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LIQUEFACTION POTENTIAL ANALYSIS BASED ON THE GLOBAL GEOSPATIAL MODEL (GGM) METHOD IN TARUTUNG DISTRICT

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Abstract

This study focuses on knowing the Vs30 value in Tarutung District, knowing the Peak Ground Velocity (PGV) value in Tarutung District, knowing the potential for liquefaction in Tarutung District using the Global Geospatial Model (GGM) method. The results of this study are that the Vs30 value in Tarutung District has a distribution in the range of 255 M / S which is in the North to the Northeast and covers almost half of the Tarutung District area with a classification of medium soil type, very dense soil or soft rock, up to 897.8 M / S which is spread in the lower southwest direction of Tarutung District to several points to the southeast of Tarutung District with a classification of very dense soil type or soft rock and rock. The PGV value in Tarutung District based on the worst earthquake scenario in the Toru segment of the Sumatran fault varies in the range of 7.94 cm/s to 15.20 cm/s. The potential for liquefaction in Tarutung District based on the Global Geospatial Model has various values. The lowest percentage value of liquefaction probability is 0.024, which is in the north, southeast, and northwest of Tarutung District, and the highest percentage value of probability is 0.961, which is in the northeast and southwest of Tarutung District.

Keywords: ***Liquefaction Potential, Global Geospatial Model (Ggm) Method, Vs30, Peak Ground Velocity (Pgv)***

INTRODUCTION

Indonesia is one of the countries prone to earthquakes, earthquakes are original vibrations that originate from within the earth, which then spread to the earth's surface due to the earth's cracks breaking and shifting violently. This is because Indonesia is the location of many active volcanoes causing volcanic earthquakes due to volcanic eruptions, in addition to Indonesia being on the meeting point of three major tectonic plates of the world: the Indo-Australian plate, the Eurasian plate, and the Pacific plate, which creates active tectonic conditions in the region, including in the "Pacific Ring of Fire" and the Alpide belt. The shifting and frictional activity of these plates causes a high frequency of tectonic earthquakes in Indonesia. The earthquake that struck Tarutung District on October 1, 2022, was quite large, with a magnitude of 5.8, generated by active fault activity at a shallow depth of 10 km. This event prompted research into the potential for liquefaction in the region, supported by Tarutung District's proximity to the Sumatran fault line, a source of earthquake activity. This event resulted in numerous fatalities and damage to many buildings and roads, ranging from minor to severe (National Disaster Management Agency). There were subsequent disasters following the earthquake, one of which was liquefaction.(Endah P sari, et al., 2023) Liquefaction is the loss of soil strength due to pore water pressure arising from cyclic loads (vibrations). These vibrations can be those caused by earthquakes. When subjected to these vibrations, the soil changes into a liquid, making it unable to support the weight of the building above it. Liquefaction typically occurs in saturated soil, where all the cavities within the soil are filled with water. During vibrations, this water exerts pressure on the soil particles, affecting their density.(Mario Hutagalung, Simon Dertha Tarigan, 2019). Previous studies that discussed liquefaction potential include Prabowo (2023), who conducted a liquefaction potential analysis using GGM for the Balige sub-district area. In his study, the parameters used were vs30 data and pgv (peak ground velocity) from the worst-case scenario of the Toru segment of the Sumatran fault. Other data, such as precipitation data, namely rainfall data, were obtained from the BMKG database. This study also calculated the distance of the nearest lake and river from the research location as parameters for calculating liquefaction potential. The results show that in the Balige sub-district area, the percentage probability of liquefaction varies, with the lowest value at 0.01 in the eastern, southern, and western regions of Balige sub-district. The highest probability percentage value obtained, at 0.37, is in the northern region of Balige sub-district.(Diki Prabowo, et al., 2023). Annas et al. (2020) also conducted a liquefaction potential analysis using GGM for the Sanden sub-district, Bantul Regency. In their study, the maximum ground acceleration (PGA) parameter was obtained from the Puskim website, the soil wetness index was obtained from the Center for Ecology and Hydrology (CEH) website, while the shear wave velocity (VS30) value was obtained from the microtremor measurement inversion method. The results showed that the area has a fairly high liquefaction potential, especially in the eastern part, namely Srigading village, which constitutes 51% of the study area.Based on the research, there is a novelty in this research where this research focuses on knowing the value of vs30 in Tarutung sub-district, knowing the value of peak ground velocity (pgv) in Tarutung sub-district, knowing the potential for liquefaction in Tarutung sub-district using the global geospatial model (ggm) method. Which is stated in the title of liquefaction potential analysis based on the global geospatial model (ggm) method in Tarutung sub-district. This research is expected to be used as a further reference in conducting research on liquefaction potential in Tarutung sub-district, can be a source of information regarding the potential liquefaction disaster in Tarutung sub-district.

