Prediction model to predict the number of damaged houses due to earthquake

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Abstract. The earthquakes can cause serious disruption to the functioning of a community, and can cause physical damage, including damage to houses and the environment. The number of damaged houses by the earthquake needs to be predicted well, so the disaster management activities can be carried out properly as well. This research performs calculations to predict the number of damaged houses by the earthquake, using RADIUS. The results obtained from the prediction model in this study still provide a high error value, which is 71.9%. This means that the output of the prediction model in this research is not accurate enough to predict the number of damaged houses by the earthquake in Indonesia. However, the prediction model in this research is presented in a mathematical model and has clearly shown the relationship between the input and output variables. So that it is easy to understand and can be developed in further research more easily. The prediction model for the number of damaged houses in this research can then be developed into an estimation model for the relief items needed by the internally displaced persons (IDPs). After predicting the number of damaged houses, the process of estimating the number of IDPs then can be carried out, if the estimated number of IDPs is known, then an estimate of the relief items needed by the IDPs can be calculated well.

Keywords: Prediction model, Damaged houses, Earthquake

1. Introduction
Indonesia occupies a very active tectonic zone because the world's three large plates and nine other smaller plates meet each other in Indonesian territory. The existence of the interaction between these plates places the territory of Indonesia as an area that is very risky for earthquakes [1]. The 2009 Global Assessment Report on Disaster Risk Reduction [2], coordinated by UNIDSR (United Nations-International Strategy for Disaster Reduction), states that Indonesia has a risk value of 10 for earthquakes, while floods have a value of 5, and landslides have a value of 3. This is reinforced by data compiled by BNPB, disaster statistics in Indonesia since 1815-2019 show that earthquakes are a disaster with the most victims, although the frequency of events does not occur very often.

According to Chen [3], an earthquake disaster can cause serious disruption to the functioning of a society, causing a widespread impact on human life from a material, socio-economic perspective, causing death and injury, and causing physical damage, including damage to houses and the environment. Several major earthquake activities have been recorded in Indonesia, namely the Aceh earthquake accompanied by the tsunami in 2004 with a magnitude M = 9.2; The 2005 Nias earthquake with a magnitude M = 8.7; Yogyakarta earthquake in 2006 with a magnitude M = 6.3; The 2009 Tasik earthquake with a magnitude M = 7.4; and finally the Padang Earthquake in 2009 with a magnitude M
= 7.6. These earthquakes have caused thousands of casualties, collapsed and damaged thousands of infrastructure and buildings, as well as billions of rupiah in funds for rehabilitation and reconstruction.

The number of damaged houses by the earthquake needs to be predicted well immediately after the earthquake occurs, so that disaster management activities can be carried out better. For example, it can determine the number of temporary shelters needed by internally displaced persons (IDPs) better and faster, so we can immediately prepare a more comfortable shelter for IDPs. There have been several previous researchers who have focused on predicting building damage that occurs due to earthquakes. These researchers include Yüce men et al [4], Cinicioglu et al [5], Bird et al [6], Choun and Elnashai [7], and Lagomarsino and Giovinazzi [8].

One of the methods that can be used to predict the number of damaged houses by an earthquake is the RADIUS (Risk Assessment Tool for the Diagnosis of Urban Areas against Seismic Disasters) which was developed by Okazaki [9]. According to Darpito [10], the Radius program is the most feasible program to be implemented in Indonesia, considering that in developing countries, such as Indonesia, it is sometimes difficult to find the accurate data.

This research conducted the calculations to predict the number of damaged houses by the earthquake using RADIUS. The prediction model in this research is shown in a mathematical model, so the relationship between the input and output parameters can be seen clearly and also easy to understand.

2. Methods

2.1. RADIUS

RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters) is a program that can be used to predict earthquake risk. The development of RADIUS is funded by the International Decade for Natural Disaster Reduction. Radius is a project undertaken in 1996 with the aim of predicting the risk of earthquakes in urban areas, especially in developing countries. The data that must be inputted into the Radius program are as follows:

- the shape of the target area for observation;
- total population;
- the total number of buildings, as well as the types and distribution of buildings;
- the total number of facilities that ensure the continuity of life (options);
- select earthquake scenario and input parameters.

If some of the required data is not found, the missing data estimated according to the available data. Then the Radius Program validated the input data and carry out the analysis process. The output of the Radius program includes:

- seismic intensity (ground shaking), such as PGA (Peak Ground Acceleration) and MMI (Mercalli Modify Intensity);
- damage to buildings;
- damage to facilities that guarantee the continuity of life;
- the number of victims who died and suffered injuries;
- tables and thematic maps containing a summary of the analysis results.

In this paper, RADIUS only used to predict the number of houses damaged by the earthquake. The calculation process carried out to predict the number of damaged houses in this research was carried out in two stages, as shown in figure 1.

