Decomposition (problem decomposition), Comparative Judgment (pairwise comparison), Synthesis of Priority (determining priority), and Logical Consistency (consistency calculation) (Saaty 1988, 1994).

Hierarchical model (decomposition)

This study aims to determine the zoning of landslide-prone areas in Medan City. Then the second level consists of 7 (seven) criteria, namely Population, Soil Class, K_G, T_{DOM}, Land Cover, Slope, and Weather. Class division for each criterion is at the third level position. At the final level, the results obtained in this study are in the category of landslide-prone areas. There are five categories to be determined, i.e., very low, low, moderate, high, and very high. The hierarchical model is presented in the supplementary material.

Criteria assessment (comparative judgment)

The determination of the value of each criterion is based on Additional file 1: Table S3; there are values 1 to 9, which indicate the level of importance of each criterion. The results of calculations using a pairwise comparison matrix are presented in Additional file 1: Table S4.

Determining priority (synthesis of priority)

Priority determination was obtained from the calculation of weights and priorities by using a matrix or solving equations. Using the formula for the value in the n column divided by the number of each column, the normalized pairwise comparison matrix was obtained from the matrix calculation (Additional file 1: Table S4). The normalized pairwise comparison matrix is presented in Additional file 1: Table S5. From the matrix calculation, the vector of the total weights can then be searched and determined by adding up the average value with the criterion value based on Additional file 1: Table S5. Then the total weighting vector can be estimated (Additional file 1: Table S6).

Calculating logical consistency

The consistency vector was obtained by dividing the total weighting vector by the average value of the normalized pair comparison matrix (Additional file 1: Table S5) for each criterion. The value of the consistency vector is presented in Additional file 1: Table S7.

When the value of the consistency ratio is less than 0.1 ($CR < 0.1$), it can be concluded that the level of consistency in the pair comparisons is quite rational (Saaty 1994). So, the results of the calculations on the normalized pairwise comparison matrix can be used as weights in making a compilation map of geophysical survey data and environmental data as well as population data. Based on Additional file 1: Table S5, the weight values for each criterion are population 28%, site class 28%, seismic vulnerability 16%, dominant period 9%, land cover 9%, slope 5%, and weather class 5%.

Weighting

Weighting is a decision-making technique in a process that involves various factors together by giving weight to each of these factors. Weighting can be done objectively with statistical calculations or subjectively by assigning based on certain considerations.

Geophysical survey data

Geophysical survey data used in this study include MASW, T_{DOM}, and K_G (Seismic Vulnerability) measurements are referred to as geotechnical parameters. Each of the parameters has a different role which is indicated by the difference in the percentage present, MASW is given a weight of 52%, T_{DOM} 30%, and K_G 18% based on calculations using the AHP method. Class division on geotechnical parameters was presented in Additional file 1: Table S8–S10 (Irsyam et al. 2020).

Environment parameter data

Determined the landslide susceptibility, environmental factors that are considered are land cover, slope, and rainfall intensity. In the weighting of environmental parameter data, land cover is given a weight of 48%, the slope of 26%, and the weather with 26%. Class division on environmental parameters was presented in Additional file 1: Tables S11–S13 (according to regulation Permen PU No. 26/PRT/M/2007 about building expert team guidelines).

Results and discussions

In this study, we presented the result of the geophysical survey first (MASW, SPAC, and HVSR results), followed by the discussions on the Medan City environment, geotechnical and environmental analysis, and finally discussions on the potential environmental damage in Medan City due to earthquake shaking. In addition to the figures, the results are also presented as Tables in the supplementary material. The comparison of the different methods have been including discussions regarding each model.

MASW result

In this study, the used assessment to determine the classification of soil types using the value of shear wave velocity at a depth of 30 m (Vs30) with the Multi-Channel Analysis of Surface Wave (MASW) method based on the SNI 1726:2019 classification because it is considered not to contribute vertical waves from ambient noise in the dominant period microtremor (T_{DOM}) with the Horizontal to Vertical Spectral Ratio (HVSR) method (Irsyam et al. 2020).