LITERATURE REVIEW

A. Earthquake

An earthquake is a natural phenomenon that occurs when vibrations are felt within the earth, caused by the sudden release of energy in deformed rocks. Changes in the earth's internal structure, or the tectonic plates beneath the earth's surface, are one of the triggers for these vibrations, which vary in strength and cause earthquakes. The Quran extensively discusses natural disasters, including earthquakes. Here is one verse in the Quran that discusses earthquakes:

Picture1QS: Al-Waqi'ah verses 4-6

إِذَا رُجَّتِ الْأَرْضُ رَجًّا ۙ (٤) وَبُسَّتِ الْجِبَالُ بَسًّا ۙ (٥) فَكَانَتْ هَبَاءً مُنْبَثًّا ۙ (٦)

It means; When the earth is shaken as hard as possible. And the mountains were destroyed until they were completely destroyed. Then everything will become flying dust (QS: Al-Waqi'ah verses 4-6).

There are different types of earthquakes based on how they occur and where they originate.

1. Earthquakes Based on How They Occur:
   a) Tectonic Earthquake
   Earthquakes that originate from shifting rock layers on tectonic plates are known as tectonic earthquakes.(Dito Putro Utomo and Bister Purba, 2019)
   b) Earthquake Collapse
   A collapse type earthquake is an event that is felt when a limestone area or mining cave collapses.(Bella Dessy Wulan Sari, et al., 2022)
2. Earthquakes Based on the Depth of the Source: Volcanic Earthquakes, Deep Earthquakes, Intermediate Earthquakes, Shallow Earthquakes(Teguh Prayogo, 2019)

B. Seismic Waves

Seismic wave sources are divided into two categories: body waves and surface waves.

1) Body Wave

Body waves are waves that propagate in all directions throughoutEarth when propagating through elastic materials. Based on the direction of propagation, medium, and particle movement, two types of seismic waves can be distinguished: Primary Waves and Secondary Waves.

2) Surface Waves

Surface waves are waves that propagate on a free surface at low frequencies and high amplitudes. Surface waves are divided into two types based on the nature of particle motion in the medium: Rayleigh waves and Love waves.

C. Liquefaction

Liquefaction is a phenomenon in which the soil loses its strength due to earthquake vibrations, causing the soil layer to liquefy. Liquefaction occurs in loose, sandy, and water-saturated soil. When the soil tends to become liquid, liquefaction occurs, which can endanger the construction of buildings above the surface. Liquefaction can occur due to several influencing factors, including dominant and non-dominant factors.(Hendri Subakti and Windy Renagustiarini, 2022). Some of the dominant factors that can be the source of liquefaction include: Characteristics of Earthquake Vibrations in Tarutung, Soil Type, Ground Water Table, Distribution of Grain Diameter, Relative Density (Initial Relative Density), Drainage and Dimensions(Nurbani, Gea, 2019).

D. Global Geospatial Model (GGM)

Global Geospatial Model (GGM) is a tool that can be used to assess the possibility of liquefaction.

E. Peak Ground Velocity

Peak Ground Velocity (PGV) is the maximum ground velocity value experienced by a location as a result of earthquake vibrations within a certain period of time.(Sarif Hidayat, Kuswaji Dwi Priyono, Jumadi, 2014). The greater the PGV value recorded in an area, the greater the impact of the earthquake that occurred and the greater the possibility of aftershocks in the future. There are two methods for obtaining PGV values, namely from seismograph recordings and by means of an empirical approach.

