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Analysis of Flood Risks on The Power Distribution System Infrastructure at Pt PLN (Persero) Distribution Banten Due to Climate Change

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Abstract

The electricity distribution system in the work area of PT PLN (Persero) Banten Distribution Main Unit is facing increasing challenges due to the rising frequency and intensity of floods caused by climate change. Historical data show that power outages resulting from natural disasters contribute significantly to the unreliability of distribution systems, with flood events occurring in seasonal patterns and tending to be spatially widespread. This condition requires a comprehensive understanding of the factors that cause flooding and the level of flood vulnerability in the areas where the electricity infrastructure is located, serving as a basis for more targeted risk management efforts. This study employs a quantitative approach based on spatial analysis to identify and analyze flood vulnerability. The flood risk assessment is conducted by integrating four main parameters—slope, rainfall, land use, and soil type—each weighted according to its influence on flood occurrence. Rainfall data were analyzed using historical records from 2014–2024, as well as climate projections under the SSP 2-4.5 and SSP 5-8.5 scenarios. All parameters were processed using a Geographic Information System (GIS) to produce flood vulnerability maps and identify risk levels to the electricity infrastructure. The results indicate that flood vulnerability in the study area is predominantly influenced by topographic factors, followed by soil type, while rainfall and land use exert relatively balanced influences. Flood risk mapping shows variations in vulnerability levels across different climate scenarios. By 2030, areas classified as Vulnerable Risk and Moderately Vulnerable Risk are expected to dominate, while by 2050, a shift is projected toward the increasing dominance of Moderately Vulnerable Risk under both SSP scenarios.

Keywords: flood vulnerability, electricity distribution infrastructure, geographic information system (gis), risk assessment, climate change scenarios

INTRODUCTION

In the power distribution system, outages can be divided into planned outages for network maintenance activities and unplanned outages due to interference. One of the main causes of unplanned outages is force majeure, including natural disasters (Salahuddin Ali, 2025). In the last four years, power outages due to force majeure in the working area of PT PLN (Persero) main distribution Unit (UID) Banten accounted for 7.5% of the total energy Not Served (ENS) (Ibrohim & Amir, 2025; Ramadyanto, 2019). Operational Data show that in 2023 there were 9 outages due to natural disasters, and this number is happening again in 2024 with a wider coverage of outages (Brelsford et al., 2024; Demir & Demir, 2025). These disturbances are mainly triggered by high rainfall, extreme weather, floods, and landslides, with a seasonal pattern of events, namely in the period January-March and November-December (Capozzi et al., 2023; HIHimalayan, n.d.; Yandri & Nur, 2025).

Scientific studies show that such seasonal outage patterns are in line with the global trend of increasing disruptions in the power grid due to extreme weather (Hawker et al., 2024; Souto et al., 2024). Zolton and Hade (2024) report that incidents of extreme weather-induced blackouts increased from about 50 incidents per year in the early 2000s to more than 100 incidents per year in the past five years, reflecting the increasing operational risks of electrical systems. In the Indonesian context found that extreme weather events more predominantly disrupt distribution systems than power plants, with lightning disruption and extreme rain as major factors (Gonçalves et al., 2024; Panteli & Mancarella, 2015; Shield et al., 2021). These findings confirm that the distribution system is the component most vulnerable to Hydrometeorological impacts (Carlos Lam et al., 2020; Loukas et al., 2021; Mavhura, 2019).

The working area of PT PLN UID Banten holds a strategic position because it contributes around 10% of national electricity revenue; therefore, the reliability of the distribution system in this region is crucial. However, Banten's geographical characteristics, which include coastal and lowland areas, increase the vulnerability of distribution infrastructure to flooding—especially at distribution substations, medium-voltage networks, and other supporting equipment. The international literature also confirms this vulnerability. A study in Malaysia showed that flood inundation at distribution substations can cause sudden and large-scale undistributed energy loss (Afzal et al., 2024), while Leandro et al. (2021) identified MV–LV transformers as critical failure points during urban flood events. The regional risk assessment by Ye et al. (2024) likewise confirms the high exposure of the power grid in coastal and lowland regions of Southeast Asia to flood risk.

This research carries high urgency from both technical-operational and policy perspectives. Technically, power outages caused by floods not only result in direct economic losses from unchanneled energy but also disrupt supply chains, public services, and community activities that increasingly depend on a reliable electricity supply. Without an accurate spatial understanding of infrastructure vulnerabilities, mitigation and adaptation efforts risk becoming reactive, poorly directed, and inefficient in resource allocation. From a policy standpoint, integrating climate change projections into critical infrastructure planning is essential in the current era of climate uncertainty. The electricity sector, as the backbone of the economy and modern life, must possess adequate resilience. This study is particularly urgent because it provides a database and a projected risk map through 2050, which can serve as a scientific foundation for developing medium- to long-term adaptation strategies, infrastructure hardening programs, and more advanced early warning systems for PT PLN UID Banten and related stakeholders.

Based on these conditions, a comprehensive understanding of the causes of flooding and the level of flood vulnerability affecting electricity infrastructure is required. Therefore, this study focuses on identifying and analyzing the factors influencing flood occurrences and developing flood risk maps for the electricity distribution system infrastructure in the Banten area, serving as a basis for assessing the vulnerability level of electricity infrastructure to flooding.

METHODS

This study aims to identify and analyze the factors that cause flooding and compile a flood risk map for the electricity distribution system infrastructure in the work area of PT PLN (Persero) Banten Distribution Main Unit. The method used is a spatial analysis approach based on scoring and weighting, by utilizing regional physical and hydrometeorological data that affect flood events.

Research Data and Variables:

The variables used in flood risk mapping consist of four main factors, namely slope slope, soil type, rainfall, and land cover. These four factors were chosen because they have a direct influence on the surface runoff process and the potential for flooding in the study area.

Classification and Scoring of Flood-Causing Factors

1. Slope Slope

The slope slope is classified into five classes, namely flat (0–8%), sloping (>8–15%), slightly steep (>15–25%), steep (>25–40%), and very steep (>45%), referring to Darmawan and Suprayogi (2017). Areas with a more sloping slope are given higher scores because they have a greater potential for inundation. The slope slope factor is given a weight of 5, so that the final value is obtained from the result of the multiplication of the score and the weight according to the classification table.

