Journal of Current Research in Disaster Response and Emergency Management
e-ISSN: xxxx-xxx
Vol. 1, No. 1, p. 27-36, 2024
Journal Homepage: https://ejournal.hakhara-institute.com/index.php/DREM

| RESEARCH ARTICLE

Seismic Risk Reduction in South Sulawesi Province Using Geostate V2.0 Software

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| ABSTRACT
In South Sulawesi Province there is the Walanae Fault, which causes this area to often experience natural phenomena of earthquakes. This study aims to reduce the risk of earthquakes in South Sulawesi Province by knowing the estimation of shocks from the shakemap scenario model. The method used in this research is the Gutenberg Richter Method through a statistical approach. This study uses IRIS earthquake data in the South Sulawesi region in 1990 - 2020. The research location is in South Sulawesi Province by dividing the area into two segments, namely the northern segment and the southern segment. This study uses earthquake parameters with a magnitude > 1 and a depth of < 50 km. The results of the analysis show that the potential for earthquakes in the next 10 years with a magnitude of M = 7 in the northern segment is estimated at 100% with an estimated VII-VIII MMI shock level around Soppeng, Bone and Barru Regencies. The results of the estimation of shocks and the percentage of potential earthquake risk can be used as steps to carry out mitigation in order to reduce the risk of earthquakes in the area.

| KEYWORDS
Earthquake Risk; Seismic Risk Reduction; MMI.

INTRODUCTION

The island of Sulawesi is located in a complex tectonic setting by being on the collision course of major tectonic plates such as the Indian-Australian Plate in the south, the Pacific Plate in the east and the Eurasian Plate in the west. The tectonic history of Sulawesi Island is identified as the location of the collision that occurred between Sundaland and the Australian block plane (Hamilton, 1979; Yuwono et al., 1988; Coffield et al., 1993; Priadi et al., 1994; Bergman et al., 1996; Elburg and Foden, 1999; Hall and Wilson, 2000; Hall, 2002; Jaya et al., 2017) resulting in the formation of large-scale strike-slip fault lines, active thrust faults, local extensions (Bergman et al, 1996; Cipta et al, 2017). There are many active faults on the island of Sulawesi that are capable of providing potential as earthquake sources, such as the Palu Koro Fault in Central Sulawesi, the Gorontalo Fault in North Sulawesi, the Lawanopo Fault and the Kolaka Fault in the southeast and the Matano Fault and Balantak Fault in the eastern arm. Thrust faults such as the North Sulawesi mega thrust, Sangihe and Batui thrust faults in the east, thrust faults in the southeast of Makassar and thrust fault majene in southwest Sulawesi. Several thrust faults related to the subduction plate such as in the North Sulawesi section and the double subduction in Maluku are controlled on the Sangihe fault line and some even collide to form a strike slip fault at the northwest end of the Palu Koro Fault as shown in **Figure 1.**

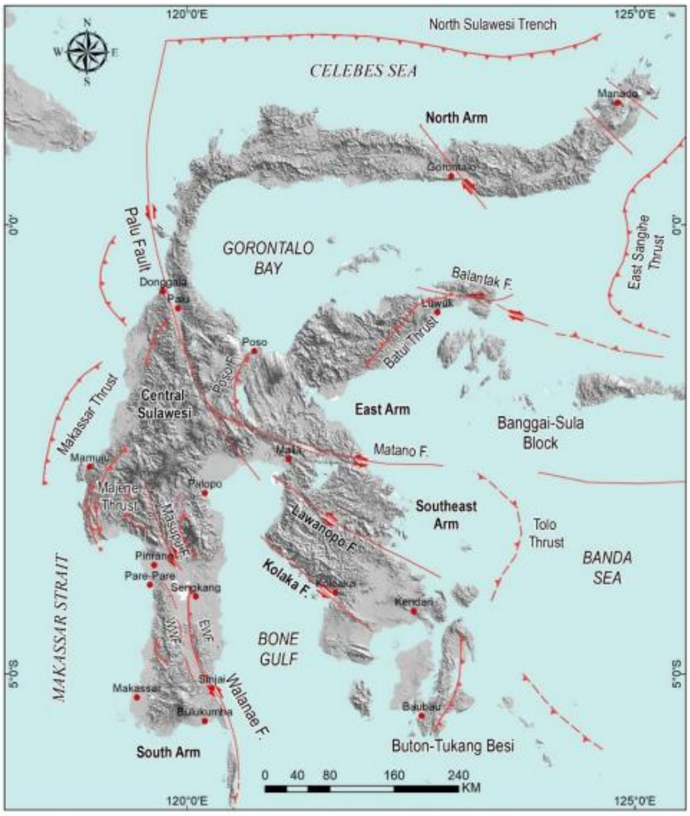


Figure 1. Sulawesi Tectonic Structure (Jaya et al., 2020)