F. Shear Wave Velocity at Depth of 30 meters (Vs30)

The shear wave velocity (Vs) is the velocity of the wave propagating through the earth in the direction of its propagation, so this velocity can be used to calculate the quality of soil stiffness.(Indra Indra, Rustan Efendi, Abdullah, 2018). The values from the shear wave velocity calculations can be used to determine the soil and rock types in the study area. The classification of soil and rock types can be seen in the table based on SNI 1726-2012:

Site Classification	Vs (m/s)
Hard Rock Rock Hard Soil, Very Dense and Soft Rock Medium Soil	>1500 750 to 1500 350 to 750 175 to 350

Table 1 Classification of soil types SNI -1726-2012

G. Precipitation

The fall of water from the sky to the ground in the form of rain, snow, fog, dew, or hail is known as precipitation. Because rain is the most common type of precipitation in tropical regions, it is often considered precipitation. Rainfall can be measured directly, but this process can only be done at a specific location identified by a rain gauge, not over the entire rainfall area. In a series of hydrological cycles, water vapor condenses and falls to the ground surface (precipitation). Rainfall depth (mm) is usually used to indicate the value of rainfall.(Shelfy Rahma Andi Sofian, 2022)

H. Distance to Body of Water

1) Distance to the Nearest Lake

The distance to the nearest lake is a necessary parameter for calculating the probability of liquefaction. This distance is determined using Google Earth Pro software, which calculates the distance from an area to the nearest river.

2) Distance to the Nearest River

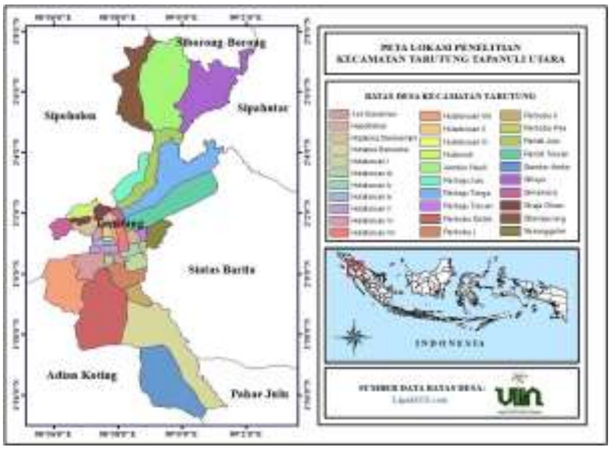
Distance to the Nearest River is a parameter used to complete the elements required to calculate the probability of liquefaction. This distance is determined using Google Earth Pro software, namely by calculating the distance from an area to the nearest beach.

METHOD

1) Time and Location of Research

In carrying out research, the researcher requires research time and research location, namely as follows:

Picture 2 Location map



This research was conducted in the odd semester of the 2025/2026 academic year. It began with a literature study. The research was conducted at Campus IV of UINSU Tuntungan for data processing purposes, with the research test location being Tarutung District, North Tapanuli Regency, North Sumatra Province, with coordinates 1°95'- 2°04' North Latitude and 98°97'- 99°02' East Longitude.

2) Research Tools and Materials
   a) Research Tools: Hardware and software
   b) Research Materials

The data used in this study is secondary data from the acquisition of shear wave velocity values up to an average depth of 30 meters ($Vs30$) through the United States Geological Survey (USGS) with the pagehttps://earthquak3e.usgs.gov/data/vs30/,by selecting the regional value in Tarutung District which has coordinate points of 1°95'- 2°04' North Latitude and 98°97'- 99°02' East Longitude, Peak Ground Velocity (PGV) value obtained from ShakeMap, precipitation data in the form of rainfall data calculated from the last five years (2019-2024), river distance and nearest beach distance measured using Google Earth Pro.

3) Vs30 Value Retrieval on USGS

Vs30 value retrieval is done online via the USGS website. data Vs30 with addresshttps://earthquake.usgs.gov/data/vs30/ .

4) Data processing

The final results of the research were obtained through several stages of data processing such as determining the grid (research points), using the $Vs30$ value previously obtained through USGS to determine the distribution of its values, determining the distribution of Peak Ground Velocity (PGV) values, calculating the distance of the lake and the nearest river from the research point, calculating the precipitation value, determining the distribution of liquefaction potential susceptibility values, and determining the distribution of liquefaction potential probability.

