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Distribution of peak ground acceleration in Pandeglang Regency, Banten

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Abstract. Pandeglang Regency is an area prone to earthquakes because in the subduction zone of the Indo-Australian plate and the Eurasian plate in the Sunda Strait. This study analyses the average and maximum values of the Peak Ground Acceleration (PGA) got from earthquakes in the period 2000 to 2020 around Pandeglang Regency with the calculation method. Gutenberg-Richter with the Richter formula combined with the intensity attenuation formula which is a function of magnitude, epicentre distance, and earthquake intensity. From the maximum PGA data, the lowest value is 273 gals, and the highest is 427.5 gals. Meanwhile, for the distribution of the average PGA value, the minimum value is 54 gals, and the maximum value is 67 gals. From the PGA data, the maximum distribution of the highest PGA value is in the center of Pandeglang Regency, and the lowest value of the PGA maximum is in the northern and southern parts of Pandeglang Regency. The PGA value is potentially damaging at the VII MMI scale, where the area with the highest vulnerability is in the sub-district Angsana, Munjul, Panimbang, and Sidangresmi with the highest PGA scores, so this sub-district has the highest risk than other districts.

Keywords: Earthquake intensity, epicenter distance, Eurasian plate, Indo-Australian plate, Peak Ground Acceleration (PGA)

1. Introduction

Earthquakes are natural disasters that cannot be predicted beforehand, earthquakes are a geological phenomenon that occurs because of the release of energy collected in the earth. The energy released will cause vibrations which will later propagate through the medium of the earth’s surface and the earth’s depths [1]. Pandeglang Regency which is next to the Sunda Strait is an area that is prone to being hit by tsunamis because it is an area Subduction between the Indo-Australian plate and the Eurasian plate in the Sunda Strait. The presence of a meeting of the two plates results in an accumulation of energy in the subduction zone so that the two plates are subjected to stress and strain. Until finally the collision of the two plates is locked and there is a release of energy [2]. This energy release event causes earthquakes. The potential for movement of the Indo-Australian earth plate is quick, even reaching 4 centimeters per year [3] this making the potential tsunami and earthquake in Pandeglang Regency is huge.

In addition, earthquakes in the Pandeglang Regency area can also occur due to volcanic eruptions in the Sunda Strait, namely Mount Krakatau which has the potential to cause earthquakes and tsunamis. One of the biggest earthquakes recorded in the last 20 years occurred on Friday, August 2, 2019 with a magnitude of 6.8 on the Earth’s Richter scale which resulted in many houses being damaged and tsunami
early warning given by BMKG. For this reason, it is necessary to have a comprehensive study to understand the earthquake that occurred in Pandeglang Regency as a first step in disaster mitigation. This process uses multi-event earthquake data, namely the period 2000–2020. The method used is the calculation of PGA (Peak Ground Acceleration) using the [4]. Most of the determination of the PGA equation is derived outside of Indonesia because there is no specific PGA equation in Indonesia. Therefore, studies on the level of earthquake risk in an area in Indonesia still use many equations obtained in other regions outside Indonesia with the assumption that there are similarities in geological and tectonic conditions with regions in Indonesia [5].

The method we use has been used in several studies, such as research in the same objective of finding PGA values with hybrid soft computing by [6], furthermore, the use of this method is also stated in the Bayesian Hierarchical Model to determine the spatial distribution of PGA by [7]. This study uses propagation and attenuation modeling using GIS, this is intended to simplify calculations for a wider area. The mean and maximum value of PGA discussed in this paper aims to visualize how likely the destructive ability of an earthquake will occur, using predictions from existing earthquakes, the distribution of PGA values can be determined for future earthquakes [8].

By knowing the distribution of the PGA, it can facilitate decision making related to disaster mitigation in the future, where disaster anticipation and management will be more effective and efficient. In areas with a high PGA distribution value certainly requires special attention from the government, the community and even 3rd parties, with forms of attention that can be in the form of community education, design of evacuation routes, maximizing tsunami early warning in the area, to building safe properties. where the design is able to reduce vibrations, and at a further level, tourism-based partnership that is safe for tourists can be developed, so as to design regulations that limit long-term activities that are not disaster-oriented.

