# Climate Change Impacts on Lightning Density in The Operation of 150 kV High Voltage Transmission Lines in Aceh Province

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***Abstract.***

*Global climate change has emerged as a major issue affecting multiple sectors, including the energy sector. Rainfall variability in Aceh Province ranges from low to very high levels and occurs almost throughout the year. This study aims to identify the correlation between rainfall intensity and lightning intensity around the 150 kV high voltage overhead transmission line, as well as to assess the vulnerability level of each 150 kV transmission segment in Aceh Province. The correlation between rainfall intensity and lightning density, as a climate change factor, was analyzed using an overlay method within a Geographic Information System (GIS) framework. The vulnerability ranking of each 150 kV transmission segment was determined through a weighted assessment of external parameters lightning-related disturbance history and Isokeraunic Level (IKL). The results show that correlation between rainfall intensity and IKL (Isokeraunic Level) values for each segment shows a generally neutral relationship in five segments 150 kV High Voltage Transmission Lines in Aceh Province, where rainfall intensity tends not to have a direct effect on lightning density along the 150 kV segments. One segment, Nagan Raya–Sigli, shows a positive correlation between rainfall intensity and IKL values during the 2020–2024 period. The Langsa–Pangkalan Brandan segment is the most vulnerable to lightning, with an IKL value of 52.22%, categorized as very high.*

***Keywords:*** *Climate adaptation; Rainfall intensity; Lightning density and Climate change.*

## I. INTRODUCTION

Climate change and global warming have been suggested as factors that may potentially influence lightning activity worldwide, both in terms of frequency and intensity, adding another layer of complexity to long-term planning and design **[1]**. Extreme weather and climate have severe societal, economic, and environmental impacts worldwide. Different climate-related extreme events (such as extreme precipitation events, floods, droughts, and heat waves) have been affecting the world's agriculture, economy, ecosystems, environment, urban infrastructure, and human society adversely.**[2]** Research on trends in the correlation between temperature and lightning occurrences has found that nearly 95% of total Cloud-to-Ground (CG) lightning flashes are negative, while only 5% are positive. Most lightning activity is likely to occur during the southwest monsoon season, which brings warm air and typically takes place in the afternoon or evening. During this period, evaporation from warmer surfaces leads to cloud formation. Airborne particles also reduce the distance between positive and negative charges. There is a positive correlation between lightning density and temperature in Kuala Lumpur and Johor Bahru **[3]**. There is a positive correlation between lightning activity and surface temperature. This indicates the need to consider increases in the global average temperature in infrastructure design to ensure the required performance. The assessment also shows that climate events, such as El Niño, can have a significant effect on lightning exposure events affecting transmission assets, and furthermore that these impacts may disproportionately affect transmission networks located in regions with above-average lightning density.

Lightning strike density variables along transmission network routes can be used to optimize lightning-related outage expenditures in order to improve transmission network performance **[4]**.Climate change is a global challenge that will have a major impact on our future business environment. Consumption of fossil fuels is the main contributor to climate change and reducing these emissions is the most important objective of climate change policies. The power sector is a significant emitter of CO2 and therefore key in reducing these emissions. Also recent studies have shown that climate change may lead to fewer but more violent thunderstorms, study says how a changing climate will impact specific elements of weather, such as clouds, rainfall, and lightning **[5]**. Globally, climatological studies show an increasing probability of heavy rainfall events around the world in the past decades under the influence of global warming (Min et al., 2011, Trenberth, 2011). During the 2021–2024 period, lightning was the largest cause of disturbances in transmission installations, particularly on 150 kV High Voltage Overhead Transmission Lines. During this period, within the operational area of PT PLN (Persero) UPT Banda Aceh, a total of 1,500 disturbances occurred due to lightning, accounting for 76% of all 150 kV High Voltage Overhead Transmission Lines disturbances in the same period. Disturbances on 150 kV High Voltage Overhead Transmission Lines constitute a critical issue as they have the potential to disrupt the delivery of electrical energy to consumers and can result in power outages, leading to Energy Not Served (ENS).