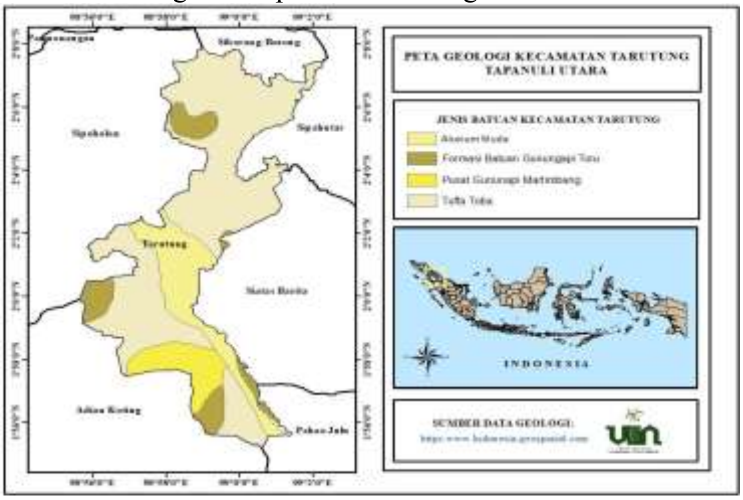
RESULTS AND DISCUSSION

In this study, an analysis of the potential for liquefaction in Tarutung District was conducted using the Global Geospatial Model (GGM) method, by taking into account several parameters that can be factors in the occurrence of liquefaction, such as analyzing the shear wave velocity value up to an average depth of 30 meters, analyzing the Peak Ground Velocity value, calculating precipitation data (average annual rainfall) and calculating the distance to water bodies (nearest lakes and rivers). After that, the liquefaction susceptibility value was obtained which was used to obtain the liquefaction probability value.

A. Geological Conditions of the Research Area

Located at an altitude of 900-1,200 meters above sea level, Tarutung District has very humid air. There are 7 sub-districts and 24 villages in Tarutung District, which consists of 31 villages/sub-districts.
The coordinates of Tarutung District are 1°95'- 2°04' North Latitude and 98°97'- 99°02' East Longitude.This area has an uneven topography and has varying slopes and steepness (Central Statistics Agency, 2016). There are several different geological formations visible in Tarutung District.

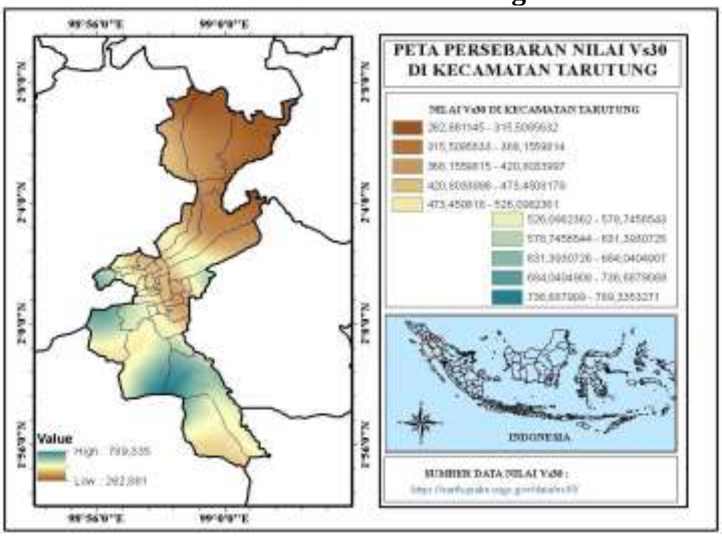
Picture 3 Geological Map of the Tarutung District Research Area



B. Shear Wave Velocity (Vs30)

The shear wave velocity value up to a depth of 30 meters obtained in this study, namely by visiting the open access data link, which can be seen through the USGS slope Vs30. The Vs30 value distribution data was obtained after segmenting the Vs30 value slope distribution in the research area to be studied by obtaining data in the form of a link which will then be processed to see the Vs30 value through mapping in the ArcGis 10.8 application.