2. Method

Earthquake wave vibration parameters recorded by seismographs are generally the velocity deviation or velocity in units of kine (cm/s). Besides velocity, other parameters such as displacement (deviation in micrometer units) and acceleration (acceleration in gal units or cm/s²) can also be specified. Seismic or frequent wave acceleration parameters called the acceleration of the ground is one of the important parameters in science seismology [9]. Acceleration is the parameter that states changes in speed from rest to a certain speed. Peak Ground Acceleration is the value of the greatest ground vibration acceleration that ever happened somewhere caused by earthquake waves [10]. In this study, calculations using the Gutenberg-Richter method with the Richter formula is combined with the intensity attenuation formula Sunarjo which is a function of magnitude, epicenter distance, and earthquake intensity, with the use of the Gutenberg-Richter method combined with the Sunarjo formula which discusses attenuation, it will be known that the distribution of vibration energy that experiences attenuation is directly proportional to the distance from the epicenter of the earthquake to each sub-district in Pandeglang district, so that the PGA value in each region can be known in a straightforward manner. Certainly, with a calculation element in the form of distance, this study focuses on estimating the PGA value with calculations based on the combination of the Gutenberg-Richter method and the Sunarjo formula, so that the change in reference distance becomes a vital point in the existing calculations. In real earthquakes, the layer content and soil plasticity are of course a part that determines the attenuation of earthquake vibration waves [11], and this requires further study regarding the large area of the area in Pandeglang district.

The greater the PGA that occurs, the greater the risk. PGA data which is a parameter of the source of damage caused by an earthquake, obtained through functions of magnitude, epicenter distance, and earthquake intensity earth [6]. The PGA calculation value is carried out the steps as follows [4, 12]:
a. Calculate epicenter distance
The epicenter distance is determined by calculating the distance from the epicentre (e) to the point x (x), using the formula:

\[
\cos \Delta^o = \cos \lambda_e \cos \lambda_x + \sin \lambda_e \sin \lambda_x \cos (\lambda_e - \lambda_x)
\]

where:
- \( \cos \Delta^o \): Linear epicenter distance to point X
- \( \lambda_x \): The geographical latitude of the point X, for which the PGA value will be calculated;
- \( \lambda_e \): Geographic longitude of point X, for which the PGA value will be calculated;
- \( \lambda_e \): Epicenter geographical latitude
- \( \lambda_e \): Epicenter geographical longitude
- \( \Delta^o \): Distance between points e and x in degrees.

b. Calculate the intensity in the hypocenter, with the formula,

\[
I_0 = 1.5 (M - 0.5)
\]

where:
- \( I_0 \): Intensity at the source (Richter scale)
- \( M \): Magnitude of body wave (Richter scale)

c. Calculate the intensity at point x, with the formula of the attenuation constant,

\[
I = (I_0 \cdot \text{Exp} - b \cdot \Delta)
\]

where:
- \( I \): Surface intensity
- \( I_0 \): Intensity at the source
- \( \Delta \): Distance to the source of the earthquake (epicenter), diverting 111.11 km for every 1 °
- \( b \): The attenuation constant (energy decay), worth 0.0021
- \( \text{Exp} \): Natural number, worth 2.786

d. Calculate the PGA value at point x, with the formula,

\[
\log \alpha = (1/3) - 0.5
\]

where:
- \( \alpha \): Peak Ground Acceleration (PGA) in gal (cm/second)
- \( I \): Surface intensity on the MMI scale and the numbers 3 and 0.5 are constants

The point of the earthquake taken in this study was that an earthquake that had occurred in the Banten Province with a coordinate limit of -5.988 North; -7.112 South; 104.755 West; and -106.232 East (decimal degree coordinates) sourced from Earthquake USGS and BMKG. Determination of the reference point is done by making the center of gravity. Determination of the emphasis is done on each subdistrict in Pandeglang Regency, as many as 35 reference points. In one earthquake event, the PGA value was calculated at each center of gravity so that at each point a PGA value was obtained.
Then the PGA value was calculated for all reference points from the PGA values. A maximum PGA value is sought at each point. After getting the maximum PGA value in each subdistrict in Pandeglang Regency, then the same point value will be calculated and will form a contour-like line using the interpolation method [10]. In this study, earthquake data was divided into two groups, i.e. maximum PGA and average PGA. The division of these two groups is based on different patterns and levels of earthquake risk. Then the minimum and maximum values of each group are categorized into five classes with the equal interval method. Each class has the same interval in the interpolation’s division class.