Table 1 Slope Classification

Slope (%)	Description	Value	Weight	Score
0 - 8	Flat	5	5	25
>8 - 15	Sloping	4	5	20
>15 - 25	A bit steep	3	5	15
>25 - 40	Curam	2	5	10
>45	Very Steep	1	5	5

Source: Darmawan and Suprayogi, 2017

2. Soil Type

Soil types are classified based on the level of infiltration sensitivity into insensitive, moderately sensitive, moderately sensitive, sensitive, and highly sensitive. Soils with low infiltration ability were given higher scores because they tended to increase surface runoff. The soil type factor is given a weight of 3, and the factor value is obtained from the result of the multiplication of the score and weight according to the classification used.

Table 2 Classification of Soil Types

Soil Type	Infiltrating	Value	Weight	Shoes
Alluvial, Palnosol, Kelabu / Gleisol Hydromorph, Laterik	Insensitive	5	3	15
Latosol	Somewhat Sensitive	4	3	12
Cambohydrate, Brown Forest Soil, Mediterranean Soil	Moderate Sensitivity	3	3	9
Andosol Laterik Grumosol, Podsol, Podsolic	Point	2	3	6

Regosol, Litosol, Organosol, Renzina	Highly Sensitive	1	3	3

Source: Darmawan and Suprayogi, 2017

3. Rainfall

Rainfall is classified based on average annual rainfall into low (2000–2500 mm/year), medium (2500–3000 mm/year), high (3000–3500 mm/year), and very high (>3500 mm/year), referring to the National Disaster Management Agency (2020). The higher the intensity of the rainfall, the greater the score given. The rainfall factor is given a weight of 2, so that its contribution to flood risk is obtained from the result of multiplying the score and weight.

Table 3 Rainfall Classification

Average Rainfall (mm/yr)	Rainfall	Value	Weight	Shoes
2000 - 2500	Low	1	2	2
2500 - 3000	Medium	2	2	4
3000 - 3500	Height	3	2	6
>3500	Very High	4	2	8

Source: Darmawan and Suprayogi, 2017

4. Land Cover

Land cover is classified into forests, shrubs, fields/moors/gardens, rice fields and open land, and settlements or built land. Each type of land cover is given a score and score based on its ability to retain and absorb rainwater. Built-up land and open land are given the highest scores because they have low infiltration ability and increase surface runoff.

Table 4 Land Cover

Land Use	Value	Weight	Shoes
Forest	1	2	2
Bushes	2	2	4
Farms/Moors/Gardens	3	2	6
Rice Fields/Bare Land/Sand/Ponds/Lakes/Situ/Reservoirs	4	2	8
Settlements / Built Land	5	2	10

Source: Darmawan and Suprayogi, 2017

Preparation of Flood Risk Maps

All maps of flood factors were processed using the Geographic Information System (GIS). The value of flood risk at each location was obtained by summing the scoring and weighting values of all factors, according to the scheme used in the classification table. The value of the merger was then classified into four levels of flood risk, namely Somewhat Vulnerable, Moderately Vulnerable, Vulnerable, and Very Vulnerable.

RESULTS AND DISCUSSION

Analysis of Factors Causing Flooding

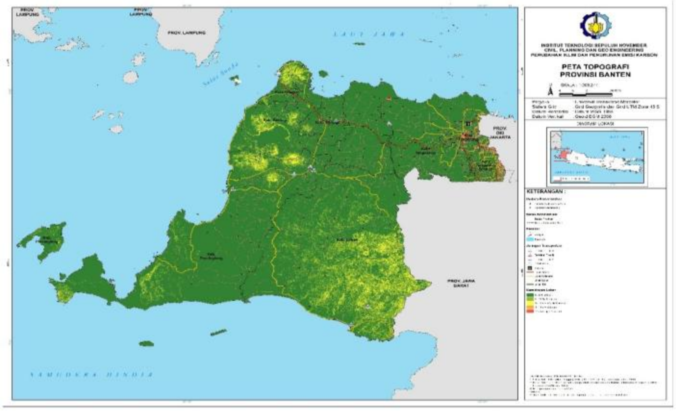
To assess flood vulnerability, it is necessary to identify and analyze the main factors influencing flood occurrence. The factors examined in this study include slope, rainfall, land use, and soil type. These four parameters serve as the primary variables in the flood vulnerability analysis for the study area because each exerts a different level of influence on inundation and surface runoff. The difference in influence is expressed through weighting, where a higher weight indicates a greater contribution to overall flood vulnerability. These weights are then used to calculate the flood vulnerability index according to the established weighting scheme.

Based on the weighting results, slope is the factor that contributes the most to flooding. Slope, or land gradient, represents the percentage ratio between vertical distance (elevation) and horizontal distance (length of flat land). The gentler the slope, the higher the potential for flooding; conversely, steeper slopes have lower flood potential because water drains more quickly. The classification of slope gradients follows the Guidelines for the Preparation of Patterns of Land Rehabilitation and Soil Conservation (1986) as referenced in Darmawan (2017). The next influential factor is soil type. The characteristics of soil type play a critical role in the infiltration process—namely, the vertical movement of rainwater into the soil layer. This process is governed by several physical factors, including soil structure and texture, compaction level, moisture conditions, and the presence of surface vegetation. Rainfall and land use factors carry equal weight in determining flood vulnerability risk.

Topography of Banten Province

This Topographic Map of Banten Province depicts the distribution of elevation and slope of land throughout the province's administrative area. The northern region of Banten such as Tangerang City, South Tangerang, Cilegon, and parts of Serang Regency is dominated by flat to sloping areas (slope <15%), indicated by dark green to light green colors. This area is a lowland area that is very vulnerable to inundation flooding, especially during the rainy season and when runoff from the southern region moves downstream.

Image 1 Topographic Map of Banten Province



On the other hand, the central and southern parts of Banten Province, especially Lebak and Pandeglang Regencies, show the dominance of steep to very steep slopes, characterized by yellow to red colors. This topography shows hilly and mountainous areas, which naturally serve as water catchment areas. However, when extreme rains occur, this area has a high potential for flash floods and landslides, especially if it experiences land cover degradation.

This topographic distribution has important implications for the management of hydrometeorological disaster risks, including floods and landslides, as well as the placement of critical infrastructure such as power distribution networks. Low-lying power distribution systems need to be protected from inundation, while infrastructure on steep slopes needs to be strengthened against the risk of landslides and torrential surface flows. The topography also affects the direction of the river flow in Banten, which generally flows from south to north, towards the Java Sea.