The diversity of active faults in this region is associated with fairly intense earthquake activity in this region, both from active faults on the surface and in the slab plane (Cipta et al., 2017). Sulawesi tectonic structure has a moderate to high slip rate category. This has the potential to produce a large earthquake with a magnitude of M6-M8 for the fault plane and M>8 for the slab plane (Cipta et al., 2017; Irsyam et al., 2010; PuSGeN, 2017). In addition, the MMI scale that can be generated based on the calculation of the 500-year return period is able to reach V-IX MMI and almost all faults in the Sulawesi region are in lowlands with sedimentary segments so that there is a high potential for liquefaction to occur (Cipta et al., 2017).

Seismic studies and earthquake risk analysis are a form of earthquake prediction analysis study through observing earthquake phenomena seen from the parameters obtained as a benchmark for earthquake activity in an area. After knowing the level of earthquake risk, it is continued by mapping the shock level scenario as a form of worst scenario modeling to find out how big the level of shock and damage is from the resulting earthquake parameters. Identification and calculation of the level of risk of potentially damaging earthquakes in the future, of course, requires more intensive follow-up from public stakeholders as an effort to be prepared and at the same time mitigate earthquake disasters in order to minimize the impact of earthquakes and reducing seismic risk.

The Walanae Fault is a fault with a length of up to 130 km that stretches in the southern Sulawesi Province (Cipta et al., 2017; Van Leeuwen, 1981; Sukamto, 1975; Berry and Grady, 1987; Van Leeuwen et al., 2010; Jaya and Nihshikawa, 2013). The tectonic structure of the Walanae Fault is divided into two parts, namely the eastern Walanae Fault and the West Walanae Fault (Van Leeuwen, 1981; Sukamto, 1975). The process of Fault Formation in the West Walanae Fault is included in the sedimentary rock formations in the West to East Sengkang Basin (Tempe and Walanae depression). The eastern Walanae fault line crosses the eastern sedimentary rock of the Sengkang basin so that it can be seen that the age of the rocks in the eastern Walanae fault is younger than the western Walanae fault (Van Leeuwen, 1981; Van Leeuwen et al., 2010; Jaya and Nihshikawa, 2013; Grainge and Davies, 1985).