3. Results dan discussion

3.1. Earthquake distribution in Pandeglang Regency

In the last 20 years, starting from the period 2000–2020, there were 50 earthquakes that occurred in Pandeglang Regency with a depth of less than 100 KM. All recorded earthquakes have magnitudes that vary from 5 on the Richer scale to 6.8 on the Richer scale. Earthquakes with a magnitude of 5 on the Richer scale occurred 17 times, 5.1 on the Richer scale 7 times, 5.2 on the Richer scale for 6 times, 5.3 on the Richer scale for 5 times, 5.4 on the Richer scale for 4 times, 5.5 on the Richer scale for 2 times, 5.6 on the Richer scale for 1 time, 5.9 Richer scale 1 time, 6 richer scale 1 time, 6.1 Richer scale 3 times, 6.8 Richer scale 1 time, and 6.8 Richer scale 1 time (figure 1). The biggest and most destructive earthquake in Pandeglang Regency occurred on Friday, August 2, 2019 with a magnitude of 6.8 on the Richter scale, the earthquake damaged 139 houses in the Mandalawangi area, Pandeglang Regency and resulted in a Tsunami early warning by BMKG.

The earthquake in Pandeglang Regency was greatly affected by subduction activity between the Indo-Australian plate and the Eurasian plate in the Sunda Strait, which is part of the Sunda Megathrust.

![Figure 1. Distribution of the epicenter in Pandeglang Regency.](image-url)
Based on the results of a historical analysis of earthquakes in the last 20 years since early 2000, most of the earthquakes that occurred in the Pandeglang Regency area occurred because of tectonic activity in the Sunda Strait which is part of the Sunda megathrust [11], as the newest and largest example ever recorded in the last 20 years is the 6.8 Ritcher Scale Earthquake on Friday, August 2, 2019, where the epicenter is located at 7.282 ° S 104.791 ° E with a depth of up to 49 KM. In addition, there are other earthquakes whose epicenter is in the waters of the Sunda Strait. therefore, these earthquakes prove that the subduction in the Sunda Strait is tectonically active.

The tendency of the earthquake epicenter to be more in the south direction, causing a tendency for the distribution of the average value of PGA to increase with the increase in the number of epicenter points towards the south. This occurs due to the convergent movement of the Indies-Australia and Eurasian plates [13] so that the epicenter will certainly increase if the area is closer to the core of the subduction zone.

3.2. Distribution of average Peak Ground Acceleration (PGA) in Pandeglang Regency

The average distribution of the average PGA in Kabupaten Pandeglang is classified into five major sections (Very High, High, Moderate, Low and Very Low) with the lowest average PGA level having a value of 54 gals and the highest being 67 gals. In addition, the average PGA value of Pandeglang Regency is between 60.5, which in the classification of this research model is in a moderate area, which means we can conclude it that it has a moderate risk. The areas with the lowest average PGA (< 56.6) are in the north of Pandeglang Regency, including sub-districts; Carita, Cadasari, Karangtanjung, Koroncong, Majasari and Mandalawangi with the lowest total PGA area of 20476 Ha or 7.5 % of the total area of Pandeglang Regency.

Figure 2 shows the dynamics of the average PGA in Pandeglang Regency the regions with the lowest scores are in 3 sub-districts, namely: Cadasari, Karangtanjung, Koroncong which covers a total area of 6313 Ha or if converted in the form of a percent only 2.2 % of the total area Pandeglang Regency.
Most of the areas in Pandeglang Regency have high average PGA levels such as Sumur, Cimmangu, Cibirung, Cibaliung, Cikeusik, Panimbang, Sobang, Angsana, Munjul and Sindangresmi areas, which requires more attention because it has a higher average PGA value than other areas, and the effect of the resulting earthquake damage will be more damaging.