Picture 4 Vs 30 Value of Tarutung District

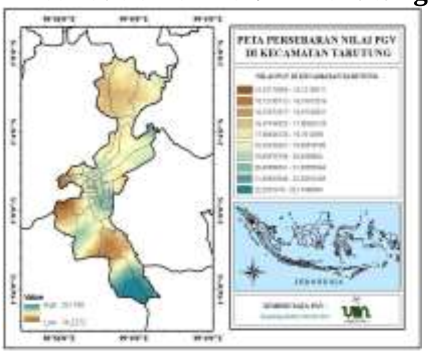


The image shows that the Vs30 value in Tarutung District has a distribution in the range of 262.8 m/s which is in the northern part and covers almost half of the Tarutung District area to 789.3 m/s which is spread in the southwest direction of Tarutung District to several points in the west direction of Tarutung District area. The shear wave velocity value (Vs30) in Tarutung District is dominated by a range of values of 262.8 m/s to 578.7 m/s marked by dark brown to cream colors that almost cover the entire Tarutung District area. The Vs30 results in the northern part of Tarutung District show that the area is dominated by medium and very dense soil or soft rocks that have geological formations in the form of Samosir formation deposits, consisting of Toba tuffa, Toru volcanic rock formations, and Martimbang volcanic centers and young alluvium consisting of loose clay, silt, sand, or gravel that has been deposited with water through riverbed flow, in flood plains, in alluvial fans, so that these types of rocks can allow liquefaction events to occur.

C. Peak Ground Velocity (PGV)

The PGV values obtained in this study were processed using ShakeMap software, which is to obtain the distribution of PGV in the study area. To obtain the distribution of PGV values with ShakeMap software, earthquake parameters are required as input, including the coordinates of the earthquake epicenter, depth, earthquake magnitude, and time of occurrence (year, month, date, hour, minute, and second). Next, processing is carried out to obtain a model of the distribution of earthquake impacts. The output of this processing is the distribution of PGA, PGV, Pseudo-Acceleration, PGA uncertainty ratio, and also a list of stations. This study used an earthquake scenario from the Toru segment of the Sumatran fault, which is based on research by the National Earthquake Center, Toru has the greatest potential for an earthquake of M7.4. The earthquake scenario was carried out in the central region of the Toru segment of the Sumatran fault, with a depth of 10 km with a latitude of 1.61 N and longitude of 99.24 E.

Picture 5 Distribution of PGV in Tarutung District



In this study, the earthquake scenario used on the Toru segment of the Sumatran fault shows that the distribution values obtained are dominated by values in the range of 14.22 cm/s to 19.59 cm/s, covering almost the entire northern region. Furthermore, the distribution values obtained in the range of 22.28 cm/s to 23.17 cm/s indicate that the northeastern, southern, and southwestern regions of Tarutung District have high distribution values.

D. Distance to Body of Water

Distance to the Nearest Lake

The distance from the research location to the water source is one of several factors considered to be a potential cause of liquefaction in an area. The research location in this case, Tarutung District, is adjacent to Lake Toba, the largest volcanic lake in Indonesia, located not far north of Tarutung District.

Distance to the Nearest River

The presence of rivers influences the potential for liquefaction in an area. Furthermore, the presence of rivers is also related to the volume of the groundwater table. The relationship between depth and volume of the groundwater table is directly proportional to the level of liquefaction potential. A high (shallow) groundwater table is more dangerous and has a higher potential for liquefaction disasters during earthquakes. Furthermore, the volume of the groundwater table will influence the area that is potentially liquefied.

