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Study Of Potential Earthquake Vulnerability In Serang City, Banten Based On Seismic Vulnerability Index And Ground Shear Strain Values

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Abstract—The population of Banten Province's Serang City is growing at a pace of 2.59% annually, which raises the need for infrastructure development and urban expansion. However, the city is in a high-risk seismic zone due to its geological location within the Sunda Strait region, which is situated between the Indo-Australian and Eurasian Plates. Assessing the region's seismic vulnerability is crucial for risk reduction and disaster preparedness because the existence of active fault lines increases the likelihood of earthquake risks. Using the Horizontal to Vertical Spectral Ratio (HVSR) approach, which establishes crucial parameters including the ground shear strain (GSS) and seismic vulnerability index (Kg), this study seeks to assess Serang City's seismic susceptibility. 111 measurement sites were used in the study and the data was processed using Geopsy software to derive amplification (A_0) and natural frequency (f_0) values using the H/V spectral curve. To get precise seismic response characteristics, the data analysis procedure included horizontal component combining, spectrum smoothing, H/V ratio averaging, and Fast Fourier Transform (FFT) signal processing. Because of their geological makeup, which includes the Banten Tufa formation—a loose volcanic deposit known to magnify ground motion during earthquakes—Walantaka and Taktakan Districts are found to have high seismic sensitivity (>20 s^2/cm). Furthermore, fault lines and coastal locations with Alluvium deposits have the highest ground shear strain (GSS) values, ranging from 1.66×10^{-6} to 1.83×10^{-4}. This makes these areas particularly vulnerable to soil deformation caused by seismic activity. These findings highlight the need for stringent building regulations, earthquake-resistant infrastructure, and efficient urban planning in order to lower Serang City's seismic risk. The study's conclusions give politicians, urban planners, and disaster management authorities crucial information that makes it easier to create focused mitigation plans that would improve infrastructure resilience and public safety in the event of future earthquakes.

Keywords—HVSR; Earthquake; Serang; Seismic Vulnerability Index; Ground Shear Strain.

I. Introduction

One of the most devastating natural catastrophes, earthquakes frequently cause extensive infrastructure damage, large financial losses, and a terrible death toll. They are particularly deadly because of their unpredictable nature, which allows them to strike abruptly and intensely. Seismic activity is frequent and severe in Indonesia, which is situated along the Pacific Ring of Fire, a seismically active zone where many tectonic plates converge. Because of its geographical location, the nation is extremely vulnerable to earthquakes, hence being prepared for them is an essential part of national disaster management. Serang City in Banten Province has a moderate earthquake risk, one of many areas susceptible to seismic risks. Its proximity to active faults,

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especially the Cimandiri Fault, which has historically caused seismic activity in western Java, is the main cause of this risk[1]. The potential impact of earthquakes is further increased by the city's rapid urbanization and population density, underscoring the urgent need for a thorough evaluation of its seismic susceptibility.

An in-depth analysis of a number of crucial indications that aid in forecasting how various soil compositions would react to seismic forces is necessary to comprehend seismic vulnerability. Ground Shear Strain (GSS) and the Seismic Vulnerability Index (Kg) are two of the most important metrics in this evaluation. These variables shed light on the level of soil instability and the potential for ground shaking to be exacerbated in a particular location. By examining the natural frequency and amplification of seismic waves when they interact with subsurface materials, the Horizontal to Vertical Spectral Ratio (HVSR) approach is frequently employed to assess these characteristics. Researchers can use this method to find soil types that are susceptible to resonance effects, which can greatly increase ground motion during an earthquake. In addition to improving the precision of seismic risk assessments, the HVSR approach is a useful instrument for anticipating possible harm in urban settings, which supports disaster preparedness initiatives.

By examining several seismic indicators, such as the seismic vulnerability index, peak ground acceleration (PGA), and ground shear strain, this study seeks to thoroughly map and assess Serang City's seismic risk. In order to provide a thorough evaluation of earthquake-prone zones, the research uses the HVSR approach to categorize regions according to their geological formations and ground motion characteristics. In order to make well-informed decisions about infrastructure development, urban planning, and disaster mitigation methods, the results of this study will offer crucial insights into the relationship between local soil characteristics and seismic activity. Authorities will be able to prioritize structure reinforcements, put targeted safety measures in place, and allocate resources efficiently to reduce earthquake-related damages if they can identify areas with increased seismic risk.