Table 1 describes the area of Peak Ground Acceleration (PGA) for each subdistrict in Pandeglang Regency. We can conclude from the table 1 that the area that has a very low PGA is Koroncong subdistrict, This is because Kercong sub-district is at the farthest location when a linear line is drawn from the existing 50 epicenter points (figure 1), so that the earth's shaking energy caused by plate subduction experiences attenuation due to far travel distances [14] this causes Cadarasi District, Karang Tanjung, and Majasari which are close to Koroncong sub-district also have low PGA mean values.

| Subdistrict | Very low | Peak Ground Acceleration Area (Ha) | Very high | Total (Ha) |
|-------------|----------|-----------------------------------|------------|------------|
| Angsana     | -        | Low 1290.69 Moderate 3276.34 High 11172.03 | - 11172.03 | 8896.04 8896.04 |
| Banjar      | 2967.28  | - 3137.89 - - - | - 3137.88 | 2967.28 |
| Bojong      | 4184.20  | 206.324 2580.50 - - | - 6971.02 | 2967.28 |
| Cibaliung   | - - - - | 12327.46 | - | 12327.46 |
| Cibitung    | - - - - | 17403.25 | - | 17403.25 |
| Cigeulis    | - - - - | 2575.77 | - | 2575.77 |
| Cikedal     | - - - - | 19440.26 | - | 19440.26 |
| Cikeusik    | - - - - | 23529.40 | - | 23529.40 |
| Cimanggu    | - - - - | 2602.51 | - | 2602.51 |
| Cimanuk     | 2550.92  | 1325.91 - - - | - 2789.58 | 7406.45 |
| Cipeucang   | 1463.67  | 2433.64 - 226.22 - | - 2865.07 | 2602.51 |
| Citata      | 205.20   | 733.55 - - - | - 7370.04 | 7370.04 |
| Jiput       | 5044.94  | 733.55 - - - | - 7370.04 | 7370.04 |
| Kadohejo    | 2972.48  | - 2028.66 - - | - 2028.66 | 2028.66 |
| Karangtanjung| - - - - | 2146.54 | - | 2146.54 |
| Koroncong   | 16.14    | - - - - | - 1631.25 | 1631.25 |
| Labuan      | 1580.33  | - - - - | - 1580.33 | 1580.33 |
| Majasari    | 577.60   | 1459.10 - - - | - 2036.71 | 2036.71 |
| Mandalawangi| 5559.96  | 2636.43 - - - | - 8216.40 | 8216.40 |
| Mekarjaya   | 827.85   | 1975.75 - - - | - 2803.61 | 2803.61 |
| Menes       | 164.092  | 2112.89 - - - | - 2276.88 | 2276.88 |
| Munjul      | - 7479.68 | - - - - | - 7479.68 | 7479.68 |
| Pagelaran   | - 4213.60 | - - - - | - 4213.60 | 4213.60 |
| Pandeglang  | 980.68   | 4213.60 - - - | - 1631.25 | 1631.25 |
| Panimbang   | - - - - | 9821.52 | - | 9821.52 |
| Patia       | - - - - | 582.67 | - | 582.67 |
| Pecung      | - - - - | 1715.34 | - | 1715.34 |
| Pulosari    | 3560.01  | 72.214 - - - | - 3632.23 | 3632.23 |
| Saketi      | 319.57   | 4656.03 - 753.88 - | - 5729.48 | 5729.48 |
| Sindicresmi | - - - - | 199.95 6119.48 - | - 6319.44 | 6319.44 |
| Sobang      | - - - - | 13620.15 | - | 13620.15 |
| Sukaresmi   | - 3528.27 | 1498.44 199.95 - | - 4053.85 | 4053.85 |
| Sumur       | - 55755.02 | - - - - | - 55755.02 | 55755.02 |
| Grand total | 274.863.35 | - - - - | - 274.863.35 | 274.863.35 |
With the same area that is 16,164 Ha at very low intervals. Then the highest PGA cluster there is a Sumur sub-district with an area of 55,755.02 Ha. This is also caused by the same theory as what happened to how Kercong sub-district had the lowest average PGA value, where Sumur sub-district was an area that was very close to several earthquake epicenters and became the closest sub-district of the 3 earthquake epicenter with a scale of 6.0– 6.5 SR (figure 1).