The measurements result from 198 points in 21 districts in Medan City produced shear wave velocity data up to 30 m depth (Vs30). The obtained value vary from 61.86 to 307.22 m/s. The distribution table for the Vs30 value is presented in Additional file 1: Table S14.

Generally, Medan city in the central and southern parts is composed of medium soil (SD), and theVs30 value ranges from 180.29 to 307.22 m/s (orange to light green). Whereas the northern part of Medan City is composed of soft soil (SE). with Vs30 values ranging from 61.86 to 179.81 m/s (red color). This medium soil (SD) and soft soil (SE) dominate almost all Medan City areas, it can be seen in Fig. 2a.

SPAC result

Measurement of engineering bedrock depth in the Medan City area using the Spatial Autocorrelation (SPAC) method (Kita et al. 2011) was done three times. From field measurements and data processing, the results of the dispersion curve and shear wave velocity profile

(See figure on next page.)

Fig. 2 Result of some parameters describing microzonation of Medan City, North Sumatra. **a** Top left: soil classification based on Vs30. Color Vs30 value in m/s. **b** Bottom left: bedrock depth based on the SPAC (spatial autocorrelation) analysis at 8 measurement sites. Color represents bedrock depth in meters. **c** Top right: soil classification based on microtremor dominant period (T-dom). Color represents the microtremor dominant period in seconds. **d** Bottom right: seismic vulnerability (K_G) map. Color represents the seismic vulnerability index. Inset depicts the Northern Sumatra and the active tectonic structures

