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Mapping The Risk Level of Earthquake Damage in Central Java Based on Data From PGA, PD and HDI

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Abstract

Central Java is one of the provinces in Indonesia with a fairly high level of seismicity. During January 2021 alone there were 22 tectonic earthquakes, one of which occurred in Banyumas (M.5). With this fairly high seismicity, it is necessary to reduce its impact through mitigation. One of the efforts that can be done is to map the level of risk of damage. This mapping can be made based on the Peak Ground Acceleration (PGA) value combined with the Population Density (PD) and Human Development Index (HDI) values. Two methods were used to calculate PGA based on the 1970-2020 earthquake data, namely the Crouse (1991) and Donovan (1973) methods. The results of the calculation using the Crouse method obtained the highest PGA value of 92–180 gal (VI-VII MMI) and the Donovan method obtained the value of 92-107 gal (VI MMI). From this PGA value combined with the PD and HDI values in each district in Central Java, a map of the level of risk of damage caused by the earthquake is made. The results of the mapping show that the districts of Klaten, Cilacap, Kebumen, Banyumas, Brebes, Magelang, Demak and Semarang have a fairly high risk of damage.

***Keywords**:* Mapping, the risk level, earthquake, Central Java.

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INTRODUCTION

Indonesia's geological position which is in the zone of active tectonic plate boundaries causes earthquakes to occur almost every day. Monitoring results from the Meteorology, Climatology and Geophysics Agency (BMKG) show that the trend of earthquakes in Indonesia will increase in 2021, reaching 300 to 400 earthquakes every month. Throughout April 2021 alone, the BMKG recorded 807 earthquakes ranging from subtle to destructive (BMKG, 2021). This high seismicity is due to the fact that the Indonesian archipelago is composed of broken and uplifted continental chunks originating from Gondwana and Cathaysian (Hutchison, 1989). These islands are surrounded by active plate margins forming complex plate encounter paths of the world's three major plates and nine minor plates that meet each other (Bird, 2003). The three major plates are the Indian-Australian Ocean Plate moves from south to north, the Pacific Plate from east to west and the Asian Plate moves from north to south southeast (IEMRT, 2010). Tectonic structures such as faults, local faults, folds, land subsidence and so on are formed in almost the entire Indonesian archipelago due to the activities of these three plates (Milson, 2003).

Earthquakes occur due to the sudden Earthquakes occur due to the sudden release of elastic energy in rocks at the source location because the received energy has exceeded the elastic limit and the energy is released in the form of plastic deformation and elastic waves. The location of the release of elastic energy

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is generally a weak area so that it experiences plastic deformation, while the area far from the source occurs elastic deformation in the form of seismic waves (Sunarji, 2012). Seismic waves that propagate to the surface and cause ground vibrations. Earthquakes have a fairly clear start and end time (Afnimar, 2009)]. An earthquake that occurs at an early time is called a foreshock, followed by a main earthquake and a number of aftershocks that follow it (Helmstetter, et.all, 2003).

Every earthquake that occurs will provide one value of ground vibration acceleration at an affected site. The maximum ground vibration acceleration value at a place in an area calculated from all earthquake events in a certain period of time is called Peak Ground Acceleration (PGA). This value can be used as a reference in planning an infrastructure. The calculation of the PGA value is carried out by taking into account the magnitude and distance of the hypocenter and the dominant period of the soil from that point (Hanfewi, et.all, 2014). This PGA value is equivalent to the greatest absolute acceleration amplitude value recorded on the accelerogram at a place during an earthquake (Douglas, 2003). The largest PGA that has ever occurred illustrates the magnitude of the physical disaster impact on the affected areas (Brotopuspito, 2006). In other words, the magnitude of the PGA value will provide an overview of the level of risk of damage due to earthquakes at a location (Daz, 2008).