Table 5 Topography of Banten Province

Wilayah	Klasifikasi (Ha)					Grand Total
	Agak Curam	Curam	Datar	Landai	Sangat Curam	
Kab. Lebak	7.126,8	245,5	106.919,2	37.759,5	1,5	152.052,5
	7.065,1	200,2	135.999,8	35.784,5	0,1	179.049,8
Kab. Pandeglang	1.664,4	68,8	169.756,6	13.273,7	1,7	184.765,2
	11,0	0,0	40.470,7	168,6		40.650,3
	1.706,1	54,7	44.242,1	5.552,1	0,1	51.555,1
Kab. Serang	1.418,9	83,9	30.952,2	6.465,2	0,3	38.920,4
	1,1		70.786,3	192,0		70.979,5
	1.060,8	12,0	15.323,1	3.390,5		19.786,5
	634,6	17,1	14.715,0	1.879,7		17.246,5
Kab. Tangerang	0,7		47.793,4	56,7		47.850,7
	3,4		20.726,4	75,3		20.805,0
			34.084,5	25,3		34.109,8
Kota Cilegon	43,8		3.997,7	308,1		4.349,6
	648,8	4,8	9.398,6	1.841,9		11.894,0
Kota Serang	68,3	0,0	25.781,4	718,7		26.568,4
Kota Tangerang	1,0	0,0	17.748,3	85,9		17.835,2
Kota Tangerang Selatan	5,3		16.393,5	88,6		16.487,3
Total	21.460,2	687,2	805.088,8	107.666,1	3,6	934.905,9

Each class of slope slope was then analyzed and weighted with the following details:

Table 6 Slope Area of Banten Region and Weighting

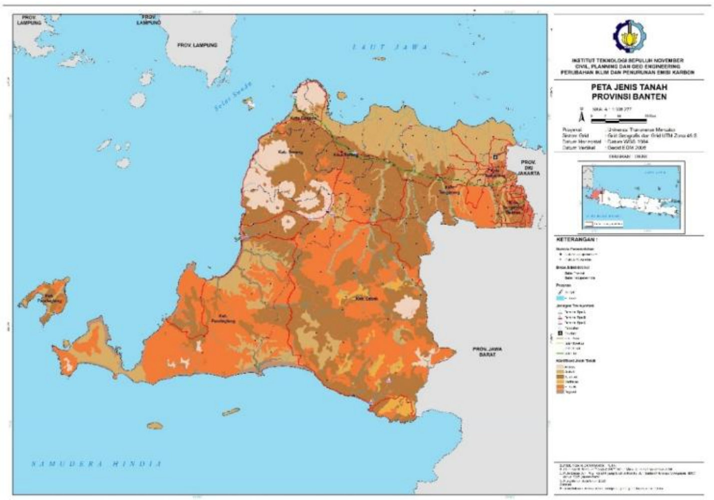
Kemiringan (%)	Kelas	Luasan	Persentase Luasan	Bobot	Skor
0 - 8	Datar	805.088,77	0,86	5,00	25,00
>8 - 15	Landai	107.666,11	0,12	5,00	20,00
>15 - 25	Agak Curam	21.460,23	0,02	5,00	15,00
>25 - 40	Curam	687,20	0,00	5,00	10,00
>45	Sangat Curam	3,60	0,00	5,00	5,00

Soil Type

Based on the map of land types of Banten Province, the Banten region is dominated by several main types of soil, namely Kambisol, Mediteran, Podsolik, Andosol, Gleisol, and Regosol. Spatially, Andosol soil is widely developed in the mountainous and highland zones of the southern and western parts, especially in the Lebak and Pandeglang Regency areas which are located in the mountainous areas and slopes of Mount Halimun-Salak and the Kendeng Mountains. This type of soil has a crumb structure and high porosity, so its infiltration capacity is relatively good. This condition provides a high absorption ability of rainwater, so that it naturally reduces the potential for surface runoff and reduces the level of flood vulnerability in upstream areas.

In contrast, the lowland and northern coastal areas of Banten, especially in Serang Regency and City, Tangerang Regency, Tangerang City, and South Tangerang City, are dominated by Gleisol, Allaluvial, and Podsolik. These soils have poor drainage properties, a finer texture, and low infiltration power, making them highly susceptible to inundation accumulation. This zone is also an area with high urbanization development and dominance of built-up land use, which further reduces the ability of soil infiltration. The combination of less permeable soil characteristics and the pressure of land use change has caused the northern area of Banten to become the area with the highest flood vulnerability.

Image 2 Soil Type Map



When associated with projected rainfall due to climate change, the Banten region is expected to experience an increase in the intensity of extreme rainfall and a more uncertain shift in rainy season patterns. Increased rainfall intensity will raise the volume of surface runoff, especially in areas with low-infiltration soils such as Gleisol and Podsolik in the lowlands, thereby increasing the frequency, extent, and duration of flooding. In the southern mountainous regions dominated by Andosol and Regosol, infiltration capacity is relatively good; however, increased extreme rainfall still poses the potential to generate high runoff on steep slopes, which then flows downstream to northern areas, exacerbating flood risk in urban and coastal zones.

Thus, the spatial configuration of soil types in Banten Province serves as a key factor controlling flood vulnerability patterns. The upstream areas with high-infiltration soils function as infiltration zones, while the downstream zones with low-infiltration soils become runoff accumulation areas. When combined with the trend of increasing extreme rainfall due to climate change, this soil structure contributes to heightened vulnerability in the hydrological system—particularly in the northern and coastal regions of Banten, which also serve as centers of economic activity and major electricity infrastructure networks.