In addition to its scholarly contributions, this research has important applications for engineers, legislators, urban planners, and disaster management representatives. To guarantee that future development projects comply with seismic safety standards, the findings will assist local governments in creating mitigation plans, enforcing strict building codes, and putting zoning regulations into place. Retrofitting existing structures and infrastructure will be crucial to improving earthquake resistance in high-risk locations. Additionally, emergency response organizations can create more efficient evacuation plans and disaster response frameworks by pinpointing particular areas with increased earthquake susceptibility. Such preventative actions will be essential in lessening the overall effects of earthquakes, saving lives, and preserving vital infrastructure.

In summary, by offering a thorough and empirically supported evaluation of seismic susceptibility, this study seeks to improve earthquake risk management in Serang City. The findings will be used as a basis to improve public safety, increase structural resilience, and fortify readiness for disasters. This study aims to lessen the effects of upcoming seismic events and support Serang City's sustainable development by combining geophysical analysis with urban planning techniques. Prioritizing seismic risk reduction initiatives will be crucial as urban areas continue to grow in order to provide a safer and more resilient future for the city's expanding population.

II. Method

Data processing for this study was done at the Meteorology, Climatology, and Geophysics Agency (BMKG) in Central Jakarta during the course of three months, from June to August 2024. Three different kinds of seismic wave recordings—two horizontal and one vertical—that were supplied by BMKG were used in the study as secondary seismic data. These recordings were crucial for assessing Serang City's seismic activity and the reaction of its various soil types. A variety of software and computational techniques were used to guarantee an organized and methodical study. Excel was used for statistical and numerical computations, ArcGIS was used for spatial mapping and visualization, Geopsy software made it easier to process microtremor data and create Horizontal to Vertical Spectral Ratio (HVSR) curves, and a laptop was used for data processing.

A methodical approach was used, starting with a review of the literature that concentrated on the HVSR method, historical seismic activity in Banten Province, and Serang City's geological features. The theoretical underpinning required to create an efficient method for data collecting and analysis was supplied by this pioneering study. Microtremor measurements were made at

111 different places in Serang City during the data collection phase. Essential seismic characteristics were extracted by processing the gathered seismic wave data using Geopsy software after it was saved in .mseed format.

Several analytical methods were used throughout the data processing stage to transform unprocessed seismic data into insightful knowledge. The accuracy of seismic wave interpretation was increased by applying Fourier Transform analysis to convert time-domain signals into the frequency domain. Using the Konno and Omachi (1998) smoothing filter with a bandwidth coefficient of 40 and a cosine taper of 5%, the natural frequency (f_0) values were made clearer and more consistent. By reducing noise, this filtering procedure improved the HVSR curves' dependability.

Key seismic metrics, such as the seismic vulnerability index (Kg) and amplification factors, were determined using the HVSR curves produced from the microtremor data. These curves were essential for evaluating the earthquake susceptibility of various Serang City districts. Furthermore, the Ground Shear Strain (GSS) and Peak Ground Acceleration (PGA) values were computed using Nakamura's (1997) approach. While the GSS values assisted in assessing the possibility of soil deformation and structure instability during seismic events, the PGA values offered insight into the magnitude of ground motion anticipated in different areas of the city.

Seismic hazard mapping and spatial analysis were part of the study's last phase. The analyzed seismic data was shown using ArcGIS software to create thematic maps that categorized various areas according to their seismic susceptibility levels. These maps provided useful information for assessing earthquake hazard by clearly highlighting high-risk areas. In developing mitigation strategies, enforcing stringent building codes, and making sure that current and future structures in earthquake-prone areas are built to withstand seismic activity, urban planners, government officials, and disaster management agencies rely heavily on the study's findings.

This study offers a thorough, data-driven method of evaluating seismic hazards in Serang City by combining geophysical approaches, computational modeling, and sophisticated spatial mapping. To improve readiness measures for possible seismic events in the area and further refine earthquake risk estimates, future research may integrate 3D subsurface modeling and real-time seismic monitoring systems.

III. RESULT AND DISCUSSION

3.1. Dominant Period Analysis

The dominating period is a crucial metric examined in this study to evaluate soil vulnerability in Serang City. Figure 1 shows the strategic distribution of 111 microtremor measurement stations in several districts, such as Cipocok Jaya, Curug, Kasemen, Serang, Taktakan, Walantaka, and Ciruas in Serang Regency.