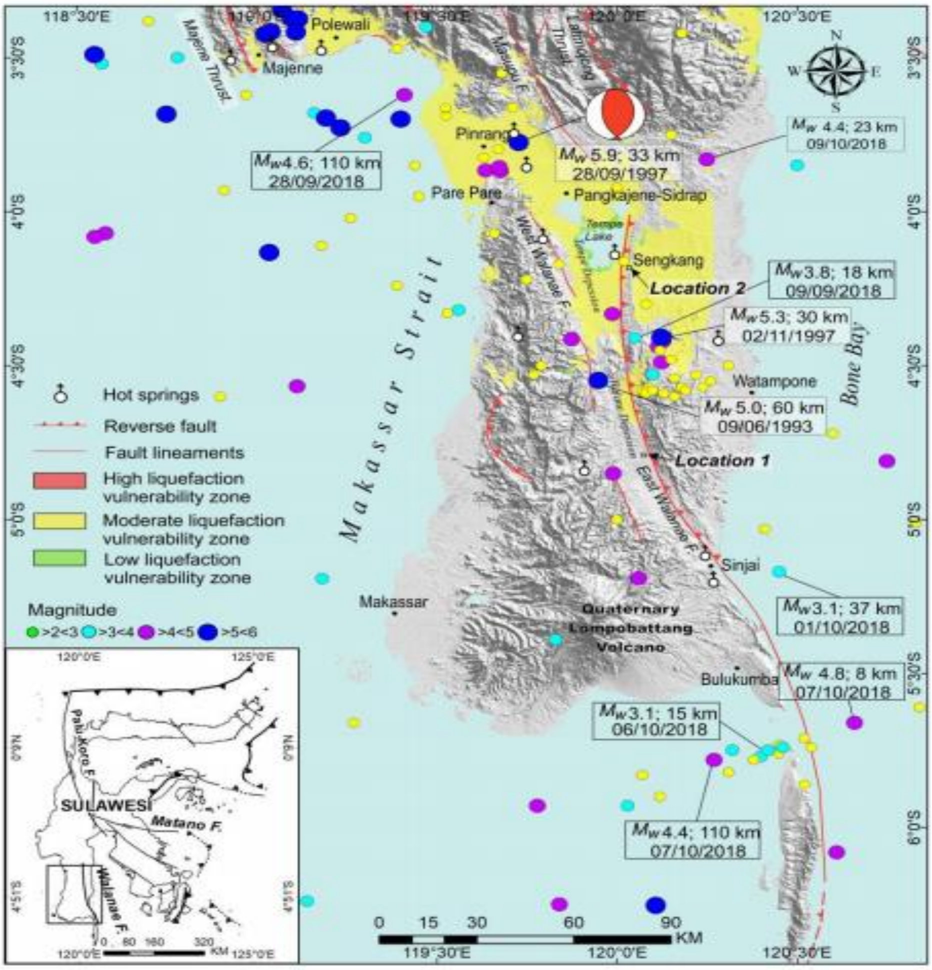


Figure 2. Tectonic Structure of South Sulawesi and Distribution of Earthquakes Around the Walanae Fault (Jaya et al., 2020)

METHODS

In this study, the authors used earthquake data from The Incorporated Research Institutions for Seismology (IRIS) in the South Sulawesi region from 1990 to 2020 with magnitude M>1 and depth (D < 50 km). The research coordinates are at 3.5° – 5.5° south latitude and 119.5° – 120.5° east longitude. The research location is divided into two parts, namely the northern part with coordinates 3.5° – 4.5° south latitude and 119.5° – 120.5° east longitude and the southern part with coordinates 4.5° – 5.5° south latitude and 119.5° – 120.5 ° East Longitude. Approach The method used in this study is the likelihood approach contained in the GEOSTAT V2.0 software. In general, there are several stages carried out in the analysis of this research:

a. Search earthquake data through the IRIS earthquake catalog;
b. Calculating the frequency of earthquakes at the study site;
c. Determine the *a-value*, *b-value*, seismicity index, earthquake return period and earthquake risk level using GEOSTAT V2.0 Software;
d. Create an earthquake shock level scenario map using the BMKG Shakemap application;
e. Determine the estimated shock level.

An earthquake is a rock deformation process due to a shift in rock that causes a sudden release of energy so that it can trigger shaking of the ground surface. At the meeting place of the tectonic plates will trigger the stress caused by the shift or collision of tectonic plates. Voltage will occur continuously and accumulated from the voltage will be released energy. The mechanism of earthquakes is explained in the Elastic Rebound Theory (Lay and Wallace, 1995).

Table 1. Types of Magnitude.

No.	Name	Means
1	Magnitude Local	Local area, $Ts \pm 1$, Wave length 0.3 -6 km, R < 1000 km
2	Magnitude Surface	Surface Wave, R> 1000 km, wave length 60 km, $s \pm 20\ second$
3	Magnitude Body	Deep Earthquake, $T\ wave : 1 - 3\ secon$
4	Magnitude Moment	Calculated from released energy

Earthquake magnitude is a measure of the earthquake that is presented in the form of numbers calculated based on the magnitude of the earthquake wave amplitude (Lay and Wallace, 1995). There are types of earthquake magnitude (Prawirodikromo, 2012). Rohadi et al. (2008) explain how to analyze earthquake activity in an area for mitigation steps, one of which is by analyzing the relationship of Frequency Magnitude Distribution (FMD). The frequency-magnitude distribution (FMD) of earthquakes was proposed by Ishimoto and Lida (1939) and Gutenberg and Richer (1964). The general equation for analyzing the relationship between magnitude and frequency is based on the empirical formula derived by B. Gutenberg Ritcher and C. F. Ritcher:

$$\log_{10} N(M) = a - bM$$

Bilim (2019), *N* is the frequency of seismic activity and *M* is the magnitude, while *a* and *b* are constants. The constant *a* describes earthquake activity in a certain area which is influenced by the research area, the research period and the level of seismic activity in an area. The constant *b* describes the tectonic parameters of a research area. Utsu (1974) explains that *b-value* can be found through the maximum likelihood equation.

$$b = \frac{\log e}{\overline{M} - M_0}$$

With $\log e$ of 0.4343, $\overline{M}$ is the average Magnitude dan M_0 merupakan Minimum Magnitude.