Disturbances on 150 kV High Voltage Overhead Transmission Lines caused by lightning occur due to the phenomena of Back Flashover (BFO) resulting from indirect strikes and Shielding Failure (SF) resulting from direct strikes. Back flashover is a flashover mechanism that occurs when a lightning strike hits the ground wire (shield wire) and the tower. In many cases, this leads to ground faults and is one of the main causes of line outages (Diamantis G. Patsalis, 2024). Lightning strikes to towers or shield wires and the occurrence of back flashover are among the primary causes of failures in transmission lines **[6]**.Lightning disturbances due to Back Flashover (BFO) occur partly because the tower grounding is inadequate, causing the lightning current—which should be safely dissipated into the ground—to fail to do so, resulting in a very large potential difference between the tower and the conductor. If this potential difference exceeds the Basic Insulation Level (BIL) of the insulator, a breakdown in the form of a flashover occurs. Shielding failure in overhead transmission lines, namely a direct lightning strike to a phase conductor, is one of the main causes of line disturbances and can also lead to substation failures, caused by incoming surges with amplitudes exceeding the insulation level of substation equipment **[7]**. Such direct-strike disturbances may occur due to failure of the shielding angle of the tower ground wire, allowing lightning to strike the conductor directly and resulting in a potential difference between the tower and the conductor.Research on adaptation to lightning events around 150 kV High Voltage Overhead Transmission Lines is conducted to identify appropriate methods to minimize the potential for disturbances on 150 kV High Voltage Overhead Transmission Lines. These adaptation efforts must take into account ease of implementation, effectiveness, and cost considerations.

## II. METHODS

This study examines the impacts of climate change, particularly rainfall intensity patterns, and their correlation with lightning intensity in the vicinity of 150 kV Transmission Lines, which have the potential to cause infrastructure damage and disruptions to the electricity transmission system in Aceh Province. The results obtained will serve as a basis for determining strategic climate change adaptation measures related to lightning intensity in order to minimize significant future losses. The method used is an overlay analysis between rainfall intensity and lightning density occurring within a 1-kilometer radius around the 150 kV Transmission Lines. This approach produces a database and spatial distribution maps of lightning strikes around towers and the 150 kV Transmission Lines network, as well as annual changes in lightning intensity as a figure 1.Lightning data from the Vaisala LS7002 Lightning Detection System (LDS) sensors are processed using the FALSS Client application through the Exposure Analysis menu. The lightning data analyzed consist of strikes detected within a 1-kilometer (km) radius around 150 kV Transmission Lines towers in Aceh Province.

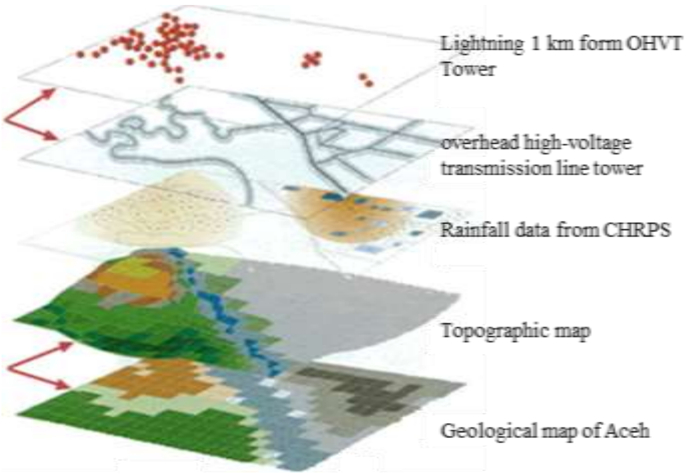


**Fig 1.** Overlay Methode

## III. RESULT AND DISCUSSION

### Inventory of Lightning Events on 150 kV High Voltage Overhead Transmission Lines

Research on trends in the correlation between temperature and lightning occurrences has found that nearly 95% of total Cloud-to-Ground (CG) lightning flashes are negative, while only 5% are positive. Most lightning activity is likely to occur during the southwest monsoon season, which brings warm air and typically occurs in the afternoon or evening. During this period, evaporation from warmer surfaces leads to cloud formation. Airborne particles also reduce the distance between positive and negative charges. There is a positive correlation between lightning density and temperature in Kuala Lumpur and Johor Bahru **[8]**