Earthquakes are not deadly natural disasters but the resulting damage to infrastructure can cause fatalities. This natural disaster is unpredictable, therefore it must continue to be watched out for through disaster mitigation efforts. Disaster mitigation can be done through mapping of development areas, capacity building and/or community preparedness in dealing with them. In earthquake mitigation efforts, this discussion will examine the assessment of the risk level due to the earthquake in Central Java by combining Peak Ground Acceleration (PGA) data, Population Density (PD) and Human Development Index (HDI). This combination needs to be done because disaster risk is an interaction between regional vulnerabilities and existing hazard threats. There are three factors that influence the earthquake disaster, namely hazard, vulnerability and capacity. Hazard and vulnerability are important factors in determining disaster risk, while capacity is the opposite of vulnerability (Firmansyah, at.all. 2014). Several levels of risk of disaster damage have been carried out only based on the PGA value not yet combined with population data. This combination needs to be done because there are times when an area has a PGA value as if it is a hight risk area. If the PD in this area is low, the risk level will be reduced, especially if the HDI is high then the risk will be low. A high HDI indicates that the community is better prepared to face disasters.

There are many methods or value approaches that can be used to determine the PGA in a region. In this paper, the empirical method or approach used is the method of Crouse (1991) and Donovan (1973). From the PGA value of an area under study, a PGA map can be made that can describe the risk due to earthquakes in the area. To be more comprehensive, this PGA data needs to be combined with population data as stated above. The Central Java region was chosen to be studied because Central Java is a province with a fairly high level of seismicity in Indonesia.

RESEARCH METHODE

Seismicity data used to create a map of the level of risk of damage due to earthquakes in the Central Java region were obtained from the BMKG earthquake catalog and the United States Geological Survey's (USGS) in the period 1970 - 2020 or in the span of 50 years. The magnitude used is > 5 M with the depth of the earthquake source between 0-60 km at the boundaries of the region 108.6340 - 111.3070 East Longitude and 6.250 - 9.8190 South Latitude. The steps taken to create this map are as follows:

- Data collection from data providers as stated above, in the form of latitude, longitude, magnitude, depth, and compile historical earthquake data in the study area based on data from destructive earthquakes in the 1970-2020 range with the criteria as stated above according to the chosen method.
- Collecting latitude and longitude data for each sub-district throughout the Central Java region.
- Creating grids according to districts with ArcGis 10.4.
- Converts the type of magnitude according to the required magnitude of each selected method.
- Calculate the distance from the epicenter and hypocenter at the earthquake point to the observation point. To determine the epicenter distance, the following equation is (Utoyo, 2007):

$$\Delta^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 \quad (1)$$

Where:

Δ = Epicenter distance (°)
x_1 = Latitude in the measurement area (°)
x_2 = Latitude at the source of the earthquake (°)
y_1 = Longitude in the measurement area (°)
y_2 = Longitude at the source of the earthquake (°)

and for the distance of the hypocenter to each grid equally:

$$R^2 = \Delta^2 + h^2 \quad (2)$$

Where:

R = Hypocenter distance (°)
Δ = Epicenter distance (°)
h = Earthquake depth (km)

- Calculating the PGA value on each observation grid uses an equation according to the chosen method or approach, which in this case is the formula of Crouse (1991) and Donovan (1973).
- Sort the calculated PGA values and take the highest PGA value on each grid.
- Create PGA contour maps with ArcGIS 10.4 software.
- Converts PGA values into MMI scale.
- Collect PD and HDI data according to sub-districts in the mapping area from the Central Bureau of Statistics website.
- Scoring MMI, PD and HDI values.
- Mapping risk levels due to earthquakes based on MMI, PD and HDI scores using ArcGIS 10.4 software. The Disaster Risk Index can be calculated using the following formula (DRSPT, 2018):

$$Risk = Hazard\ x\ \frac{Vulnerability}{Capacity} \quad (3)$$

RESULT AND DISCUSSIONS

The following will explain how to make a map of the level of risk of damage due to earthquakes and explanations for the Central Java region. There are two maps made based on different methods, namely using the method or approach of Crouse (1991) and Donovan (1973). In general, making this map begins with selecting earthquake events and creating a grid according to the method. Furthermore, the epicenter and hypocenter of the selected earthquake were determined measured from the grid points (site). From the grid points the PGA is calculated and the highest PGA value is chosen. By using the appropriate program, from the highest PGA value, a PGA map was made to map the level of risk of damage throughout Central Java. To be more comprehensive, the risk level map based solely on the PGA value needs to be combined with the population map, including PD and HDI at each site (grid) in the studied area.