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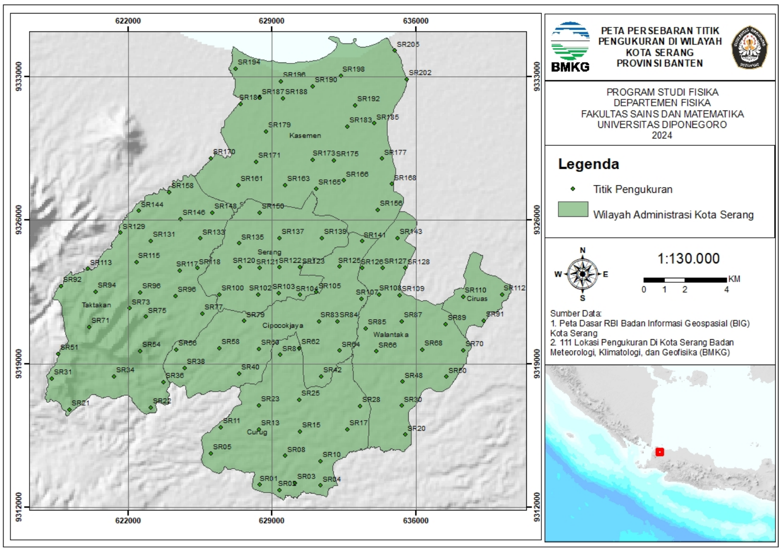

Figure 1. Microtremor measurement points distribution map

The dominant period was ascertained using the data gathered from these measurement points. Seismic wave data from Serang City was processed using the Horizontal to Vertical Spectral Ratio (HVSR) approach in order to recover the natural frequency values. Geopsy software, which offered three waveform renderings as part of the research, was used to process the data. The average duration of BMKG's 2020 microtremor measurements was 30 minutes. Accurate readings could be hampered by the presence of human activity noise in addition to seismic signals in these recordings. As suggested by Nakamura, a windowing procedure was used to separate stationary signals in order to lessen this. In order to provide a crisper signal during H/V analysis, an anti-trigger windowing approach was also used to remove transient disturbances[2]. Figure 2 shows the anti-trigger process at point SR01.

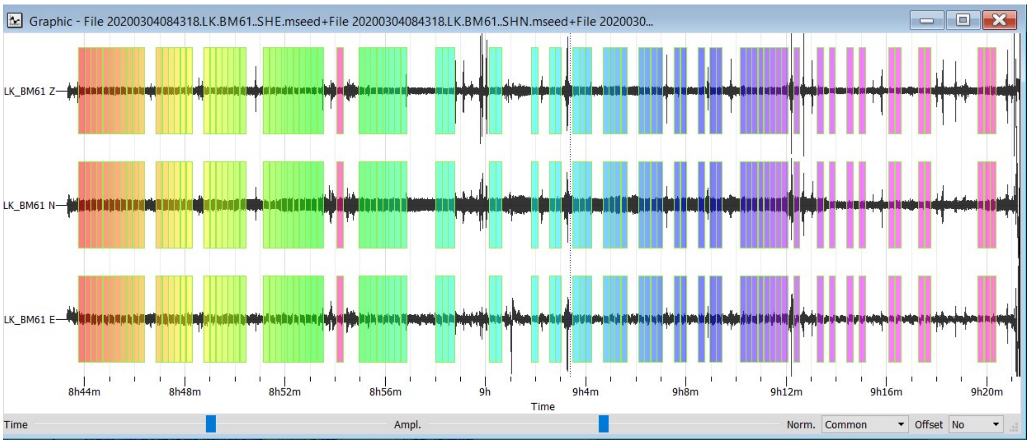

Figure 2. Microtremor data processing anti-trigger process at point SR01

The creation of the H/V curve (Figure III) was the next step in the data processing process. A 3 Hz low-pass filter was used in the anti-trigger procedure to improve the spectral analysis. To further improve data reliability, a Konno & Omachi smoothing filter with a bandwidth coefficient of 40 and a cosine taper of 5% was employed. In order to preserve uniformity in the analysis and provide quality control of the HVSR curves, the SESAME (2004) standard was also applied[3].