In this study, lightning detected by the LDS sensors during the 2020–2024 period around the 150 kV High Voltage Overhead Transmission Lines within a 1 kilometer radius is classified as negative Cloud-to-Ground (CG−) lightning, with the average lightning current magnitude varying annually from −1 kA to −99 kA. The selection of a 1 km lightning detection radius is based on historical disturbance data, which show that most lightning-related disturbances on the 150 kV transmission line are caused by lightning strikes occurring within a radius of ≤ 1 km from the tower. A higher average number of lightning strikes per tower indicates a higher frequency level of a tower being affected by lightning events. Based on the data in Table 1, the number of lightning strikes per tower in the Langsa–Pangkalan Brandan, Bireuen–Sigli, and Nagan Raya–Sigli segments is relatively high. This condition may increase the likelihood of disturbances if the installed lightning protection does not meet the required standards.

**Table 1.** Average Number of Lightning Strikes per Tower per Segment

| Segment | Number of Towers | Number of Lightning Strikes | | | | | Average Number of Lightning Strikes per Tower | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2020 | 2021 | 2022 | 2023 | 2024 | 2020 | 2021 | 2022 | 2023 | 2024 |
| Bireun-Sigli | 316 | 2.387 | 5.544 | 6.550 | 5.595 | 1.996 | 7,55 | 17,54 | 20,73 | 17,71 | 6,32 |
| Bireun-Takengon | 203 | 961 | 2.560 | 1.749 | 2.171 | 741 | 4,73 | 12,61 | 8,62 | 10,69 | 3,65 |
| Langsa-Lhokseumawe | 405 | 2.964 | 4.579 | 6.268 | 4.462 | 2.423 | 7,32 | 11,31 | 15,48 | 11,02 | 5,98 |
| Langsa-Pangkalan Brandan | 235 | 3.454 | 6.308 | 7.162 | 8.230 | 4.879 | 14,70 | 26,84 | 30,48 | 35,02 | 20,76 |
| Lhokseumawe-Arun-Bireun | 215 | 1.359 | 3.541 | 3.546 | 2.509 | 998 | 6,32 | 16,47 | 16,49 | 11,67 | 4,64 |
| Naganraya-Blangpdie | 326 | 1.229 | 1.064 | 1.130 | 3.068 | 2.603 | 3,77 | 3,26 | 3,47 | 9,41 | 7,98 |
| Naganraya-Sigli | 501 | 3.134 | 6.135 | 6.161 | 9.103 | 5.112 | 6,26 | 12,25 | 12,30 | 18,17 | 10,20 |
| Sigli-Banda Aceh | 281 | 1.065 | 2.947 | 2.447 | 2.777 | 1.149 | 3,79 | 10,49 | 8,71 | 9,88 | 4,09 |

In 2020, the average lightning current was −29.93 kA; in 2021, −20.04 kA; in 2022, −18.89 kA; in 2023, −25.51 kA; and in 2024, −29.28 kA. Based on the historical record of disturbances on the 150 kV High

Voltage Overhead Transmission Lines (HVTL) the type of lightning that disrupts the operation of the 150 kV transmission line is predominantly negative lightning, while positive lightning rarely causes disturbances. Operational disruptions to the 150 kV HOVTL caused by negative lightning must also be assessed in relation to the grounding system installed at the towers. Detailed lightning current values are presented in Table 2.