Map of Peak Ground Acceleration

The creation of the PGA map begins with selecting events or sorting historical earthquake data in Central Java, including Yogyakarta, in the 1970-2020 range. This data is sorted with the appropriate parameters, namely the coordinates are between 108.6760 East Longitude – 111.5070 East Longitude and 6.4320 South Latitude - 9.4290 South Latitude, Magnitude (M) > 5 and earthquake depth > 60 km. By using these parameters, from tens of thousands of earthquake data that occurred over a period of 50 years, 23 significant and destructive earthquake data were obtained. Table 1. Shows data on significant and destructive earthquakes in the Central Java region in 1970-2020.

TABLE 1. Significant and Destructive Earthquake Data for Central Java 1970-2020

Date of Incident	Place of Incident	Longitude (°EL)	Latitude (°SL)	Depth (km)	Magnitude (SR)
SBoCJ	1976/02/14	108.607	-8.082	53	6.4
SboCJ	1981/03/13	110.428	-8.759	51	6.1
SBoCJ	1985/07/09	110.306	-8.503	58.9	5.7
SBoCJ	1989/09/12	110,503	-9.017	33	5.6
SBoCJ	1990/05/21	109.043	-8.137	27.5	5.6
SBoCJ	1990/05/21	110.423	-8.643	47.9	5.5
SBoCJ	1996/09/25	108,725	-9.295	33	5.6
SBoCJ	1997/07/12	110,527	-9.045	33	5.3
SBoCJ	2000/01/05	109.592	-9.195	33	5.8
SBoCJ	2001/01/07	108.893	-8.703	33	5.4
SBoCJ	2003/07/19	111.227	-8.682	56.2	5.9
SBoCJ	2004/12/12	108.616	-8.837	48.5	5.0
Yogyakarta	2006/05/26	110.446	-7.961	12.5	6.3
SBoCJ	2009/07/31	108.744	-8.795	17.5	5.4
SBoCJ	2010/12/21	111.197	-8,700	54.6	5.6
SboCJ	2011/05/28	108.754	-8.756	45.3	5.6
SboCJ	2013/08/08	110.979	-8.624	9.45	5.8
SboCJ	2014/04/18	110.344	-9.056	15.37	5.8
SboCJ	2015/07/24	108.916	-8.248	48	5.5
SboCJ	2017/01/02	108.797	-8.746	38.14	5.7
SboCJ	2018/08/28	110,145	-9,022	40	5.2
SboCJ	2019/08/10	108,680	-8,650	29	5.5
SboCJ	2020/07/12	109,860	-8,760	30	5.3

Note: SBoCJ = South Beach of Central Java

From the latitude and longitude parameters of the earthquake in Table 1, the epicenter of the earthquake in the studied area can be mapped. This epicenter map can be seen in Figure 1. The next step is to determine the grid. This grid is used to calculate the distance between the earthquake epicenter and the point in the study area where the observations were made. Grid points are determined in each sub-district in Central Java Province. Making the grid begins by determining the latitude and longitude of each sub-district in Central Java Province. These latitudes and longitudes are then converted from units of degrees into decimal form and then from this data a grid map is made. Figure 2 shows a grid map with 573 observation points.

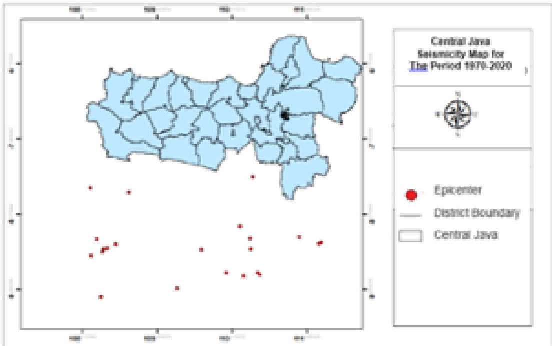

FIGURE 1. Distribution map of earthquake epicenters in Central Java.

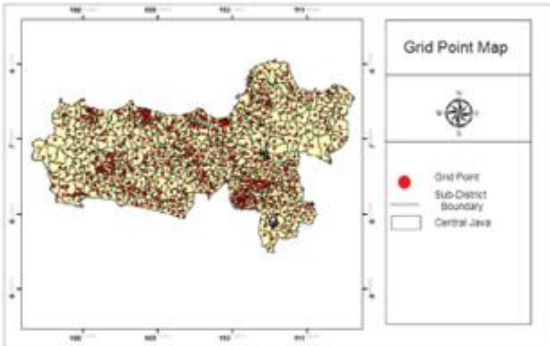

FIGURE 2. Grid map or measurement points in Central Java.