The two stages are as follows:

- Stage 1 is a calculation to predict the earthquake intensity, which consists of calculating the PGA and MMI. The data required at this stage is earthquake magnitude (G), earthquake depth (D), and earthquake's epicentre (E).
- Stage 2 is calculations to predict the number of houses damaged by the earthquake. The prediction of damaged houses was carried out for three types of houses, namely: non-permanent houses (RES1); semi-permanent houses (RES2); and permanent houses (RES4).
The data required at this stage is the total number of houses \((Q)\), the proportion of each type of house \((P)\), and the proportion of houses damaged by the earthquake \((\alpha)\).

**Figure 1.** Model scheme to predict the number of damaged houses due to earthquake using RADIUS

2.2. *Earthquake Intensity Prediction Model*

The prediction model for the impact of an earthquake on the radius Okazaki [1] begins by calculating the predicted PGA and earthquake intensity. PGA is equal to the maximum ground acceleration that occurred during earthquake shaking at a location. PGA in area \(i\) \((A_i)\) is equal to the amplitude of the largest absolute acceleration at a site during a particular earthquake in area \(i\). The PGA was calculated using Young et al attenuation formula[11]. The formula used to calculate the PGA that occurs in area \(i\) \((A_i)\) is as follows:

\[
A_i = \frac{10^{0.41G - \log \left( \sqrt{E_i^2 + D^2} + 0.032.10^{0.41G} \right) - 0.0034 \sqrt{E_i^2 + D^2} + 1.30}}{980} \tag{1}
\]

where:

\(A_i\) : PGA in area \(i\)

\(G\) : earthquake magnitude

\(E_i\) : the distance from area \(i\) to the earthquake epicentre

\(D\) : earthquake depth

The calculation of the earthquake intensity used in this research is MMI, which is used to measure how much damage is caused by the earthquake. The intensity of the earthquake that occurs in area \(i\) \((M_i)\) can be calculated using the following equation:

\[
M_i = \frac{\log(980A_i) - 0.014}{0.3} \tag{2}
\]

where:

\(A_i\) : PGA in area \(i\)

\(M_i\) : the earthquake intensity that occurs in area \(i\)

2.3. *Prediction Model for Number of Damaged Houses*

The number of damaged houses is the number of houses damaged by the earthquake, so the house is no longer suitable for housing. The prediction of the number for damaged houses was carried out on non-permanent houses (RES1); semi-permanent houses (RES2); and permanent houses (RES4). The prediction of the total number for houses damaged due to the earthquake disaster is the sum of the number of damaged houses types RES1, RES2 and RES4. The formula is as follows:
The calculation of the damaged houses number for each house type in area $i$ due to the earthquake intensity $m$ can be expressed in a mathematical equation as follows:

$$\frac{\text{Number of damaged houses of type } j \text{ in area } i}{\text{Total houses in area } i} \times \frac{\text{The proportion of type } j \text{ houses damaged by the earthquake with an intensity of } m}{\text{The proportion of type } j \text{ houses in area } i} = R_{ijm}$$

The above equation can also be stated in the following formula:

$$R_{ijm} = Q_i P_{ij} \alpha_{jm}$$

where:

$R_{ijm}$: Prediction of the total number of houses type $j$ which damaged in area $i$ by earthquake intensity of $m$.

$Q_i$: Total houses in area $i$.

$P_{ij}$: The proportion of type $j$ houses in area $i$.

$\alpha_{jm}$: The proportion of type $j$ houses damaged by the earthquake with an intensity of $m$.

Referring to equation (5), the prediction of the damaged houses number for all types of houses in area $i$ due to earthquake intensity $m$ ($R_{im}$) can be expressed in a mathematical equation as follows:

$$R_{im} = \sum_{j=1}^{3} Q_i P_{ij} \alpha_{jm}$$

where:

$R_{im}$: Prediction of total damaged houses for all types of houses in area $i$ due to earthquake intensity $m$.

### 3. Result and Discussion

#### 3.1. Data for Model Testing

The testing process for the prediction model in this research was carried out by using earthquake data that occurred in Padang on September 30, 2009 at 17:16:10 WIB. This earthquake occurred with 7.6 magnitude on the Richter scale, and the epicenter is 57 km southwest of Kota Pariaman (00.84 LS 99.65) at a depth (hypocenter) of 71 km. Based on this information, the earthquake magnitude ($G$) in this research was 7.6SR and the depth of the earthquake that occurred ($D$) was 71 km. The calculation of the prediction for the damaged houses number in this research was carried out for each sub-district in the Padang city, while the distance from the epicenter of the earthquake to each district ($E_i$) is presented in table 1.
### Table 1. Area and Distance to Earthquake Epicenter for Each Sub-district