Lusiani et al.. (2018) explain that Seismicity index is *a value* that describes the overall accumulation of earthquake activity that occurred in a certain time and area. The value of the seismicity index can be obtained from the equation:

$$N1(M \geq M_0) = 10^{(a - \log(b \ln 10) - \log \Delta t) - bM_0}$$

With $N1(M \geq M_0)$ is the seismicity index for $M \geq M_0$, a and *b* is a constant of the relationship between frequency and magnitude, *M* is the upper limit of the tested magnitude, M_0 is the lower limit of the tested magnitude and Δt is the observation time interval.

Earthquake return period is the possibility that an earthquake with a certain magnitude in a certain area will repeat itself in a certain time span. Earthquake return period calculations require earthquake data for at least one period. The short time span when obtaining data is very difficult to use as a reference to ensure good seismic activity in the area (Ibrahim and Subardjo, 2005). Lusiani et al. (2018) explained that to obtain the price of the earthquake return period, it can be calculated by the following equation:

$$\theta(M \geq M_0) = \frac{1}{N1(M \geq M_0)}$$

With $\theta(M \geq M_0)$ is the earthquake return period and $N1(M \geq M_0)$ is the seismicity indeks.

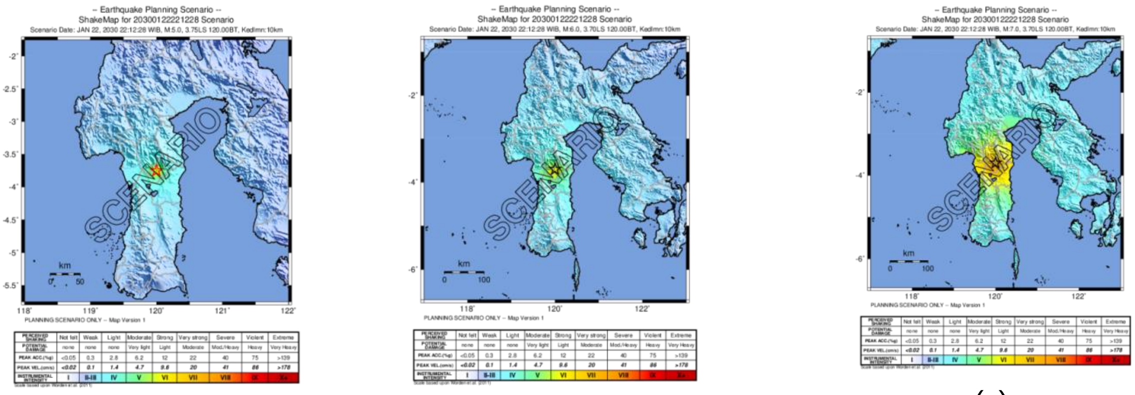
Earthquake risk is a bad impact that can occur due to an earthquake in a certain area and time frame (Prawirodikromo, 2012). Earthquake risk values can be obtained by calculating the following equation (Lusiani et al., 2018)

$$P(M \geq M_0, T) = 1 - e^{-N1(M \geq M_0, T)}$$

$N1(M \geq M_0, T)$ adalah indeks seismisitas, T is the observation time span and $P(M \geq M_0, T)$ is the level of risk of an earthquake with a certain magnitude and time.

A shake map is a map that represents the level of ground shaking, the response of people, damage to buildings and the environment above the ground due to an earthquake. Information on the level of shock, damage and the response of people due to earthquakes tends to decrease with distance from the epicenter of the earthquake that occurred (Sucuoğlu dan Akkar, 2014).

RESULT AND DISCUSSION



(a) (b) (c)

Figure 3. Shakemap Scenario of The Northern Segment Of South Sulawesi With (a) M5, (b) M6 and (c) M7.