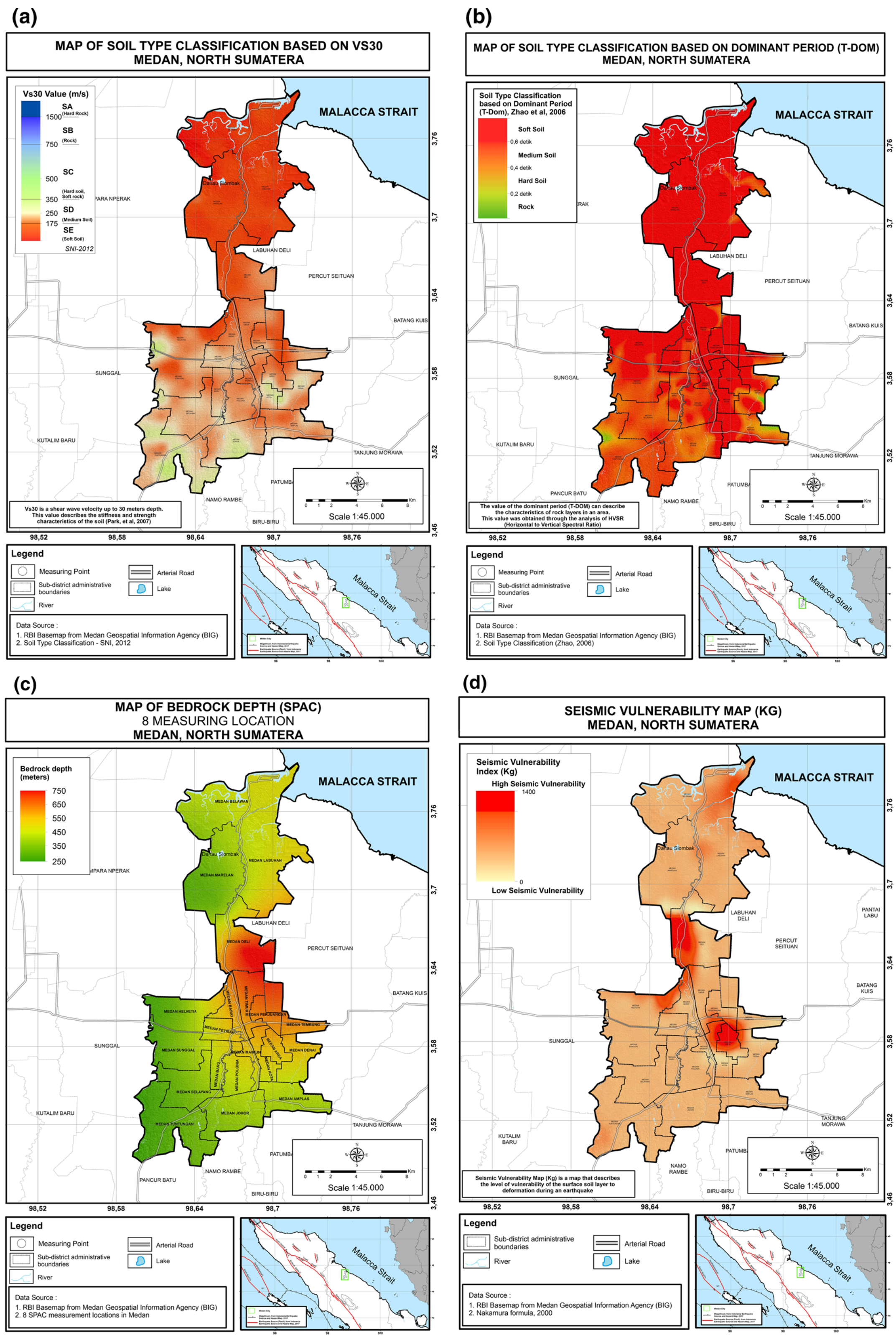

Fig. 2 (See legend on previous page.)