To The calculation of the PGA value begins by calculating the distance between the epicenter and hypocenter on each predetermined grid. Furthermore, the PGA value on each grid is calculated according to the chosen method, namely the method of Crouse (1991) and Donovan (1973). From the PGA values in each grid the highest value is selected and with the appropriate program a PGA map is created. Figure 3 shows the PGA map using the Crouse method (1991) in the Central Java region converted to MMI scale. This map illustrates the level of risk due to earthquakes based on PGA values. The highest PGA value for this method is between 150-180 gal in the Klaten district which is equivalent to the MMI VII scale. Districts with moderate levels with a PGA value of 92-150 gal are located in the districts of Cilacap, Banyumas, Kebumen, Purworejo, Magelang, Magelang City, Boyolali, Wonosobo, Sukoharjo, Wonogiri, Karanganyar, Surakarta, Semarang, Temanggung, Brebes, Salatiga, and Sragen. These areas are on the VI MMI scale. Districts with low risk with PGA values between 64-87 gal are in Purbalingga, Banjarnegara, Grobogan, Blora, Rembang, Pati, Kudus, Jepara, Demak, Kendal, Batang, Pekalongan, Pemalang, Kab. Tegal, Tegal City, Semarang City, and Pekalongan City. These regions are on the V MMI scale level.

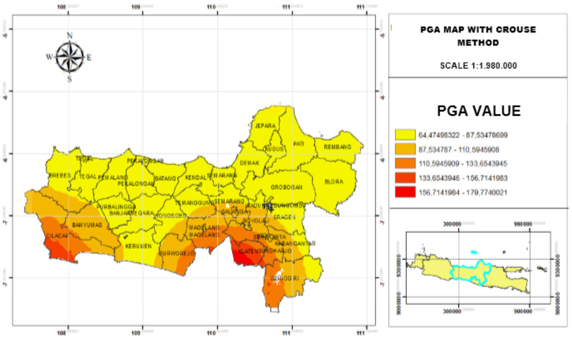

FIGURE 3. PGA map for Central Java using the method Crouse's (1991)

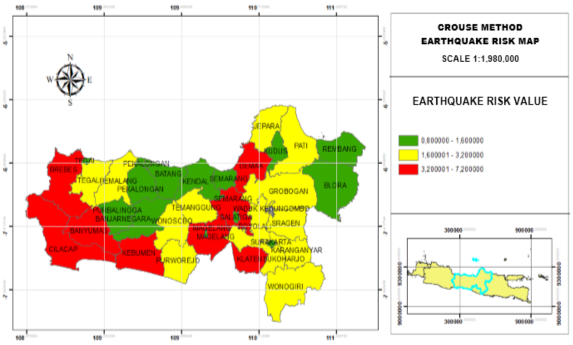

FIGURE 4. Map of the earthquake risk level combined between PGA with PD and HDI

Several districts in Central Java experienced changes in their level of risk after mapping based on a combination of data from PGA, PD and HDI values. There are districts where the risk level goes up and some goes down. As in mapping the level of risk based on the PGA value, the mapping of the level of risk resulting from this combination is also classified into 3 classes, namely high, medium, and low. According to BNPB (2018), this classification of disaster risk levels can be done by scoring, both the PGA, PD and HDI values. To calculate the level of risk due to earthquakes based on the combination of PGA, PD and HDI values, the formula in equation 3. From the results of this calculation, a map of the risk level due to earthquakes in the Central Java Region is made based on the selected program.