| No. | Sub-district            | Area (m²) | Distance to Earthquake Epicenter (km) |
|-----|-------------------------|-----------|-------------------------------------|
| 1   | BungusTelukKabung       | 100.78    | 102.10                              |
| 2   | LubukKilangan           | 85.99     | 101.30                              |
| 3   | LubukBegalung           | 30.91     | 97.00                               |
| 4   | Padang Selatan          | 10.03     | 94.90                               |
| 5   | Padang Timur            | 8.15      | 94.30                               |
| 6   | Padang Barat            | 7         | 92.50                               |
| 7   | Padang Utara            | 8.08      | 90.60                               |
| 8   | Nanggalo                | 8.07      | 91.50                               |
| 9   | Kuranji                 | 57.41     | 93.40                               |
| 10  | Pauh                    | 146.29    | 97.10                               |
| 11  | Koto Tangah             | 232.25    | 88.20                               |

The calculation of the number of damaged houses prediction by the earthquake in this research requires data on total houses ($Q_i$) and data on the proportion of each house type for each sub-district ($P_{ij}$). The total houses for each sub-district are needed to predict the number of houses damaged by the earthquake. If the data regarding the total houses is inaccurate, then the prediction results of the damaged houses number that have been obtained not accurate.

### Table 2. The Number and Proportion of Houses for Each Sub-district

| No. | Sub-district            | Number of Houses | Non-Permanent | Proportion Semi-Permanent | Permanent |
|-----|-------------------------|------------------|---------------|--------------------------|-----------|
| 1   | BungusTelukKabung       | 4,348            | 9.80%         | 14.54%                   | 75.67%    |
| 2   | LubukKilangan           | 9,470            | 1.82%         | 11.22%                   | 86.96%    |
| 3   | LubukBegalung           | 19,199           | 3.49%         | 9.21%                    | 87.30%    |
| 4   | Padang Selatan          | 11,186           | 6.87%         | 15.64%                   | 77.48%    |
| 5   | Padang Timur            | 18,660           | 0.41%         | 16.01%                   | 83.57%    |
| 6   | Padang Barat            | 10,997           | 1.20%         | 16.86%                   | 81.94%    |
| 7   | Padang Utara            | 12,052           | 0.46%         | 11.54%                   | 88.00%    |
| 8   | Nanggalo                | 10,596           | 3.29%         | 15.71%                   | 80.99%    |
| 9   | Kuranji                 | 27,298           | 4.85%         | 13.75%                   | 81.41%    |
| 10  | Pauh                    | 11,253           | 3.79%         | 13.22%                   | 82.99%    |
| 11  | Koto Tangah             | 40,350           | 6.07%         | 22.90%                   | 71.03%    |

Source: Statistics for Padang City 2009, Bappeda Padang City

The value of the proportion for type $j$ houses damaged by the earthquake with an intensity of $m(\alpha_{jm})$ is presented in table 3, where $j = 1$ is a non-permanent house type (RES1); $j = 2$ is a semi-permanent house (RES2); and $j = 3$ is a permanent house (RES4).
3.2. Results of Earthquake Intensity Prediction

Stage 1 calculations carried out in this research were to calculate the predicted earthquake intensity which consisted of PGA and MMI calculations. The calculations are performed using equations (1) and (2) as well as the data available in table 1. The results obtained for the PGA and MMI calculations in stage 1 are presented in table 4.

Table 4. Prediction Results of PGA and MMI

| No. | Sub-district        | PGA  | MMI |
|-----|---------------------|------|-----|
| 1   | BungusTelukKabung   | 0.06 | VI  |
| 2   | LubukKilangan       | 0.06 | VI  |
| 3   | LubukBegalung       | 0.06 | VI  |
| 4   | Padang Selatan      | 0.07 | VII |
| 5   | Padang Timur        | 0.07 | VII |
| 6   | Padang Barat        | 0.07 | VII |
| 7   | Padang Utara        | 0.07 | VII |
| 8   | Nanggalo            | 0.07 | VII |
| 9   | Kuranji             | 0.07 | VII |
| 10  | Pauh                | 0.06 | VI  |
| 11  | Koto Tangah         | 0.07 | VII |

Based on the results of the PGA and MMI calculations for each sub-district in Padang City, the results show that the effect of the earthquake in Padang City is in the range of VI - VII MMI, from Table 4 it is known that out of 11 sub-districts there are 4 sub-districts with VI MMI and 7 sub-districts with VII MMI. The difference in MMI is influenced by the distance from the epicenter of the earthquake to the sub-district, the closer the distance then the PGA be bigger and do is the MMI.