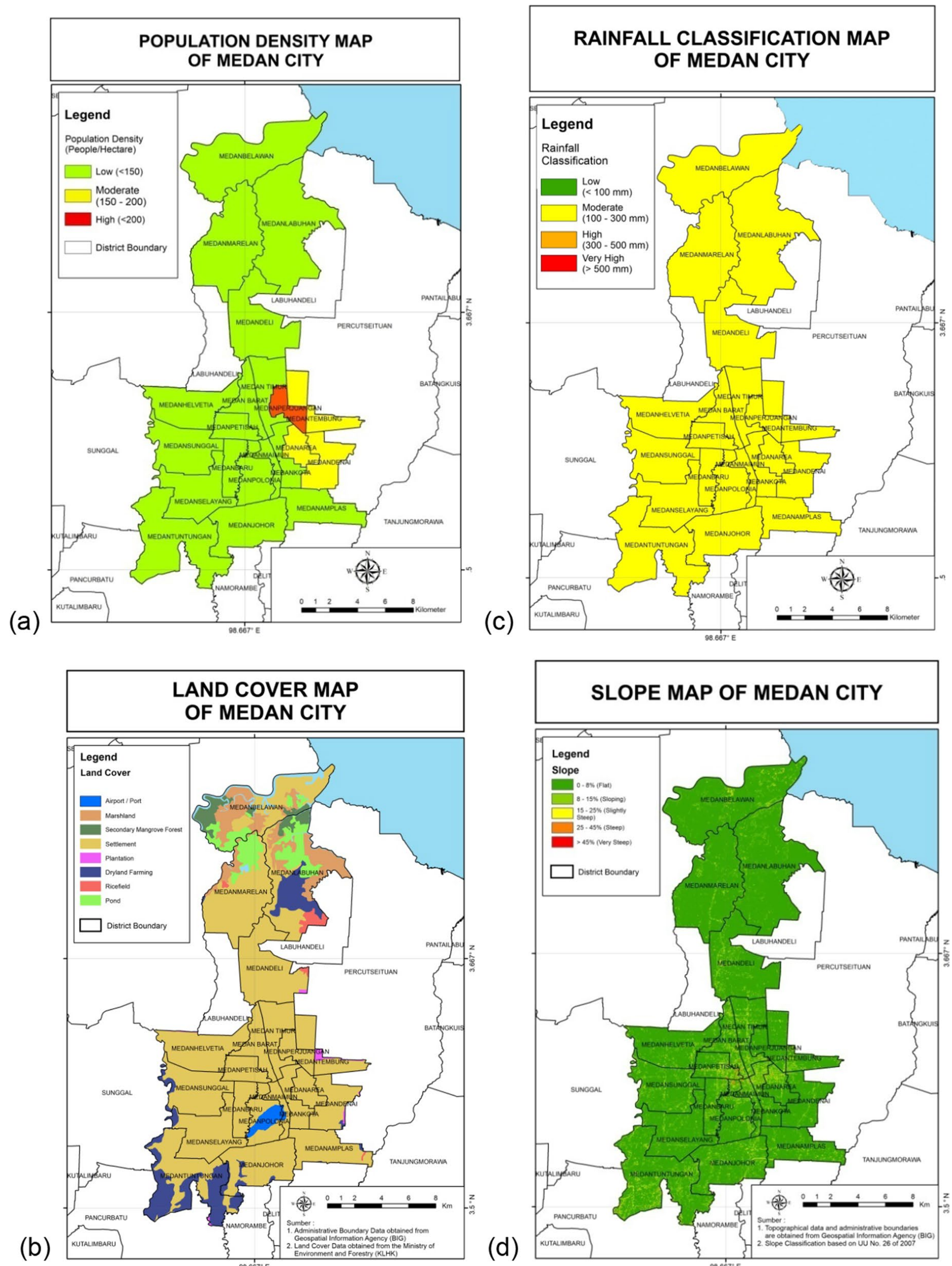

Fig. 3 Some environmental parameters impacting seismic risk to Medan City. **a** Top left: population density of Medan City. Color represents the number of people per hectare. **b** Bottom left: land cover of Medan City. Color represents the information on land cover in Medan City. **c** Top right: rainfall classification. Color represents rainfall in mm. **d** Bottom right: slope map. Color represents the percentage of surface slope

(Vs) concerning the depth of each point were obtained. The dispersion curve shows the frequency relationship to the varying velocity phase caused by different lithological conditions. Velocity profiles higher than 750 m/s were considered as velocity in engineering bedrock.

The results of measurements using the SPAC method show that the bedrock values varied with the dominant bedrock at 250–450 m depth (Fig. 2b). That depth is on the west edge of Medan city. The deepest part of bedrock is at 750 m depth, i.e., the central Medan, which are Medan Deli, Medan Timur, and Medan Perjuangan. Detailed bedrock depth in each district is presented in Additional file 1: Table S15.

HVSR result

The results of the dominant period (T_{DOM}) measurement in Medan City produced the Amplification (A) and Period (T) seismic data. Interpolation was done to be used as the contour of the T_{DOM} value in the survey area. The T_{DOM} contour was made based on the closeness between the measurement points.

Dominant period values vary from 0.09074 to 8.30724 s. This value can reflect the character of the soil type based on the Zhao equation (Zhao et al. 2006). This T_{DOM} value shows the character of soft soil types in almost all areas of Medan City (Fig. 2c). The detailed distribution of the dominant period values is presented in Additional file 1: Table S16.

The distribution of seismic vulnerability (K_G) of 21 districts in Medan City is clearly shown in Additional file 1: Table S16. From 198 measurement sites, as many as 136 measurement points produced a seismic vulnerability index value of less than five, indicated by the dominance of light brown color, which indicates that area has a low seismic vulnerability scale (Fig. 2d).

Otherwise, the 56 measurement sites show orange color, which means the seismic vulnerability has ranged from 5 to < 50, so it is included in the medium classification. High vulnerability ranges from 50 to 1486.38, which is marked as red in the northern and central parts of Medan City. Based on the seismic vulnerability index scale by Nakamura (2008), Medan city has a range of vulnerability index values on all scales from low and medium to high, with values ranging from 0.07427 to 1486.38.