The implications for the electric power distribution system are substantial, as most substations, distribution substations, and medium-voltage networks are located in low-lying areas characterized by highly flood-prone soils. The following section presents the weighting classification of soil types:

Table 7 Land Type Area of Banten and Weighting

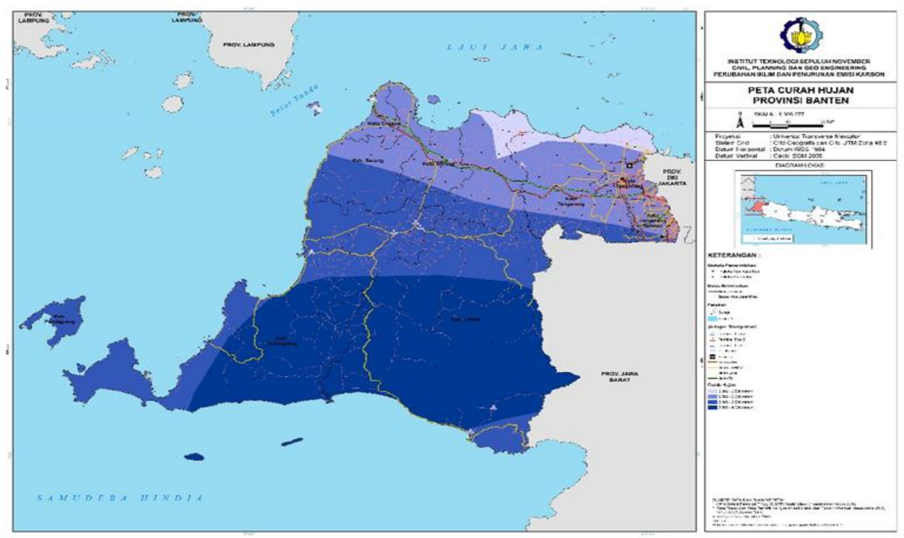
Jenis Tanah	Kelas Infiltrasi	Luasan	Persentase Luasan	Bobot	Skor
Aluvial, Palnosol, Hidromorf Kelabu / Gleisol, Laterik	Tidak Peka	207.360,87	0,22	3,00	15,00
Latosol	Agak Peka		-	3,00	12,00
Kambisol, Tanah Hutan Coklat, Tanah Mediteran	Kepekaan Sedang	366.128,52	0,39	3,00	9,00
Andosol Laterik Grumosol, Podsol, Podsolic	Peka	340.817,87	0,36	3,00	6,00
Regosol, Litosol, Organosol, Renzina	Sangat Peka	20.598,66	0,02	3,00	3,00

Rainfall

During the period 2014 to 2024, Banten Province showed significant variations in annual rainfall patterns influenced by global climate conditions, such as El Niño and La Niña phenomena. Based on rainfall data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), several years have experienced quite extreme anomalies. In 2016 and 2020, for example, there was a spike in rainfall due to the strengthening of La Niña which increased air humidity in Indonesia, while 2015 and 2019 showed a decrease in rainfall due to the influence of moderate El Niño (BMKG, 2024).

The spatial distribution of rainfall shows that the southern regions of Banten, such as Lebak and Pandeglang Regencies, tend to receive higher rainfall than northern regions such as Tangerang and Cilegon. The monthly rainfall accumulation during the rainy season (November-March) in the southern region of Banten is recorded to exceed 400 mm per month, while in the northern part it only ranges from 200–300 mm (BNPB, 2023). Topographic factors and distance from the coastline are the main determinants of this difference.

Image 3 Historical Rainfall Map 2014-2024



Historical data trends also show an increasing frequency of days with extreme rainfall, particularly in the R95p and R99p categories, which represent rainfall events above the 95th and 99th percentiles. According to an IPCC study (2021), rising global temperatures allow the atmosphere to hold more water vapor, which is later released as extreme rainfall over short durations. In Banten Province, this condition is further exacerbated by rapid urbanization that reduces soil permeability, causing a significant increase in flood risk even though the total number of rainy days has not risen drastically.

This extreme rainfall pattern has a tangible impact on the electricity distribution system in the PT PLN (Persero) UID Banten area. Historical data indicate that flood events triggered by intense rainfall often lead to widespread power outages, particularly from January to March and November to December. By scientifically understanding these trends, PLN can integrate climate projections into risk mitigation strategies, such as elevating distribution substations and implementing extreme weather-based early warning systems (Sánchez Muñoz & García, 2021). Therefore, historical rainfall trends form an essential basis for strengthening climate change adaptation measures in the electricity sector.

The correlation between rainfall intensity and flood incidence in Banten Province shows a strong relationship, especially during the rainy season from November to March. Based on historical data from BNPB (2023) and BMKG (2024), the Banten region experiences more frequent flooding whenever extreme rainfall exceeds 100 mm/day. For instance, in early 2020 and 2024, several major flood incidents were recorded in Serang and Lebak Regencies, caused by very high-intensity rainfall over short periods, resulting in overflowing rivers and drainage systems that could not accommodate the surface runoff.

In general, flood characteristics in Banten fall into two categories: flash floods and inundation floods, depending on topography and land use conditions. In high-slope areas such as the hills of Lebak Regency, heavy rainfall triggers rapid and erosive surface runoff, increasing the risk of flash floods. Meanwhile, in urban areas such as Tangerang and Cilegon City, floods commonly occur in the form of inundation due to limited drainage capacity and the expansion of impervious surfaces. A study by Axelsson et al. (2021) shows that highly urbanized areas are particularly vulnerable to flooding, even when annual total rainfall is not high, as long as daily extreme rainfall events increase.

The results of spatial analysis also demonstrate a relationship between the distribution of PLN's electricity substations and flood-prone locations. Several substations situated in low-lying areas and near major rivers are indicated to be within flood zones based on overlays of historical flood maps and high-intensity rainfall data. This condition directly affects the reliability of the electricity distribution system, as flooding from extreme rainfall is a major cause of power supply disruptions. Therefore, monitoring rainfall intensity is a crucial indicator for early flood risk mitigation and for anticipating impacts on vital infrastructure, such as power grids.