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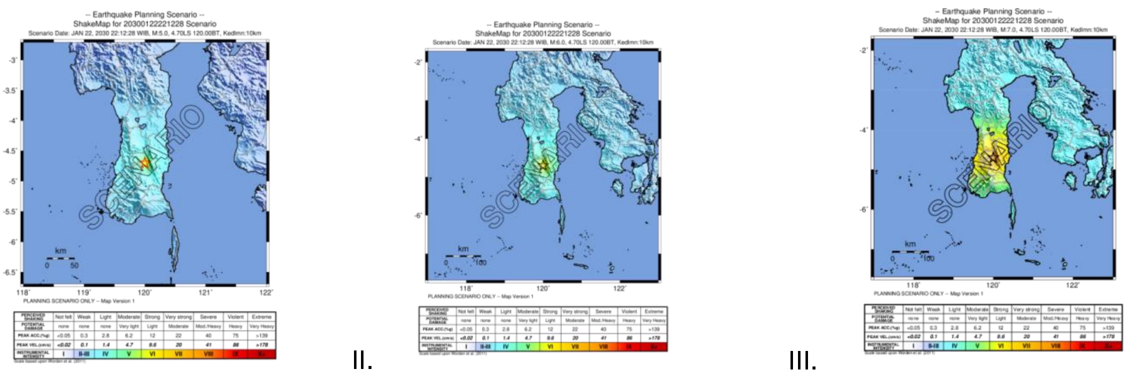
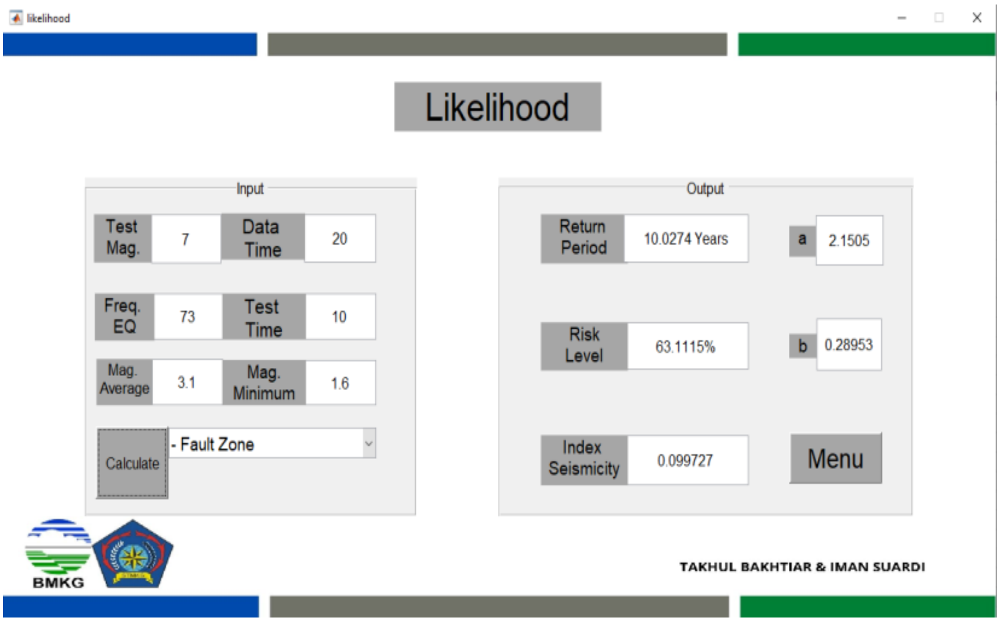


(a) (b) (c)

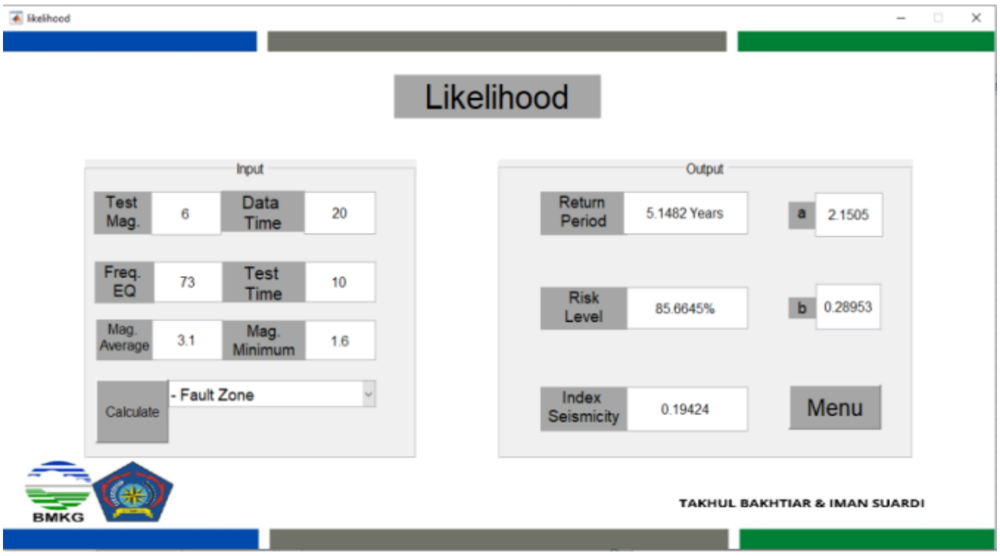
Figure 4. Shakemap Scenario of The Southern Segment Of South Sulawesi With (a) M5, (b) M6 and (c) M7