Medan city environment

Medan City is an area with a dense population. The most densely populated areas are concentrated in the central part of Medan city (Medan Perjuangan, Medan Tembung, and Medan Denai) (Fig. 3a). The land cover of the city of Medan is quite varied but is dominated by settlements (Fig. 3b). The Medan city area has a flat slope, only between the Districts of Medan Petisah (Fig. 3d), Medan Maimun, and Medan Area where there are steep areas. The population density of the city of Medan compared to the area occupied, the highest is in the Medan Perjuangan area with more than 200 people/ha. Then followed by Medan Denai District and Medan Area, with a population density of more than 150 people/ha. Meanwhile, the other 18 Districts in Medan City have an average population density of fewer than 150 people/ha. So that the potential impact of a disaster is very significant if it occurs in the Medan Perjuangan area. Rainfall in the Medan city area is generally classified as medium rainfall (class 2) with an average rainfall range of 190–220 mm (Fig. 3c). The highest level of rainfall in the city of Medan is in the southern region, followed by the central area and then north of the city of Medan.

Geotechnical and environmental analysis

Based on the Compilation of Environmental Parameters of the Medan City Map, the areas with the highest risk parameter values are in the central to the southern region of Medan City, and the lowest areas are in the northern region (Fig. 4a). The area that has the potential to have a significant impact on landslides is the downtown area of Medan because the slope is quite steep (15–45%) and land cover in the form of dense settlements is in the area. The population density in the downtown area of Medan is also quite dense, namely 7000–24,000 people/km.

The Compilation Map of Geotechnical Parameters for Medan City (Fig. 4c) was obtained from the combination of geotechnical parameters, Site Class (MASW/Vs30), Seismic Vulnerability (K_G), and Dominant Period (T_{DOM}) with a weight of each parameter, i.e., 52% of Site Class (MASW) parameters, 30% Seismic Vulnerability (K_G), and 18% Dominant Period (T_{DOM}). Based on the Geotechnical Parameter, the area with the highest geotechnical parameter value is in the northern region, and the lowest area is in the southern region.

(See figure on next page.)

Fig. 4 Result of the microzonation study of Medan City, North Sumatra based on this study. **a** Top left: compilation of environmental parameters of Medan City. Color represents the class of environmental parameters from very low to very high. **b** Bottom left: incorporation of geotechnical dan environmental parameters. **c** Top right: compilation of geotechnical parameters of Medan City. Color represents the class of geotechnical parameters from low to very high. **d** Bottom right: the final result of the zonation map of potential environmental damage due to the earthquake in Medan City. Color represents the class of potential environmental damage from very low to very high