The correlation between extreme rainfall and flood events is further reinforced by the rising trend in extreme rainfall frequency under climate change scenarios. The IPCC (2021) reports that global warming has intensified short-duration rainfall events, amplifying flood risk in tropical regions such as Indonesia. In Banten Province, with projected rainfall expected to rise under the SSP2–4.5 and SSP5–8.5 scenarios, the potential for flooding as a secondary impact becomes even greater. Hence, continuous monitoring and integration of extreme rainfall data with flood risk management systems are essential for protecting electricity infrastructure and strengthening climate change adaptation strategies. The following presents the Historical Rainfall Data 2014–2024:

Table 8 Historical Rainfall Data 2014-2024

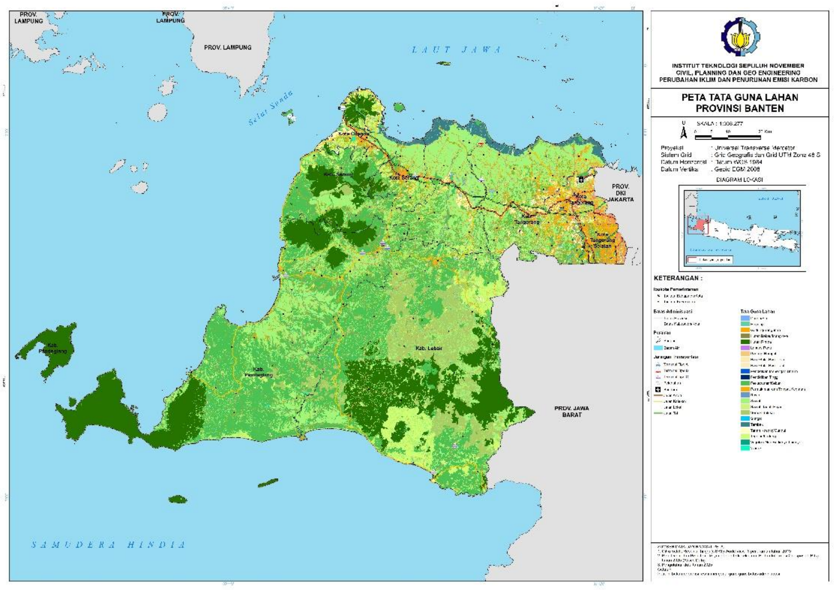
No	Tahun	Gridcode									Rata - Rata Hujan Tahunan Maksimal
		1	2	3	4	5	6	7	8	9	
1	2014	366	711	1.056	1.400	1.745	2.089	2.434	2.779	3.123	1.745
2	2015	397	770	1.142	1.514	1.886	2.258	2.630	3.002	3.374	1.886
3	2016	812	1.583	2.353	3.124	3.894	4.665	5.435	6.206	6.976	3.894
4	2017	592	1.149	1.706	2.263	2.820	3.378	3.935	4.492	5.049	2.820
5	2018	449	875	1.300	1.726	2.152	2.578	3.003	3.429	3.855	2.152
6	2019	366	711	1.056	1.400	1.745	2.089	2.434	2.779	3.123	1.745
7	2020	634	1.232	1.830	2.428	3.026	3.624	4.222	4.820	5.418	3.026
8	2021	627	1.219	1.811	2.404	2.996	3.588	4.180	4.772	5.364	2.996
9	2022	710	1.383	2.056	2.730	3.403	4.076	4.749	5.423	6.096	3.403
10	2023	418	812	1.205	1.599	1.992	2.386	2.780	3.173	3.567	1.992
11	2024	622	1.210	1.799	2.387	2.976	3.564	4.152	4.741	5.329	2.976

Based on the historical rainfall data displayed in the table, there is a significant variation between observation periods, with a maximum value of around 6,976 mm/year, an intermediate value of around 3,894 mm/year, and a minimum value of around 1,745 mm/year.

Land Use Planning

The Banten Province Land Use Map shows a fairly contrasting variation in land use between the northern and southern regions. The northern region, especially the cities of Tangerang, South Tangerang, Cilegon, and Serang, is dominated by dense settlements, industrial estates, and other built-up land that are depicted in orange to red colors. In contrast, southern regions such as Pandeglang and Lebak Regencies are dominated by tropical rainforests, plantations, and scrubs (dark green to light green color).

Image 4 Banten Province Land Use Map



This distribution of land use has direct implications for flood risk. Densely populated settlements and industrial areas in the northern region have mostly impervious surfaces, such as concrete and asphalt. This leads to increased surface runoff during heavy rains and decreases the infiltration capacity of water into the soil, which ultimately increases the potential for inundation flooding, especially in urban areas with limited drainage. Research by Putri et al. (2023) shows that the intensification of urbanization without an imbalance with green open space contributes significantly to the frequency and duration of flooding in metropolitan areas.

On the other hand, the southern region of Banten, which is still dominated by forest cover, acts as an important ecological buffer in absorbing rainwater and reducing the risk of flooding. However, the area is also vulnerable to flash floods in the event of massive land conversion, especially for plantation or mining purposes, which would upset the balance of upstream ecosystems. A study by Nurhayati & Wahyuni (2021) emphasizes that land use change from forest to non-forest, especially in hilly areas, can significantly increase the intensity and speed of surface flows.

This land use distribution is also important for the planning of electricity distribution infrastructure. Distribution substations located in densely populated areas are at higher risk of flooding due to poor drainage, while substations adjacent to agricultural or plantation areas can be exposed to the risk of landslides or river overflows in the event of upstream land degradation. Therefore, land use mapping must be the basis for the adaptation strategy of the electricity distribution system to flood risk due to changes in rainfall influenced by climate change.

In the classification of land use, the area of land was analyzed and weighted with the following details:

Table 9 Banten Area of Land Use and Weighting

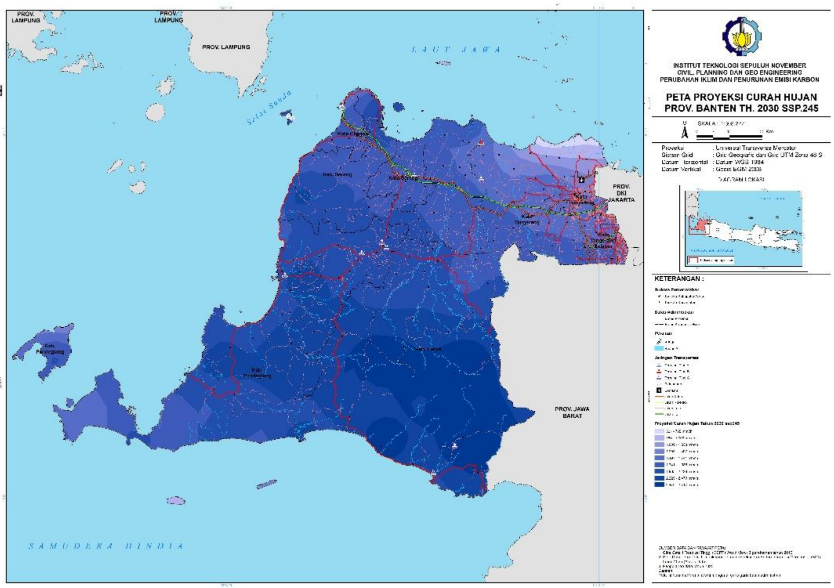
Penggunaan Lahan	Luasan	Persentase Luasan	Nilai	Bobot	Skor
Hutan	174.448,26	0,186594412	1	2	2
Semak Belukar	70.729,40	0,075654007	2	2	4
Ladang/Tegalan/Kebun	333.153,56	0,35634974	3	2	6
Sawah/Tanah Kosong (gundul)/Pasir/Tambak/Danau/Situ/Embung	279.322,35	0,298770474	4	2	8
Permukiman / Lahan Terbangun	77.252,57	0,082631367	5	2	10