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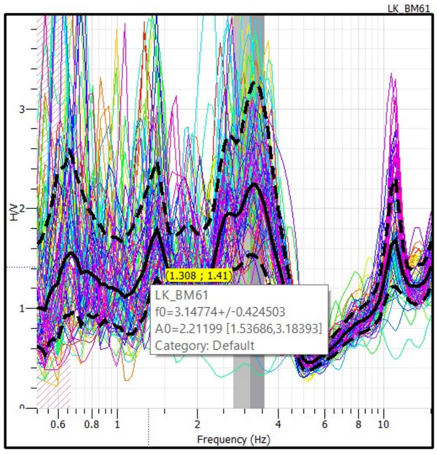

Figure 3. HVSR curve at point SR01

Across several districts, the prevalent period values found in this study varied from 0.02 to 0.69 seconds. Cipocok Jaya District had the lowest dominating period value, measuring 0.02 seconds, while Taktakan District had the greatest, measuring 0.69 seconds. Table I shows how the dominant period values are categorized by soil type in Serang City. Four different soil kinds can be found in Serang City, according to Arifin et al.'s classifications[4]. Harder soil types have shorter dominant periods, whereas softer soil types have longer dominant periods. Figure 4 shows the distribution of dominant period values throughout the city.

TABLE I. SERANG CITY'S SOIL CLASSIFICATION BASED ON DOMINANT PERIOD VALUE

Soil Classification		Dominant Period (sec)	Characteristics
Kanai	Omote-Nakajima		
Type I	Type A	0,02 - 0,15	Hard soil
Type II		0,15 - 0,25	Medium soil
Type III	Type B	0,25 - 0,38	Soft soil
Type IV	Type C	0,53 - 0,69	Very soft soil

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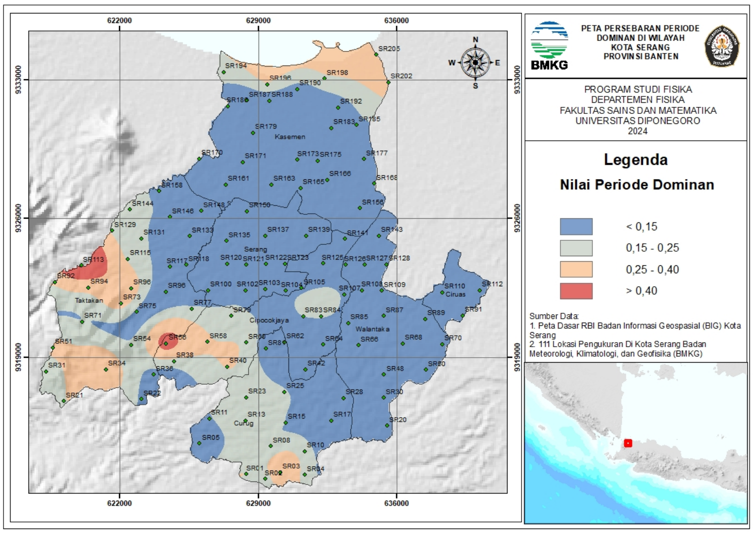

Figure 4. Dominant period distribution map

3.2 Seismic Vulnerability Index (Kg) Analysis

One of the most important metrics for determining how vulnerable soil is to seismic activity is the seismic vulnerability index (Kg). The dominant period and the amplification factor gleaned from the H/V curve are used to calculate this index. Greater seismic sensitivity and a higher chance of ground motion amplification are indicated by higher Kg values. The study's conclusions show that the districts of Walantaka and Taktakan, where the Banten Tuff formation predominates, had the highest Kg values (>20 s^2/cm). This geological formation's soft and unconsolidated composition greatly increases the amplification of seismic waves, raising the risk of earthquakes in certain areas[5].

Strong ground motion during an earthquake is more likely to occur in areas with high Kg values since these areas typically have low natural frequencies. Serang City's high-risk areas are shown in detail spatially on the seismic vulnerability map (Figure 5). These results are in line with earlier studies that indicate areas with tuff and alluvial formations typically undergo more seismic amplification than areas with compact rock formations.