3.3. Distribution of maximum Peak Ground Acceleration (PGA) in Pandeglang Regency
We found that within 20 years, starting from the period 2000–2020 with a depth of less than 100 km, there were 50 earthquakes with a magnitude of 5 on the Richer scale to 6.8 on the Richer scale. An earthquake with a strength of 5 on the Richer scale -6 on the Richer scale for 34 times, 6.1 on the Richer scale for 3 times, and 6.8 on the Richer scale for 1 time. Taken the weight coordinate reference point for each 1 point for each subdistrict, then obtained the maximum PGA value at each point. That included in range VII on the Modified Mercalli Intensity (MMI). Based on the figure 3, using the equal interval method, it is known that the PGA distribution spreads with the largest PGA pattern at the midpoint of the subdistrict and spreads and decreases to the north and south, this is because of the 6.8 magnitude earthquake that occurred on October 25, 2000 with a depth of 38 km which is the epicentre point of the highest PGA in Pandeglang Regency.

The maximum PGA distribution in Pandeglang district is shown in figure 3, with a range of 273,1693 gals to 428,246 gals. Earthquake on October 25, 2000 with strength of 6.8 Richer scale which is the biggest influence on the subdistrict of Anggasana, Cigeulis, Munjul, Panimbang, Patia, Picung, Sidangresmi, Sobang, Sukaresmi. That included in range VII on the Modified Mercalli Intensity (MMI) scale with identification in the form of: vibrations felt by all residents, slightly damaged houses with good construction, while in houses with poor construction there were cracks and even destroyed, damage to exhaust drains, and the earthquake was felt in the vehicle.
With 5 intervals of class division of PGA Pandeglang Regency, where the lowest interval is in the northern part of Pandeglang Regency with a PGA value of 273–303.9 gals. Then a small interval in the north and south with PGA values of 303.9–334.8 gals. At moderate intervals with PGA values of 334.8–365.7 gals which are in the more centered part in Pandeglang Regency. At high intervals around the center of Pandeglang Regency with an interval value of pga 365.7–396.6 gals. Finally, the highest interval is right in the middle of Pandeglang Regency with a value of 396.6–427.5 gals.

In more detail, table 2 describes the area of Peak Ground Acceleration (PGA) for each district in Pandeglang Regency. We can conclude from the table 2 that the areas that have very low PGA are Mandalawangi and Cidasari subdistricts. The high-class PGA cluster, where almost the entire subdistrict is in very high intervals including; Angsana, Panimbang, Sobang and Sindangresmi subdistrict.

| Subdistrict | Very low | Low | Moderate | High | Very high | Total (Ha) |
|-------------|----------|-----|----------|------|-----------|------------|
| Angsana     | -        | -   | -        | 2732.00 | 6164.04   | 8896.04    |
| Banjar      | -        | 2971.42 | -        | -    | -         | 2971.42    |
| Bojong      | -        | -   | 1648.36  | 2909.67 | -         | 4558.03    |
| Cidasari    | 3138.44  | -   | -        | -    | -         | 3138.44    |
| Carita      | 4831.59  | 2132.44 | -        | -    | -         | 6964.03    |
| Cibaliung   | -        | 4621.43 | 6455.14  | 95.46 | -         | 11172.03   |
| Cibitung    | -        | 12009.05 | 318.42   | -    | -         | 12327.47   |
| Cigeulis    | -        | -   | 719.94   | 14733.29 | 1949.43   | 17402.66   |
| Cikedal     | -        | 697.62 | 1878.16  | -    | -         | 2575.77    |
| Cikeusik    | -        | 10635.61 | 5325.31  | 3496.08 | -         | 19457.01   |
| Cimanggu    | -        | 15985.54 | 6424.08  | 1108.05 | -         | 23517.67   |
| Cimanuk     | 22.97    | 2579.55 | -        | -    | -         | 2602.52    |
| Cipeucang   | -        | 2382.84 | 406.55   | -    | -         | 2789.39    |
| Cisata      | -        | 607.02 | 2202.95  | 55.11 | -         | 2865.07    |
| Jiput       | 876.82   | 4774.58 | -        | -    | -         | 5651.39    |
| Kaduhejo    | 2397.89  | 1308.61 | -        | -    | -         | 3706.50    |
| Karangtanjung | 2028.67 | -   | -        | -    | -         | 2028.67    |
| Koroncong   | 2165.70  | -   | -        | -    | -         | 2165.70    |
| Labuan      | -        | 1348.80 | 227.88   | -    | -         | 1576.68    |
| Majasari    | 1928.35  | 108.37 | -        | -    | -         | 2036.72    |
| Mandalawangi | 5033.00 | 3182.07 | -        | -    | -         | 8215.07    |
| Mekarjaya   | -        | 1886.28 | 908.65   | -    | -         | 2794.92    |
| Menes       | -        | 1276.47 | 1000.52  | -    | -         | 2276.99    |
| Munjul      | -        | -    | 6792.98  | 686.70 | -         | 7479.69    |
| Pagelaran   | -        | 3777.10 | 431.18   | -    | -         | 4208.28    |
| Pandeglang  | 1283.50  | 348.75 | -        | -    | -         | 1632.26    |
| Panimbang   | -        | -    | 889.25   | 8952.27 | -         | 9841.53    |
| Patia       | -        | 87.82 | 4453.16  | 262.36 | -         | 4803.34    |
| Picung      | -        | 8.94 | 3620.72  | 1455.85 | -         | 5085.51    |
| Pulosari    | -        | 3632.23 | -        | -    | -         | 3632.23    |
| Saketi      | -        | 1173.83 | 4215.02  | 340.64 | -         | 5729.49    |
| Sindangresmi | -     | -   | 471.61   | 5838.41 | -         | 6310.02    |
| Sobang      | -        | 835.47 | 4073.43  | 8711.24 | -         | 13620.15   |
| Sukaresmi   | -        | 183.35 | 1603.60  | 3265.48 | -         | 5052.43    |
| Sumur       | 20510.60 | 35230.52 | -        | -    | -         | 55741.11   |