In **Figure 3**, it can be seen a scenario map of the level of shock in the northern segment of South Sulawesi with magnitudes M5, M6 and M7, respectively. On the M5 magnitude shock level scenario map, it can be seen that the largest estimated shock level was recorded on the III-IV MMI scale around Enrekang Regency, Luwu Regency, Pinrang Regency, Sidrap Regency,Pare-Pare City. Meanwhile, the smallest estimated shock level on the MMI II-III scale is known to be around Maros Regency, Gowa Regency, Sinjai Regency, Makassar City, Bone Regency and Bulukumba Regency. On the M6 magnitude shakemap scenario, it can be seen that the largest estimated shock level was recorded on the V-VI MMI scale around Soppeng Regency, Enrekang Regency, Luwu Regency, Bone Regency, Barru Regency and Bulukumba Regency, Pinrang Regency, Sidrap Regency and Pare-Pare City. Meanwhile, the smallest estimated shock level on the MMI III-IV scale is known to be around Maros Regency, Gowa Regency, Sinjai Regency, Makassar City. On the M7 magnitude shakemap scenario, it can be seen that the largest estimated shock level was recorded on a MMI VII-VIII scale around Enrekang Regency, Luwu Regency, Pinrang Regency, Sidrap Regency, Pare-Pare Regency. Meanwhile, the estimation of the smallest shock level on the MMI III-IV scale is known to be around Maros Regency, Gowa Regency, Sinjai Regency, Makasar City, Bone Regency and Bulukumba Regency.

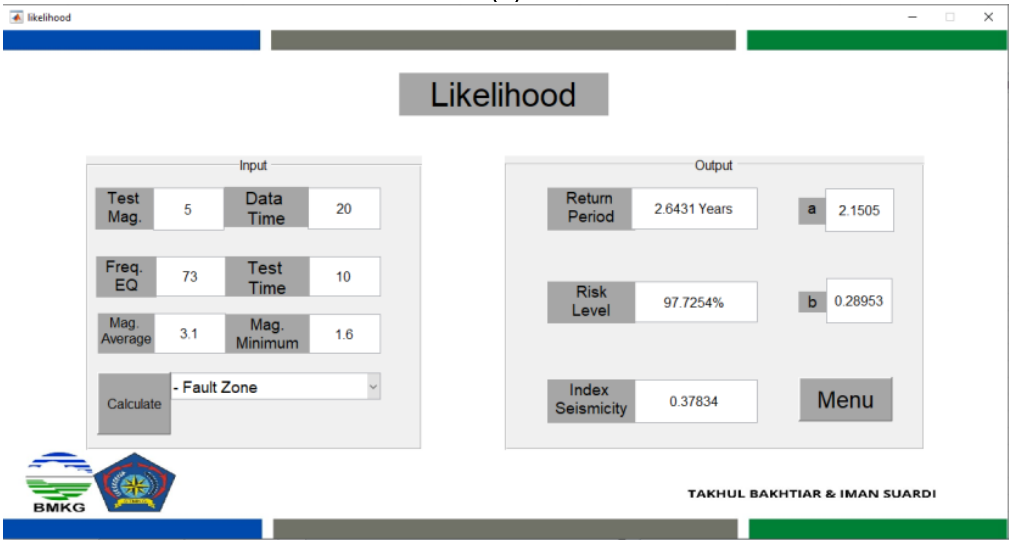
Figure 4 shows a shakemap scenario in the southern segment of South Sulawesi with magnitudes M5, M6 and M7, respectively. On the M5 magnitude shock level scenario map, it can be seen that the largest estimated shock level was recorded on the III-IVMMI scale around Sopreng Regency, Bone Regency, Barru Regency, Wajo Regency, Maros Regency, Pare-Pare City. Meanwhile, the smallest estimated shock level was recorded on a MMI II-III scale around Luwu Regency, Enrekang Regency, Tana Toaja Regency, Sidrap Regency. On the M6 magnitude shakemap scenario, it can be seen that the largest estimated shock level was recorded on the V-VI MMI scale around Sopreng Regency, Bone Regency, Barru Regency, Wajo Regency, Maros Regency, Pare-Pare City and Makassar City. on a scale III-IV MMI around Luwu Regency, Enrekang Regency, Tana Toraja Regency, Sidrap Regency. On the M7 magnitude shakemap scenario, it can be seen that the largest estimated shock level was recorded on a MMI VII-VIII scale around Sopreng Regency, Bone Regency, Barru Regency, Wajo Regency, Maros Regency, Pare-Pare City and Makassar City. on an IV-V MMI scale around Luwu Regency, Enrekang Regency, Tana Toraja Regency, Sidrap Regency.