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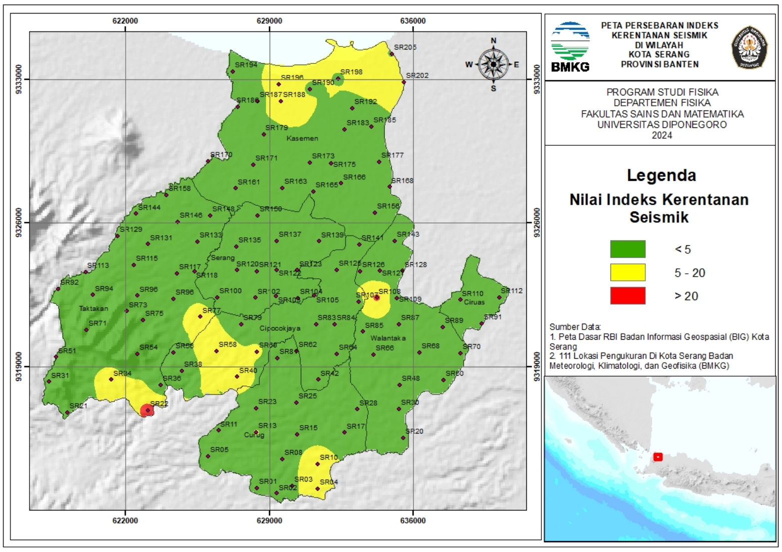

Figure 5. Seismic vulnerability index distribution map

3.3 Peak Ground Acceleration (PGA) Analysis

Peak Ground Acceleration (PGA), which measures the highest acceleration of ground motion during seismic activity, is a crucial metric in assessing earthquake danger levels. To determine which areas of Serang City are most vulnerable to severe earthquake effects, the PGA values determined in this study were mapped. According to the investigation, PGA values were higher in places close to fault lines, especially in those where loose sediments and unconsolidated formations were present. These results are consistent with other research that highlights how important geological features are in determining the magnitude of ground displacement during earthquakes. Figure 6 shows the distribution of PGA in Serang City.

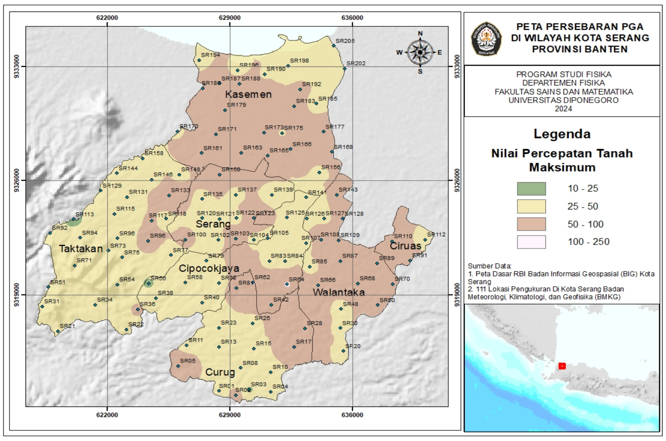

Figure 6. Peak ground acceleration distribution map

Serang City's PGA values varied from 19.49 cm/s² to 103.48 cm/s², with Taktakan District recording the lowest values and Cipocok Jaya District recording the highest. Table II displays the Modified Mercalli Intensity (MMI) scale for seismic hazard classification, which groups regions depending on the possible intensity of ground motion[6].

TABLE II. THE MODIFIED MERCALLI INTENSITY SCALE

Intensity	Effects	PGA (gal)
I	Not felt	< 1
II	Felt only by a few people at rest	1 - 2
III	Felt quite noticeably by people indoors	2 - 5
IV	Felt indoors by many	5 - 10
V	Felt nearly by everyone	10 - 25
VI	Felt by all	25 - 50
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built structures	50 - 100
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse; damage great in poorly built structures	100 - 250
IX	Damage considerable in specially designed structuresl well-designed frame structures thrown out of plumb; damage great in substantial buildings	250 - 500
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed	500 - 1000

3.4 Ground Shear Strain (GSS) Analysis

When evaluating the possibility of ground deformation and structure instability in reaction to seismic activity, ground shear strain (GSS) is a crucial indicator. A greater likelihood of surface fissures, land subsidence, and soil failure is linked to higher GSS levels. Serang City's GSS values in this study varied from 1.66×10^{-6} to 1.83×10^{-4}. The highest values were seen along active fault lines in places where the Banten Tuff formation predominates and along coastal zones where alluvial deposits are present. Because of their high liquefaction susceptibility and low shear strength, these geological formations are particularly vulnerable to deformation brought on by earthquakes.

Serang City does not show GSS values above 10^{-3}, indicating a low likelihood of significant ground displacement events like liquefaction or landslides, according to seismic hazard classifications [6]. However, in regions with high GSS values, localized structural damage is still a worry. The GSS microzonation map, shown in Figure 7, shows that Walantaka District has the greatest GSS values while Kasemen District has the lowest.