Grand total 274,863.35
There is a difference in the distribution of the maximum PGA value, when compared to the distribution of the mean PGA value (figure 2) with the highest distribution in the southern part, while the maximum PGA value distribution is in the middle of Pandeglang district, this is because the epicenter of the earthquake is 6.8 magnitude. The SR which is parallel to the middle of Pandeglang district, besides that, in the high class with 365.7–396.6 gals it tends to be wider in the southern part, this is due to the 3 earthquake epicenter with a magnitude of 6.0–6.5 SR, and with a maximum distribution means ignoring the historical data there is from the lowest range to below the highest.

In another study that discusses the same topic, namely the distribution of the average PGA value and the maximum value of PGA in Pandeglang district, one of them is [15], which uses the earlier method by entering the MMI scale as the core calculation to get the PGA value, where the MMI scale is a scale that is subjective because the observations are based on the effects of the damage. In this study we used a comparison of attenuation to distance units to obtain the PGA value. As a result in [15], there are differences, including the calculation process which only calculates the average of the PGA, and the reference point, so that in visualizing the distribution of the PGA values there is a difference, where in this study the reference point of the calculation leads to each central part of the sub-district which means the distribution of PGA values will be oriented in an administrative area to support decision making by citizens, government, and third parties in each district.

4. Conclusion
With the criteria for the epicenter depth of an earthquake of less than 100 km, and within 20 years recorded from 2000 to 2020, at least until this data is collected, there are 50 earthquakes spread over a magnitude of 5–6.8 on the Richter scale. This shows the high frequency of earthquakes that occur in Pandeglang Regency. From the average PGA data, the highest value is in the middle decreasing to the southern tip of Pandeglang Regency with a value of 67 gals, while the distribution of the minimum value is from the middle to the north end of Pandeglang Regency with a value of 54 gals. Meanwhile, from the maximum PGA data, the area of centralized PGA with the highest PGA value is in the middle of the district and decreases as it spreads to the north and south with the lowest PGA value is 273,394 gals on the northern side of Pandeglang Regency and the highest PGA value is 427.47 gals located in the middle of Pandeglang Regency, which is located in Aangsana, Munjul, Panimbang, and Sidangresmi subdistrict. The high PGA value allows it to enter the MMI VII scale. With the indication of the MMI scale, it requires more attention to the districts with high PGA values to mitigate disasters.

By knowing the distribution of the mean and maximum PGA values in Pandeglang district, the PGA distribution of future earthquakes can be estimated [8], and there will not be many changes in distribution in the future [16], this is because when an earthquake occurs smaller than the largest earthquake that has occurred (< 6.8 SR), the area of the distribution with the highest PGA distribution class on the average PGA distribution and the maximum PGA distribution will be smaller, as well as the expansion at the lowest value. larger (> 6.8 SR), where the area of the lowest class on the average distribution of the PGA and the maximum distribution of the PGA will be smaller because the area of the maximum value will increase.

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