(a)

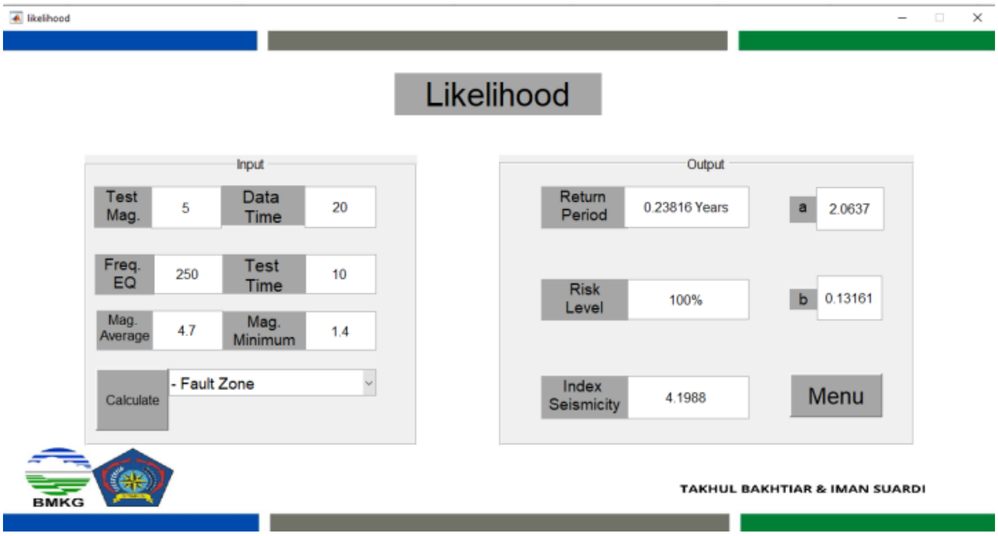


(b)

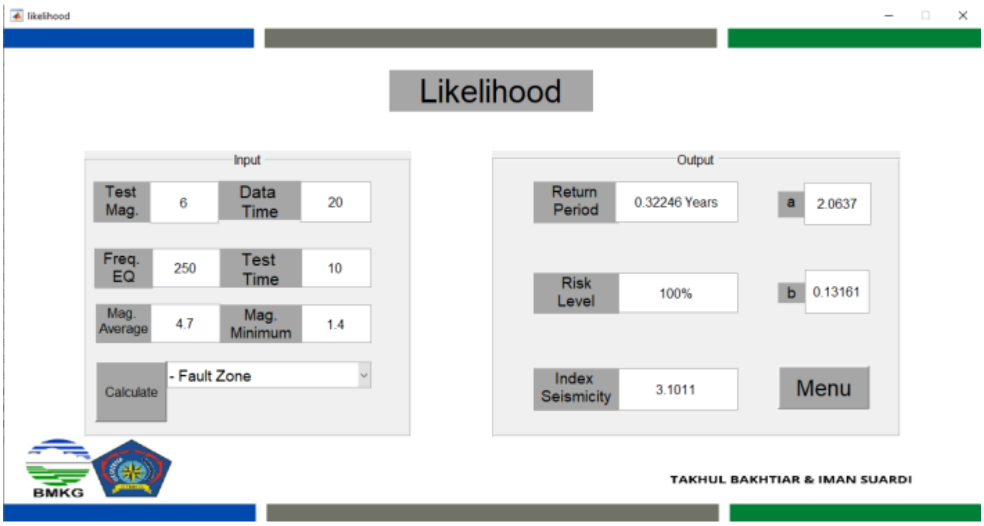


(c)