Figure 4 shows a map of the level of risk due to earthquakes based on a combination of PGA data from Crosue (1991) method, PD and HDI data. In this image, the area that has the highest risk is the red one. The area includes the Districts of Cilacap, Kebumen, Banyumas, Brebes, Magelang, Klaten, Semarang, Demak. The risk is high in this area because the intensity of the earthquake is on the VI-VII MMI scale. The tremors of the earthquake can be felt by everyone inside and outside the room. Earthquake vibrations caused objects to break and fall, old buildings and buildings that were not earthquake-standardized to collapse and were damaged, liquefaction occurred, soil cracks, landslides, residents' wells were cloudy, gutters and irrigation canals were damaged [ludmand]. Areas of moderate risk impact marked in yellow on the map are on the V MMI scale. The districts in this area include Purworejo, Wonogiri, Tegal, Pemalang, Temanggung, Wonosobo, Banjarnegara, Temanggung, Boyolali, Sragen, Jepara, Pemalang, Pati, Grobogan, Sukoharjo. The tremors of the earthquake could be felt by everyone indoors and outdoors. The vibrations of this earthquake can cause plates, window panes and glass to shatter, cracking walls. The areas with low risk are marked in green on the map which is on the MMI IV scale. The districts in this area include the City of Tegal, Pekalongan, Batang, Kendal, Purbalingga, Banjarnegara, Salatiga, Semarang City, Blora, Kudus, Magelang City, Surakarta City and Rembang. Earthquake tremors at this level were felt outdoors, sleeping people woken up, doors swung, frames on walls moved.

By looking at the maps in Figures 3 and 4, it can be seen that there are areas experiencing changes in the level of risk. Some districts experienced an increase in the level of risk, but some experienced a decrease. The district with a high level of risk based on PGA data is only Klaten district, but based on the combination of

PGA, PD and HDI data, Cilacap, Kebumen, Banyumas, Brebes, Magelang, Semarang, and Demak districts whose risk level was initially moderate (PGA data) became high risk. The increase in the level of risk is generally due to the high population density (PD) while the low capacity (HDI). Meanwhile, several districts actually experienced a decrease in the level of risk from moderate to low, namely Magelang City, Surakarta City and Salatiga. In general, the cause of the reduction in risk levels in these three districts/cities is due to good capacity (HDI) so that the score is good.

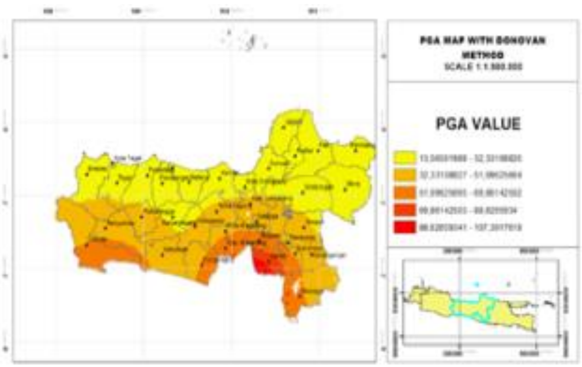

FIGURE 5. PGA map for Central Java using the method Donovan's (1973)

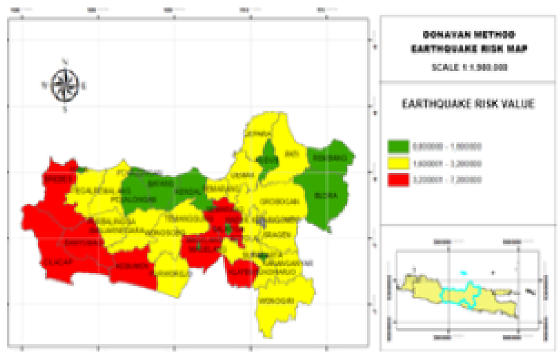

FIGURE 6. Map of the earthquake risk level combined between PGA with PD and HDI

Figures 5 and 6 show a map of the earthquake risk level based on PGA data using the Donovan (1973) method which was converted to the MMI scale and from the combination of PGA, PD and HDI data. Similar to the Crouse method (1991), the highest PGA value for the Donovan method (1973) was in the Klaten district with a value between 107-188 gal or equivalent to the VI MMI scale. Areas in Central Java that are at moderate risk include Cilacap, Banyumas, Purbalingga, Banjarnegara, Kebumen, Purworejo, Wonosobo, Magelang, Boyolali, Sukoharjo, Wonogiri, Karanganyar, Sragen, Semarang, Temanggung, Brebes, Magelang, Surakarta, Salatiga districts. , and the City of Semarang. The PGA value for this region is between 44-88 gal or the equivalent of the V MMI scale. The areas that are at a low risk level with PGA values between 30-36 gal or equivalent to MMI IV scale include Grobogan, Blora, Rembang, Pati, Kudus, Jepara, Demak, Kendal, Batang, Pekalongan, Pemalang, Tegal, Pekalongan Districts. , and the City of Tegal.