3.3. Prediction Results of the Damaged Houses Number

After stage 1 is completed, the next step is the process of stage 2, namely the calculation to predict the number of houses damaged due to the earthquake. Stage 2 calculations are carried out using equation (5) and the data available in Table 2. The results obtained for the calculation of the prediction number for damaged houses each sub-district in Padang City can be seen in table 5.
Based on Table 5, the results show that the total number of damaged houses in Padang City due to the earthquake that occurred on September 30, 2009 was 3,042 units, with a representation of the number of houses damaged for each house type are presented in Figure 2. The highest number of damaged houses was non-permanent houses, which is 57%. This type of non-permanent house is a house that is at risk of being damaged during an earthquake, because this type of house is generally a house built of bamboo or wood in the form of non-permanent construction. The number of semi-permanent and permanent houses that were damaged during the earthquake was relatively small compared to non-permanent houses. This is because semi-permanent and permanent houses have a stronger construction than semi-permanent houses.

![Figure 2. Proportion of the Predicted Number of Damaged Houses for Each Type](image)

From Table 5, it can be seen that the sub-district with the highest predicted number of damaged houses is Koto Tangah sub-district, which is 1,237 units or 40.65% of the total predicted number of damaged houses in Padang City. Koto Tangah has the highest percentage of damaged houses, this is because Koto Tangah is the sub-district with the largest number of houses in Padang City and has the closest distance to the epicenter of the earthquake when compared to other sub-districts.

The prediction of the damaged houses number in an area is influenced by the number of houses in that area, the proportion of the houses number (non-permanent; semi-permanent and permanent), and also influenced by the distance from the area to the epicentre of the earthquake. The greater the
number of houses and the greater the proportion of the number of non-permanent and semi-permanent houses, than the prediction of the number of damaged houses also higher. The closer the distance from the area to the epicentre of the earthquake, the more likely the house damaged. The closer the area to the epicentre of the earthquake, the greater the PGA and MMI, so that the damage to houses caused by the earthquake also be even greater.

3.4. Model Validation Process
In this research, model validation was carried out by testing the model, which is by comparing the model output with the actual data. If the error value generated from the output of this prediction model is small, that is, if the model's output is close to the actual data and the error is close to zero, then the model is declared valid. Conversely, if the error value generated from the output of this prediction model is large, then the model is declared invalid. In this research, the testing process was carried out on the earthquake disaster that occurred in Padang on September 30, 2009.

The comparison of the model output with the actual data on the number of damaged houses for each district caused by the earthquake on September 30, 2009 is presented in Table 6.

| No. | Sub-district                  | Number of Damaged Houses | Error |
|-----|-------------------------------|--------------------------|-------|
|     |                               | Prediction Mode Output   | Actual Data |     |
| 1   | BungusTelukKabung             | 83                       | 395     | -312 |
| 2   | LubukKilangan                | 41                       | 359     | -318 |
| 3   | LubukBegalung                | 266                      | 1,04    | -838 |
| 4   | Padang Selatan               | 151                      | 1,539   | -1,388 |
| 5   | Padang Timur                 | 34                       | 569     | -535 |
| 6   | Padang Barat                 | 67                       | 470     | -403 |
| 7   | Padang Utara                 | 28                       | 875     | -847 |
| 8   | Nanggallo                    | 211                      | 1,105   | -894 |
| 9   | Kuranji                       | 668                      | 903     | -235 |
| 10  | Pauh                         | 258                      | 1,584   | -1,326 |
| 11  | Koto Tangah                  | 1,237                    | 732     | 505  |
|     | Total                         | 3,042                    | 9,635   | -6,593 |

Based on the comparison between the output model and the actual data, it is found that the output model still produces a fairly high error value. The total number of damaged houses produced by the prediction model in this research was 3,042 units, while the actual data on the total number of damaged houses that occurred due to the Padang earthquake on September 30, 2009 was 9,635. The Mean Absolute Percentage Error (MAPE) of the model output is 71.9%.

4. Conclusion
Referring to the model testing results presented in Table 5, it is known that the model prediction results are still far from the actual data, this is supported by the MAPE value of 71.9%. This means that the prediction results using the Radius Model are not accurate enough to predict the number of houses damaged by the earthquake in Indonesia.

However, this Radius Model has clearly shown the relationship between the input and output variables. In this research, the Radius model is displayed in a mathematical model equation, so that it shows each stage of the calculation process clearly, and shows the mathematical relationship of the equation in detail, thus helping the process of developing mathematical models easily, if in the future this model will be developed in further research.
The prediction model for the number of damaged houses in this research then can be developed into an estimation model for the relief items needed by the internally displaced persons (IDPs). After predicting the number of damaged houses, the process of estimating the number of IDPs then can be carried out, if the estimated number of IDPs is known, then an estimate of the relief items needed by the IDPs can be calculated well.

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