Rainfall Projections

The rainfall projection map for Banten Province in 2030 and 2050 based on the climate scenarios SSP2-4.5 and SSP5-8.5 shows a tendency to increase rainfall intensity, especially in the southern regions such as Lebak and Pandeglang Regencies. This increase occurs spatially evenly, with color gradations indicating a spike in rainfall accumulation over time.

In 2030, in both the SSP2-4.5 and SSP5-8.5 scenarios, the southern region of Banten Province is projected to experience high rainfall intensity (indicated by dark blue), while northern regions such as Tangerang City and Cilegon show relatively lower values (light purple to light blue). However, projections for SSP5-8.5 show a wider coverage of high-intensity areas than SSP2-4.5, indicating a high-emissions scenario has the potential to accelerate an increase in extreme rainfall events.

Image 5 Rainfall Projection Map 2030 Scenario SSP 2.45



Meanwhile, in 2050, where the entire southern and central regions of Banten—including Lebak Regency and most of Pandeglang—are projected to fall into the category of very high rainfall (>3,000 mm/year). While the northern region shows moderate increases, it remains at high risk due to its lowland and urbanization characteristics. This suggests that not only is the volume of precipitation increased, but also the distribution became more spatially wider in SSP5-8.5 compared to SSP2-4.5.

Flood Risk Assessment

Flood vulnerability risk assessment is carried out using rainfall projection data to obtain an overview of potential flood risk in the future time period. The analysis was carried out using rainfall projection data for 2030 and 2050 with two climate change scenarios, namely SSP 2-4.5 and SSP 5-8.5. The calculation of the flood vulnerability index was carried out using a scoring and weighting approach based on four main parameters, namely slope slope, soil type, rainfall, and land use, according to the criteria displayed in the scoring and parameter weighting table.

Based on the results of the calculation of the flood vulnerability index using Equation (2.1), the maximum and minimum vulnerability values were obtained which were then used to determine the interval of flood risk class.

Table 10 Highest and Lowest Scores in Rainfall Projection Risk Assessment

No.	Year	Skenario	Highest Score	Lowest Score
1	2030	SSP 2-4.5	58	12
2	2030	SSP 5-8.5	58	12
3	2050	SSP 2-4.5	58	12
4	2050	SSP 5-8.5	58	12

The determination of the class interval is carried out with Equation (2.2), namely:

$$I = \frac{R}{n} \text{Type equation here.}$$

From these values, the class interval is then calculated using Equation 2.2 : = 12. The following is the distribution of flood risk class intervals: $\frac{(58-12)}{5}$

Table 11 Flood Risk Class Interval from Rainfall Projections

No.	Flood Risk Class	Class Intervals
1.	Not Prone	12 - 21,2
2.	A Bit Prone	21,2 - 30,4
3.	Quite Prone	30,4 - 39,6
4.	Prone	39,6 - 48,8
5.	Highly Vulnerable	48,8 - 58

After the process of summing scores and determining the flood risk class, data processing is carried out spatially using the Geographic Information System (GIS). From these stages, a flood vulnerability risk map for the research area for 2030 and 2050 was produced. The risk map represents the level of flood risk as a result of *overlays* of several main parameters, namely slope slope, rainfall, land use, and soil type. The level of flood risk is classified into five classes, namely non-vulnerable, moderately vulnerable, moderately vulnerable, vulnerable and very vulnerable. The following is attached a flood vulnerability map in 2030 and 2050 with climate change scenarios SSP 2-4.5 and SSP 5-8.5:

Image 6 Flood Vulnerability Map Scenario 2030 SSP 2-4.5

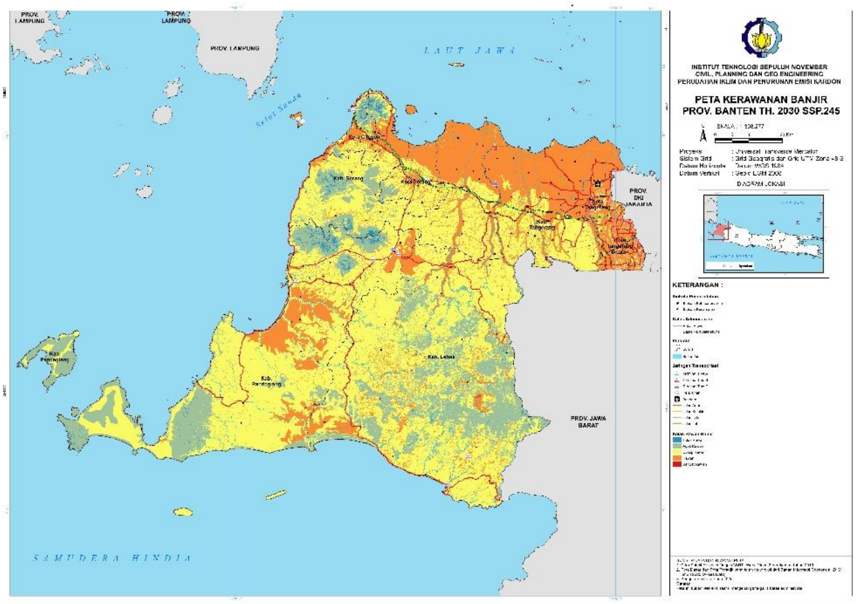


Image 7 Flood Vulnerability Map Scenario 2050 SSP 2-4.5

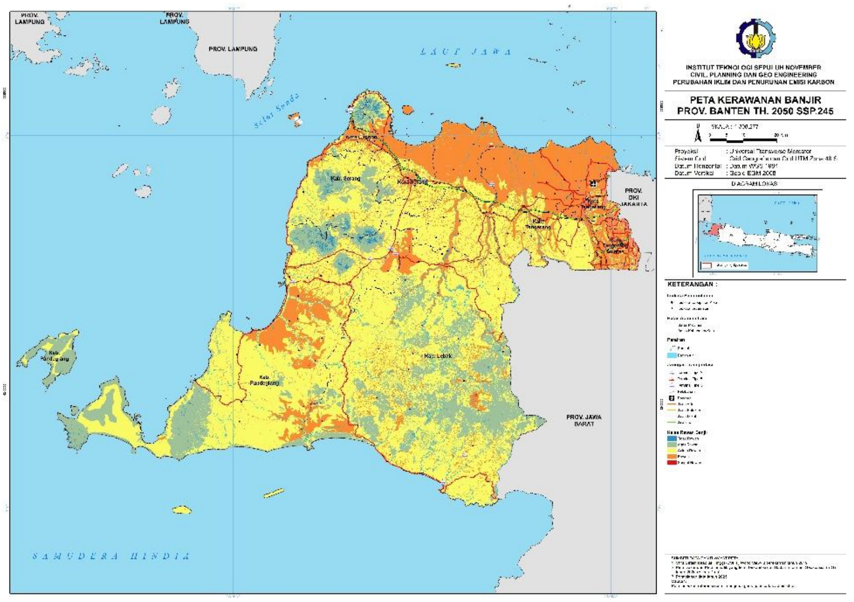


Image 8 Flood Vulnerability Map Scenario 2030 SSP 5-8.5

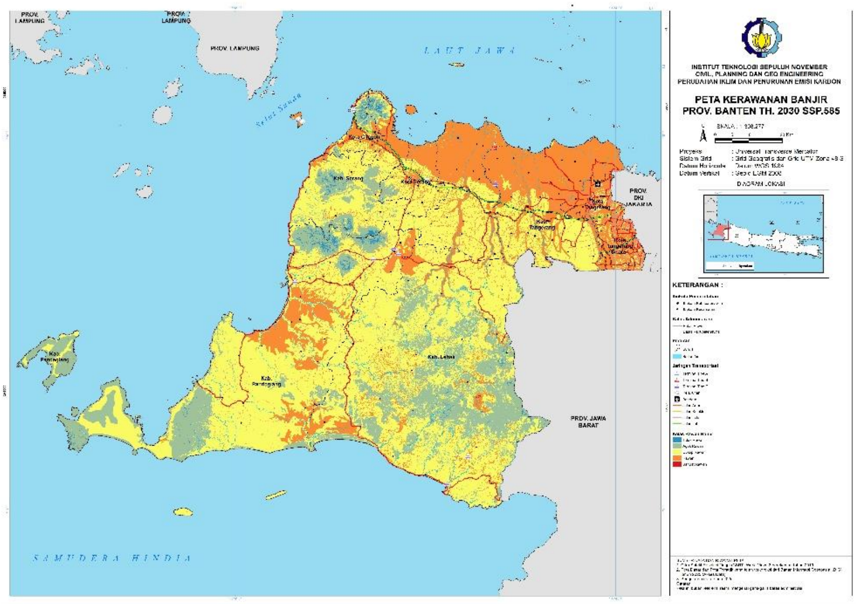
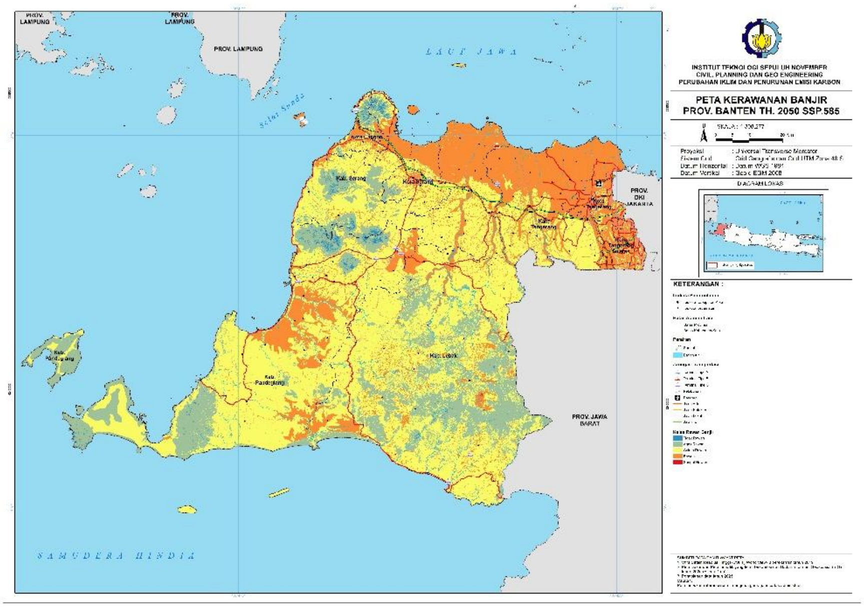


Image 9 Flood Vulnerability Map Scenario 2050 SSP 5-8.5



From the map, an analysis of the area for each flood vulnerability risk class was then carried out with the following data:

Table 12 Flood-prone Area

Skenario	Sangat Rawan (Ha)	Rawan (Ha)	Cukup Rawan (Ha)	Agak Rawan (Ha)	Tidak Rawan (Ha)	Grand Total (Ha)
Tahun 2030 SSP 2-4.5	145.016,6	408.922,4	341.618,0	39.136,0	213,2	934.906,2
Tahun 2030 SSP 5-8.5	144.990,5	423.348,0	324.771,5	41.616,3	179,8	934.906,2
Tahun 2050 SSP 2-4.5	38.608,9	323.194,2	427.748,0	145.186,6	168,4	934.906,2
Tahun 2050 SSP 5-8.5	39.537,1	325.187,5	425.108,7	144.903,6	169,3	934.906,2

The results of the analysis show that the distribution of Flood Risk shifts in pattern between 2030 and 2050 under both the SSP 2-4.5 and SSP 5-8.5 scenarios. In 2030, flood risk distribution in the SSP 2-4.5 and SSP 5-8.5 scenarios is dominated by Vulnerable Risk and Moderately Vulnerable Risk. The area classified as Vulnerable Risk in the 2030 SSP 2-4.5 scenario is recorded at 408,922.4 ha, while in the 2030 SSP 5-8.5 scenario it increases to 423,348.0 ha, indicating a tendency toward greater vulnerability in the more extreme emission scenario. Meanwhile, the Very Prone Risk category remains relatively stable in both scenarios—145,016.6 ha and 144,990.5 ha, respectively—showing that scenario differences in 2030 have not yet significantly affected the extent of extreme risk areas.