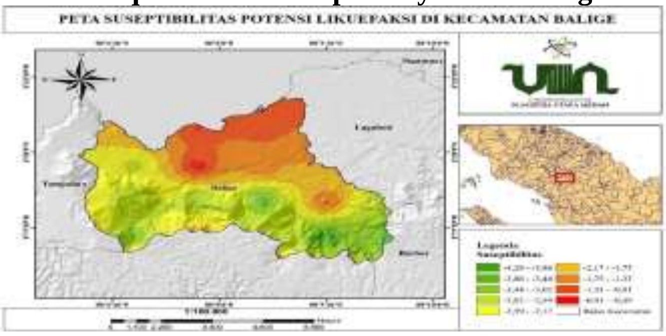
E. Precipitation

In this study, average rainfall data was obtained from NASA's GEOVANI website. The data obtained was the average annual rainfall data, taken over the last five years (2020-2024). The rainfall received in each area in Tarutung District shows that the range of values obtained ranges from 4,900 millimeters/year to 6,348 millimeters/year. Zhu (2017) stated that the average annual rainfall value that is classified as high is more than 1,200 millimeters/year.

F. Liquefaction Susceptibility

Susceptibility or vulnerability is a condition of geological, hydrological, and geographical characteristics of an area that can reduce the level of ability to prevent, the ability to mitigate a disaster that has the potential to occur. In this case, it can be interpreted that liquefaction susceptibility is the level of vulnerability of an area to the potential for liquefaction disasters, areas that are said to be vulnerable to liquefaction disasters mean that the area is an area that is influenced by factors that cause or support liquefaction to occur. In this study, several factors that can influence the potential for liquefaction disasters to occur include the average velocity of shear waves to a depth of 30 meters (Vs30), the highest ground vibration velocity (PGV), precipitation, and the distance of the body of water (distance to the lake and the distance to the nearest river). All these parameters will then be calculated using equation (2.10), to obtain the results of the susceptibility or liquefaction vulnerability value in the research area.

Picture 6 Liquefaction Susceptibility of Tarutung District

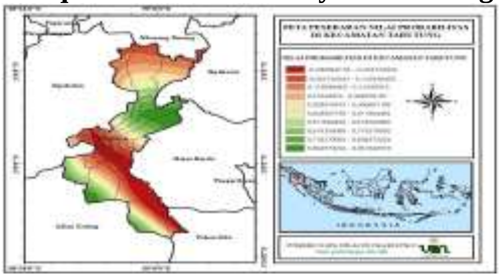


In the earthquake scenario carried out, the Toru segment of the Sumatran fault had the worst earthquake strength at M7.4 and produced the highest PGV value at 15.20 cm/s. Using other parameters, the susceptibility value was calculated. For the PGV scenario of the Toru segment earthquake, the liquefaction susceptibility value in Tarutung District varied, in the range of valuesbetween -4.28up to the value-0.49.The lowest susceptibility value is at the bottom of the east direction to the bottom of the south direction.south and westTarutung District, which is marked by areas colored green to yellow, has a variety of values with the lowest value being-4.28.Meanwhile, the area with the highest liquefaction susceptibility value is invalue -0.49, seen in areas that haveorange to red, with a value of -2.17up to the value-0.49, is in the areatop of the north, and a small area in the direction ofsouth and westTarutung District. It can be concluded that the liquefaction susceptibility value is dominated by the area with the highest distribution value, namely the northern part of Tarutung District.

A. Liquefaction Probability

Probability is a value that indicates the level of likelihood of an event occurring in an experiment. In this study, the probability of liquefaction can be interpreted as a value that can indicate how likely liquefaction is to occur under certain conditions based on predetermined parameters. The range of probability values is between 0 and 1, where if the probability value is 0, the possibility of a liquefaction disaster will not occur, and if the probability value is 1, the possibility of a liquefaction disaster will definitely occur. This means that if the probability value approaches 1, the possibility of occurrence will be higher. Conversely, if the probability value approaches 0, the possibility of occurrence will be low. The probability of liquefaction according to Zhu (2014) is calculated by Equation (2.5) with a logistic regression function that produces probability values within a spatial area. The probability function in this study depends on the susceptibility value proposed by Zhu (2017), namely using equation (2.10). Based on the PGV scenario, the Toru segment of the Sumatran fault earthquake produces susceptibility values with a range of-4.28 to -0.49.Based on the susceptibility values obtained, the liquefaction probability values were generated in Tarutung District with a value range between 0.024 and 0.961.