The map in Figure 6 shows that areas that have a high risk of earthquake disasters based on a combination of PGA, PD and HDI values include the districts of Cilacap, Banyumas, Kebumen Brebes, Magelang, Semarang, and Klaten. When compared with the Crouse method (1991), only Demak district was not found in the Donovan method (1973). Affected areas with moderate risk include Grobogan, Temanggung, Purworejo, Wonogiri, Sukoharjo, Karanganyar, Boyolali, Tegal, Pati, Pemalang, Wonosobo, Purbalingga, Banjarnegara, Temanggung, Salatiga, Boyolali, Sragen, Semarang, Demak, and Jepara districts. The areas with low risk include Pekalongan City and Districts, Tegal City, Magelang, Surakarta, Salatiga, Batang, Kendal, Blora, Kudus and Rembang Districts.

Similar to the Crouse method (1991), in the Donovan method (1973) several districts/cities experienced changes in their level of risk after PGA data was combined with PD and HDI data. Some districts/cities have an increased level of risk and some have decreased. The districts of Cilacap, Banyumas, Kebumen, Brebes, Magelang and Semarang have an increased risk level from moderate to high risk, while those with a low to moderate level of risk include Grobokan, Pati, Jepara, Demak and Tegal districts. The areas that experienced a decrease in the level of risk from moderate to low included the cities of Magelang, Surakarta, Salatiga, and Semarang. The increase in the level of risk is generally caused by a high PD score with a low HDI, while cities that experience a decline are solely due to a high HDI because the city is densely populated.

Geology and Tectonic Studies

The geodynamics of Central Java, including its earthquakes, is strongly influenced by the dynamics of the subduction zone in the south of this region. This zone is a convergent plate boundary that extends to the south of the island of Java. The movement of plates in this zone causes the formation of faults, folds, land subsidence and so on. Other secondary processes due to activity in this subduction zone also cause the formation of troughs, non-volcanic outer arcs, fore arcs, volcanic arcs and back arc basins [19]. The dynamics of this zone also causes the formation of regional geological structures on the Java mainland. This structure extends from western Java to eastern Java. These structures include the Banten Fault, Cimandiri Fault, Citarik Fault, Baribis Fault, Citanduy Fault, Bumiayu Fault, Kebumen Fault- Semarang-Jepara, Lasem Fault, Rawapening Fault, Opak Fault, Pacitan Fault, Wonogiri Fault, Pasuruan Fault, and Fault Jember (Suhaimi, 2008). On the mainland of Central Java there are also seven active faults, namely Baribis Kendheng, Ajibarang, Merapi Merbabu, Muria, Pati/Lasem, Ungaran 1 and 2 (Prayoedhie, 2020).

There has been a jump in seismic activity, especially in the last five years. In 2015 there were 99 earthquakes recorded in Central Java. In the last five years before, the number of earthquakes that occurred was also relatively small between tens to hundreds of events. But starting in 2016, the graph of the number of earthquakes in Central Java increased sharply to 663 in 2016, 553 in 2017, 660 in 2018, 624 in 2019 and 523 events in 2020 (Prayoeedhie, 2020). Therefore, efforts to be aware of and mitigate earthquake disasters that may occur in the future must continue to be carried out. A study on disaster vulnerability and earthquake risk in Central Java is a necessity to be carried out immediately and continuously from the provincial, district and city levels to the sub-district level.

CONCLUSIONS

From Klaten is the district in Central Java with the highest risk of earthquakes based on PGA values, both for the Crouse method (1991) and Donovan (1973). However, when combined with PD and HDI data, some districts experienced an increase in the level of risk and some experienced a decrease. For the Donovan method (1973) districts with high risk include Cilacap, Kebumen, Banyumas, Brebes, Magelang, Semarang and added Demak district for the Crouse method (1991). The increase in the level of disaster risk in several districts is generally caused by a relatively high PD score with a relatively low HDI. Several districts experienced a decreased level of risk from moderate to low, namely the cities of Magelang, Surakarta and Salatiga. In general, the three cities are relatively densely populated, but their HDI scores are relatively better than others.

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