By 2050, changes in flood risk distribution become increasingly evident. Under the SSP 2-4.5 and SSP 5-8.5 scenarios, the area classified as Highly Vulnerable Risk decreases sharply to 38,608.9 ha and 39,537.1 ha, respectively, followed by a reduction in Vulnerable Risk areas to 323,194.2 ha and 325,187.5 ha. Conversely, the Moderately Prone Risk category expands significantly and becomes the dominant risk class, covering 427,748.0 ha in the SSP 2-4.5 scenario and 425,108.7 ha in the SSP 5-8.5 scenario, accompanied by an increase in the Moderately Vulnerable Risk category to approximately 145 thousand ha.

Overall, comparisons between scenarios show that the SSP 5-8.5 scenario tends to produce a larger extent of Vulnerable Risk areas than the SSP 2-4.5 scenario, particularly in 2030. However, by 2050, the differences between the two scenarios become relatively small, indicating that long-term flood risk is likely to shift from the extreme category toward intermediate and transitional levels. This shift should be a major consideration in adaptation planning and flood risk management strategies.

Identification of Flood-Prone Electricity Infrastructure

Table 12 presents the number of distribution substations affected by flood risk across the Very Vulnerable Risk, Vulnerable Risk, Moderately Vulnerable Risk, Moderate Vulnerable Risk, and Non-Vulnerable Risk categories in the SSP 2-4.5 and SSP 5-8.5 scenarios for 2030 and 2050. Information regarding the administrative locations of substations with Very Vulnerable Risk, organized by districts and work areas, is included in the attachment sheet. This information is expected to serve as the basis for identifying priority areas in adaptation scenario planning and in strengthening the resilience of electricity distribution infrastructure.

Table 13 Number of Affected Forks

Skenario	Jumlah Gardu Terdampak					
	Sangat Rawan	Rawan	Cukup Rawan	Agak Rawan	Tidak Rawan	Grand Total
SSP 2-4.5 Tahun 2030	23	6512	4314	316		11165
SSP 5-8.5 Tahun 2030	21	6496	4323	325		11165
SSP 2-4.5 Tahun 2050	27	5382	3679	264	1813	11165
SSP 5-8.5 Tahun 2050	20	6519	4304	322		11165

In the SSP 2-4.5 scenario for 2030, substations affected by flooding are dominated by 6,512 substations classified as Prone Risk, followed by 4,314 substations with Moderately Prone Risk and 316 substations in other risk categories. The number of Very Prone Risk substations is recorded at 23, all located in Lebak Regency, South Banten Region, within the

PLN UID Banten working area, specifically in the Rangkasbitung and Malingping Customer Service Units.

In the SSP 5-8.5 scenario for 2030, the number of Highly Prone Risk substations is recorded at 21, while the Prone Risk category increases to 6,496 substations. Substations with Moderately Prone Risk and Somewhat Prone Risk are recorded at 4,323 and 325, respectively. All Very Prone Risk substations are located in Lebak Regency, South Banten Region, within the PLN UID Banten work area, specifically under the Rangkasbitung and Malingping Customer Service Units.

In the SSP 2-4.5 scenario for 2050, the number of Highly Prone Risk substations increases to 27, while Prone Risk decreases to 5,382 substations and Moderately Prone Risk to 3,679 substations. In this scenario, 1,813 Non-Prone Risk substations begin to appear. The Very Prone Risk substations are located in Lebak and Pandeglang Regencies, both within the South Banten Region, in the PLN UID Banten working area, including the Rangkasbitung and Malingping Customer Service Units.

In the SSP 5-8.5 scenario for 2050, the number of Highly Prone Risk substations decreases to 20, while Vulnerable Risk increases to 6,519 substations and Moderately Prone Risk rises to 4,304 substations. Substations with Somewhat Prone Risk are recorded at 322. All Very Prone Risk substations remain located in Lebak Regency, South Banten Region, within the PLN UID Banten work area, managed by the Rangkasbitung and Malingping Customer Service Units.

Overall, Very Prone Risk substations in all scenarios are concentrated in the South Banten Region, predominantly in Lebak Regency. In the SSP 2-4.5 scenario for 2050, however, they also extend to Pandeglang Regency. This finding indicates that the region should be prioritized in adaptation planning and efforts to strengthen electricity distribution infrastructure.

CONCLUSION

Based on the research conducted, four main factors are identified as causes of flooding: topography, soil type, land use, and rainfall. The results of flood risk mapping show variations in flood vulnerability levels across different climate scenarios. In 2030 under the SSP 2-4.5 scenario, flood-prone areas cover 408,922.4 ha, moderately vulnerable areas 341,618.0 ha, and highly vulnerable areas 145,016.6 ha. Under the SSP 5-8.5 scenario, the vulnerable area increases to 423,348.0 ha, while highly vulnerable areas slightly decrease to 144,990.5 ha. By 2050, under SSP 2-4.5, the moderately vulnerable class becomes dominant with an area of 427,748.0 ha, followed by 323,194.2 ha categorized as vulnerable and 38,608.9 ha as highly vulnerable. A similar pattern appears under SSP 5-8.5, with 425,108.7 ha moderately vulnerable, 325,187.5 ha vulnerable, and 39,537.1 ha highly vulnerable.

The impact on electricity infrastructure is reflected in the number of substations affected within each flood risk class. In 2030 under SSP 2-4.5, affected substations include 23 units classified as highly vulnerable, 6,512 as vulnerable, 4,314 as moderately vulnerable, and 316 as slightly vulnerable, totaling 11,165 substations. Under SSP 5-8.5, the distribution is similar, with 21 highly vulnerable substations, 6,496 vulnerable, 4,323 moderately vulnerable, and 325 slightly vulnerable, maintaining the same total. By 2050 under SSP 2-4.5, affected substations comprise 27 highly vulnerable units, 5,382 vulnerable, 3,679 moderately vulnerable, 264 slightly vulnerable, and 1,813 non-vulnerable, totaling 11,165 substations. Under SSP 5-8.5, there are 20 highly vulnerable units, 6,519 vulnerable, 4,304 moderately vulnerable, and 322 slightly vulnerable substations, also totaling 11,165.

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