A major factor in assessing the extent of damage caused by earthquakes is geological conditions. Tuff, pumice tuff, and tuffaceous sandstone make up the Banten Tuff deposit, which makes up the majority of Serang City. The relationship between geological formations and GSS values is seen in Figure 8. Alluvial formations, which are recognized for their greater capacity to amplify waves in comparison to compact soils, were linked to comparatively high GSS values in Kasemen District. Furthermore, a geological fault structure in Serang City's southwest is identified by the seismic hazard map. It is well recognized that active faults can cause severe shaking and ground deformation, raising the possibility of seismic hazards in the surrounding areas.

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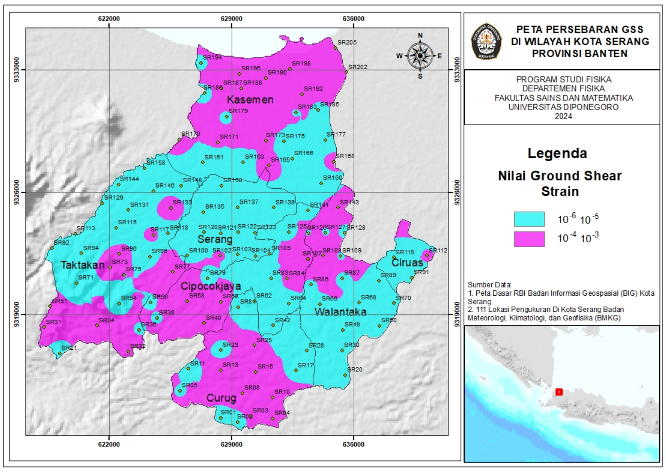

Figure 7. Ground shear strain distribution map

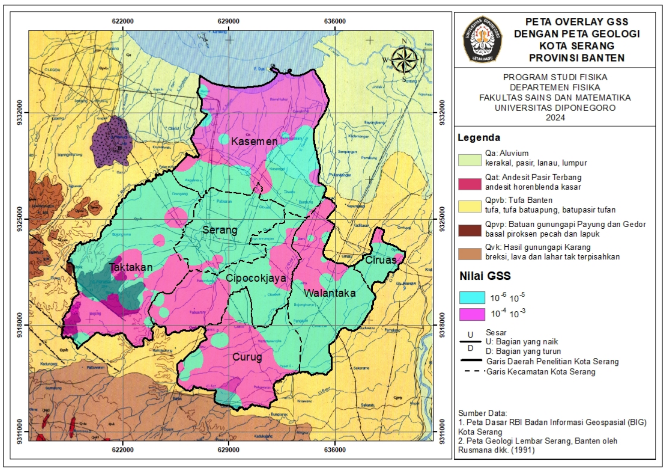

Figure 8. Overlay map of ground shear strain with geology of Serang City

This study offers a thorough evaluation of Serang City's seismic susceptibility by examining these factors, making it an invaluable tool for infrastructure development, urban planning, and catastrophe risk management. In order to improve earthquake risk assessments and mitigation techniques, future research might concentrate on integrating sophisticated 3D subsurface modeling and real-time seismic monitoring.

IV. Conclusion

The study's conclusions show that Serang City's seismic vulnerability index ranges from 0.02 to 23.42 s^2/cm with Taktakan District having the highest values, indicating a higher seismic risk there. Disparities in soil characteristics among different districts, which affect the extent of seismic wave amplification during an earthquake, were revealed by the dominant period study. The study also showed that soft soil formations, especially those with Banten Tuff and alluvial deposits, are associated with high seismic vulnerability index values. These geological characteristics greatly increase the amplification of ground motion, raising the possibility of earthquake-related damage in particular areas.

Furthermore, the ground shear strain (GSS) values obtained from this study align with the geological features of the area. The coastal regions of Kasemen District, which are made up of unconsolidated alluvial deposits, and Taktakan District, particularly the fault zones inside the Banten Tuff formation, have the highest GSS values. Serang City's GSS values, which vary from 1.66×10^{-6}

to 1.83 × 10^{-3}, show that some areas are more vulnerable to ground deformation during seismic activity. In order to reduce the possible effects of earthquakes in Serang City, our findings emphasize the need for stronger disaster preparedness measures, strict enforcement of construction codes, and the design of infrastructure that is earthquake-resistant. To further improve earthquake risk assessments and mitigation techniques, future studies should think about combining sophisticated 3D subsurface modeling with real-time seismic monitoring.

V. Acknowledgment

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