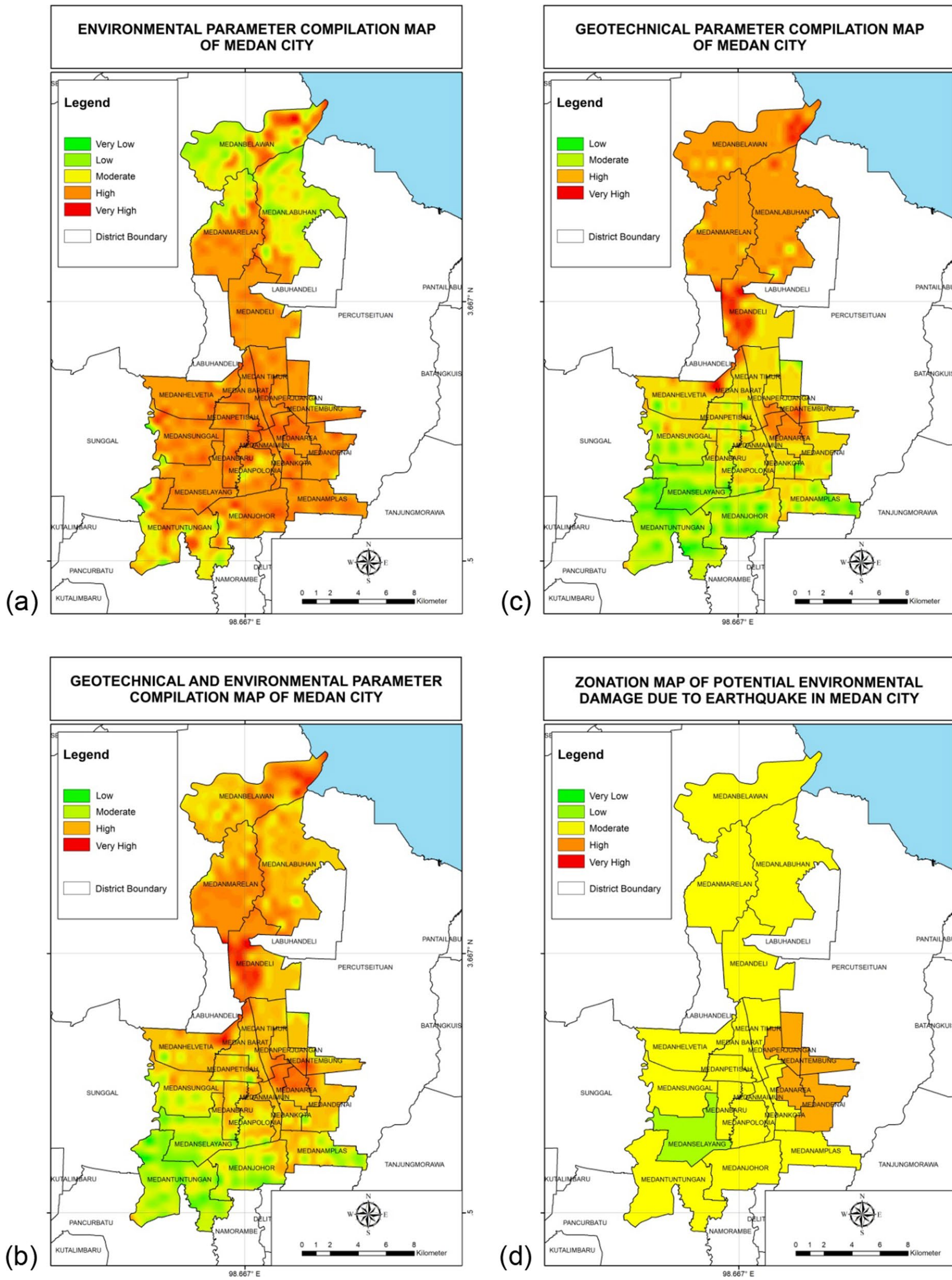

Fig. 4 (See legend on previous page.)

Map Compilation of Geotechnical and Environmental Parameters of Medan City (Fig. 4b) were obtained from a combination of geotechnical parameters, Site Class (MASW/Vs30), Seismic Vulnerability (K_G), and Dominant Period (T_{DOM}) as well as environmental parameters such as Land Cover, Slope, and Weather Conditions (Rainfall Class) with the weight of each parameter, namely 38% Site Class (MASW), 22% Seismic Vulnerability (K_G), 13% Dominant Period (T_{DOM}), 13% Land Cover, 7% Slope, 7% Weather Conditions (Rainfall Class).

Based on geotechnical and environmental parameters (Fig. 4b), the northern to central Medan area has the potential for significant impact due to earthquakes, especially the northern part of the Medan Belawan district, Medan Marelan, Medan Deli, West Medan, and Medan Area which are in the southern region.

Potential environmental damage due to earthquake in Medan city

The Zoning Map of Potential Environmental Damage in Medan City was obtained from a combination of population density parameters, geotechnical parameters, and environmental parameters with the weight of each parameter, namely 28% Population Density parameter, 28% Soil Class parameter (MASW), 16% Seismic Vulnerability (K_G), 9% Dominant Period (T_{DOM}), 9% Land Cover, 5% Slope, and 5% Weather Conditions (Rainfall Class).