Picture 7 Liquefaction Probability in Tarutung District



shows the results of the distribution of liquefaction probability values in Tarutung District. The areas with the highest probability values are in the northeast and southwest of Tarutung District, while the areas with the lowest probability values are in the northern, southeast and western parts of Tarutung District. The areas with the lowest distribution of liquefaction probability values are marked with red to yellow on the map, with a value range of 0.024 to 0.408, while the areas with a high distribution of probability values are in the light green to dark green areas on the map, which are in the northeast and southwest of Tarutung District, with a value range of 0.408 to 0.961.

Discussion

The probability of liquefaction in this study was determined using Zhu's probability model by performing logistic regression on the susceptibility values. Based on Equation (2.6), liquefaction susceptibility is influenced by supporting parameters that influence the potential for liquefaction. In their study, Zhu et al. (2017) used a model called the Global Geospatial Model with two equation functions distinguished by the type of area. The equation is influenced by parameters such as Vs30, PGV, precipitation, distance to the lake, and distance to the nearest river. Based on the distribution of the probability of liquefaction potential in Tarutung District, it can be seen that the area has the possibility of liquefaction in the northeast and southwest of Tarutung District. A similar thing is also shown in the distribution of liquefaction potential susceptibility which has the same value based on the distribution results obtained, that the area in the northeast and southwest of Tarutung District is prone to liquefaction.northTarutung District has the most potentialtallfor liquefaction to occur.These results are also supported by the PGV value obtained from modeling the worst earthquake scenario that could occur on the Toru segment of the Sumatran fault, that the southwestern and western regions...southhas a fairly high value based on Figure 4.2, the distribution map of PGV values in Tarutung District. The average shear wave velocity up to a depth of 30 meters (Vs30) is also a strong factor among several other factors that dominate the liquefaction potential in the southwestern region of Tarutung District, which has a high potential value compared to other regions in the area.

From the results of the Vs30 distribution in Figure 4.1, it shows that the northeastern region has a low average shear wave velocity value up to a depth of 30 meters, as stated at the beginning that when the Vs30 value is low, the potential for liquefaction can occur high, and vice versa. Another parameter that is considered to have an influence on the potential for liquefaction is the distance of the body of water. In this study, the thing that was taken into account was the distance of the lake in the north to the northeast.Tarutung District is home to Lake Toba, the largest volcanic lake in Indonesia, and the nearest river in Tarutung District is the Aek Sigeaon River, which flows from the north and northeast to the south. It can be concluded that the northeastern region should have a high susceptibility value because the area is quite close to the lake. This statement can be said to be supported, because it is seen from the results of the research conducted in this study that areas that are close to the lake and also with the presence of rivers, located in the northeastern region, are areas with the highest distribution of potential liquefaction.

CONCLUSION

Based on the results of the research and also previous discussions regarding the potential for liquefaction in Tarutung District, it can be concluded that the Vs30 value in Tarutung District has a distribution in the range of 255 m / s which is in the north to the northeast and covers almost half of the Tarutung District area with a classification of medium soil type, very dense soil or soft rock, up to 897.8 m / s which is spread in the lower southwest direction of Tarutung District to several points to the southeast of the Tarutung District area with a classification of very dense soil type or soft rock and rock. The PGV value in Tarutung District is based on the worst-case earthquake scenario in the Toru segment of the Sumatran fault, which varies in the range of 7.94 cm/s to 15.20 cm/s. The potential for liquefaction in Tarutung District based on the Global Geospatial Model has various values. The lowest percentage probability of liquefaction is 0.024, which is in the north, southeast, and northwest of Tarutung District, and the

highest percentage probability is 0.961, which is in the northeast and southwest of Tarutung District. The probability value range is between 0 and 1, where if the probability value is 0, the possibility of a liquefaction disaster will not occur, and if it is 1, the possibility of a liquefaction disaster will definitely occur. This means that if the probability value is close to 1, the possibility of it happening will be higher. Conversely, if the probability value is close to 0, the possibility of it happening will be low. Based on the research that has been conducted, there are several suggestions that can be used as input, namely as follows:
The Global Geospatial Model method can be used for initial prediction purposes in analyzing liquefaction potential in other areas. The parameters used in this study were secondary data, such as the average shear wave velocity at a depth of 30 meters (Vs30). In further research, it is recommended to use field observations to support data validation.

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