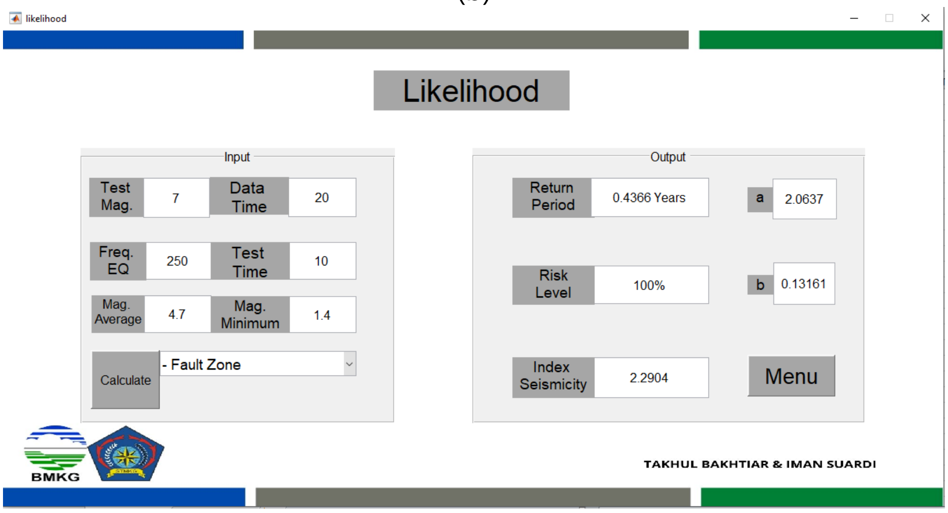
Figure 5. Calculation Results in the Southern Segment of South Sulawesi with M7 (a), M6 (b) and M5 (c)



(a)



(b)



(c)

Figure 6. Calculation Results in the Northern Segment of South Sulawesi with M5 (a), M6 (b) and M7 (c)

In the **Figure 5** and **Figure 6**, it can be seen that in the southern segment, three calculation tests have been carried out with Magnitude M5, M6 and M7 with the same test period for the next 10 years. Based on the results of the M5 calculation test, the results obtained with an *a-value* of 2.1505, a *b-value* of 0.28953, a return period of 2.6431 years, a seismicity index of 0.37734 and a risk level within the next 10 years reaching 97.7254%. Based on the results of the M6 calculation test, the results obtained with an *a-value* of 2.1505, *b-value* of 0.28953, a return period of 5.1482 years, a seismicity index of 0.19424 and a risk level within the next 10 years reaching 85,6645%. Based on the results of the M7 calculation test, the results obtained with an *a-value* 2.1505, *b-value* 0.28953, a return period of 10.0274 years, a seismicity index of 0.0099727 and a risk level within the next 10 years reaching 63.1115%.

Whereas in the northern segment, based on the results of the M5 calculation test, the results obtained with an *a-value* 2.1505, *b-value* 0.28953, a return period of 0.23816 years, a seismicity index of 4.1988 and a risk level within the next 10 years reaching 100%. Based on the results of the M6 calculation test, the results obtained with an *a-value* 2.1505,*b-value* 0.28953, a return period of 0.32246 years, a seismicity index of 3.1011 and a risk level within the next 10 years reaching 100%. Based on the results of the M7 calculation test, the results obtained with *a-value* 2.1505,*b-value* 0.28953, a return period of 0.4366 years, a seismicity index of 2.2904 and a risk level within the next 10 years reaching 100%.

It can be seen that in the northern segment of South Sulawesi, the return period when an earthquake with a magnitude of M5 occurs is shorter than the southern segment. This means that the chance of an earthquake with a magnitude of M5 in the north will occur again in a short period of time, namely 0.23816 years. Then, when viewed from the seismicity index, the northern segment has a higher index than the southern segment. This shows that the incidence of earthquakes in one year in the northern segment can reach four times a year with a magnitude of M5. In addition, the level of earthquake risk in the northern segment within a period of 10 years is higher than in the southern segment. So it can be seen that the northern segment of South Sulawesi has the potential for a higher level of earthquake risk when compared to the southern segment in the next 10 years.

CONCLUSION

The potential for earthquakes within the next 10 years in the northern segment of the earthquake has a higher risk level than the southern segment. Then, if the potential for an earthquake in the northern segment is made, a scenario model can be found to estimate the largest shock level with a magnitude of M7 recorded on the VII-VIII MMI scale. This scale gives an idea of the area where many people leave their homes and there is minor damage to buildings that have strong construction. The highest level of shock intensity occurred in locations close to the earthquake source, while the lowest level of shock intensity occurred at locations far from the earthquake source. Estimation of earthquake shocks and the percentage of earthquake risk in the future which are known to be useful as measures for mitigation and earthquake risk reduction.

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