The results of the Zoning analysis of Potential Environmental Damage Due to the Earthquake in Medan City show that the areas that have the potential to have a high enough impact are the Medan Perjuangan, Medan Area, Medan Tembung, and Medan Denai areas. The potential medium impact is in the areas of Medan Maimun, Medan Helvetia, Medan Deli, Medan Petisah, Medan Johor, Medan Amplas, Medan Baru, Medan Belawan, Medan Kota, Medan Labuhan, Medan Marelan, Medan Barat, Medan Polonia, Medan Sunggal, Medan Timur, and Tuntungan Field. Then, areas with low impact potential are only found in the Medan Selayang sub-district. The detailed zoning weighting of potential environmental damage due to the earthquake for each Medan City district is shown in Additional file 1: Table S17.

In this study, possible verification of the results has been obtained by comparing the result from various methods, such as the MASW, SPAC, and HVSR, as well as by performing the Analytic Hierarchy Process (AHP). The result is also verified by empirical information from the damage due to the recent moderate-magnitude earthquake on 16 January 2017 (Fig. 1a) (Prasetyo et al. 2018).

Conclusions

Medium soil (SD) and soft soil (SE) dominate almost all areas of Medan city. In the northern part, it is composed of soft soil (SE) with Vs30 values ranging from 61.86 to 179.81 m/s. Meanwhile, in the middle and south, it is composed of medium soil (SD) with a value of Vs30 ranging from 180.29 to 307.22 m/s. The estimated depth of engineering bedrock is at a depth of about 291.33–735.87 m from the ground surface. The shallowest engineering bedrock depth is located in the Medan Selayang sub-district, and the deepest engineering bedrock depth is located in the Medan Deli sub-district. The dominant period values ranged from 0.0907 to 8.30723 s. Soil types in Medan City based on T_{DOM} analysis are dominated by soft and medium soils.

The average population was 150 people/ha in Medan City. So, the potential disaster impact is relatively high. The land used in this city is dominated by residential areas (74.4%), which spread to almost all districts. It is very influential on disaster vulnerability in Medan city.

Based on the results of the Compilation of Environmental Parameters for the City of Medan, it was found that the area that has the potential to have a significant impact on landslides is the downtown area of Medan because the slope is quite steep (15–45%) and land cover in the form of dense settlements are in the area. The population density in the downtown area of Medan is also quite dense, namely 7000–24,000 people/km.

Based on the results of the Geotechnical Parameter Compilation of Medan City, the area with the highest geotechnical parameter value is in the northern region, and the lowest area is in the southern region. Based on the results of the Compilation of Geotechnical and Environmental Parameters, the areas that have the potential to have a significant potential impact are the north to the middle of Medan city, especially the northern part of the Medan Belawan sub-district, Medan Marelan Medan Deli, West Medan and Medan Area which are in the southern region.

The results of the Zoning analysis of Potential Environmental Damage Due to the Earthquake in Medan City show that the areas that have the potential to have a high enough impact are the Medan Perjuangan, Medan Area, Medan Tembung, and Medan Denai areas. The potential medium impact is in the areas of Medan Maimun, Medan Helvetia, Medan Deli, Medan Petisah, Medan Johor, Medan Amplas, Medan Baru, Medan Belawan, Medan Kota, Medan Labuhan, Medan Marelan, Medan Barat, Medan Polonia, Medan Sunggal, Medan Timur, and Tuntungan Field. Then, areas with low impact potential are only found in the Medan Selayang sub-district.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40677-022-00227-0.

Additional file 1. Tables showing the data and corresponding results related to the methodologies and discussions in the main text.

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Author contributions

TR: conceptualization, investigation, formal analysis, writing—original draft. ZN: supervision. RY: supervision. DK: supervision. All authors read and approved the final manuscript.

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Declarations

Competing interests

The authors declare that they have no competing interests.

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