**Table 2.** Lightning Strike Current Around 150 kV HVOTL Towers

| Years | Average Lightning Strike Current (kA) by Month | | | | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | |
| **2020** | -36,19 | **-42,66** | -35,42 | -35,92 | -36,49 | -35,99 | -35,44 | -19,24 | -18,63 | -19,33 | -23,35 | -20,44 | **-29,93** |
| **2021** | **-25,47** | -22,24 | -19,89 | -20,01 | -20,99 | -19,70 | -18,27 | -16,39 | -18,24 | -19,20 | -19,33 | -20,80 | **-20,04** |
| **2022** | -20,57 | -18,80 | -16,57 | -18,83 | -17,96 | -17,79 | -18,55 | -17,56 | -16,80 | -19,75 | **-22,24** | -21,23 | **-18,89** |
| **2023** | -21,25 | -19,48 | -18,66 | -19,90 | -24,26 | -24,69 | -25,74 | -26,61 | -27,80 | -30,93 | -32,49 | **-34,26** | **-25,51** |
| **2024** | **-34,15** | -31,79 | -29,94 | -32,16 | -28,74 | -26,50 | -22,90 | -30,20 | -27,15 | -27,51 | -27,32 | -32,94 | **-29,28** |

Based on the results of the study on the timing of lightning occurrences in Aceh Province during the 2020–2024 period, approximately 53%–63% of lightning events occurred between 12:00 and 18:00 WIB, while the remaining 29%–40% occurred between 18:00 and 24:00 WIB. Meanwhile, the probability of lightning occurring between 24:00 and 12:00 WIB was only about 1.22%–6.26%. Detailed information on the timing of lightning occurrences in Aceh Province during the 2020–2024 period is presented in Table 3.

**Table 3.** Timing of Lightning Occurrences Around 150 kV HOVTL Towers

| Years | Percentage of Lightning Activities (%) | | | |
|---|---|---|---|---|
| | **00.00-06.00** | **06.00-12.00** | **12.00-18.00** | **18.00-24.00** |
| **2020** | 4,78% | 1,22% | 59,03% | 34,97% |
| **2021** | 6,26% | 1,29% | 63,14% | 29,31% |
| **2022** | 2,90% | 0,90% | 59,43% | 36,78% |
| **2023** | 4,46% | 2,03% | 53,32% | 40,18% |
| **2024** | 6,91% | 3,26% | 60,06% | 29,77% |

The determination of lightning density uses the ISL (Isokeraunic Level) value, or isokeraunic level, which indicates the number of days in a year during which thunder is heard at a location—in other words, the frequency of thunderstorm days. The ISL value is defined as the number of thunderstorm days (Ts) in a year divided by 365 and multiplied by 100%. The ISL is expressed by the following **[9]**. Based on the IKL values calculated from lightning events detected by the LDS during the research period (2020–2024), the level of lightning vulnerability for each 150 kV HVTL segment can be determined.

**Table 4.** Lightning Density Level Based on IKL Values

| Lightning Vulnerability Classification | IKL Percentage |
|---|---|
| Very Low | 0-12,5% |
| Low | 12,6%-25% |
| Moderate | 25,1%-37,5% |
| High | 37,6%-50% |
| Very High | 50%-100% |

*Reference : Rozikan & Mira, 2013*

Based on the IKL values calculated from lightning events detected by the Lightning Detection System (LDS) stations in Aceh Province during the 2020–2024 period, the level of lightning vulnerability for each 150 kV HVTL segment can be determined. The classification of lightning strike vulnerability levels based on IKL values for each 150 kV Transmission line segment is as follows:

**Table 5.** Classification of Lightning Strike Vulnerability Levels Based on IKL Values

| Segment | IKL | | | | | |
|---|---|---|---|---|---|---|
| | **2020** | **2021** | **2022** | **2023** | **2024** | **Classification** |
| Bireun-Sigli | 32,60% | 41,10% | 42,47% | 35,07% | 30,68% | Moderate-High |
| Bireun-Takengon | 26,30% | 31,78% | 30,14% | 35,34% | 28,22% | Moderate |
| Langsa-Lhokseumawe | 33,15% | 46,58% | 53,42% | 51,78% | 43,56% | Moderate-Very High |

| | | | | | | |
|---|---|---|---|---|---|---|
| Langsa-Pangkalan Brandan | 39,18% | 52,88% | 63,01% | 61,64% | 44,38% | High-Very High |
| Lhokseumawe-Arun-Bireun | 25,21% | 34,52% | 36,16% | 35,07% | 25,21% | Modertare |
| Naganraya-Blangpdie | 31,23% | 29,04% | 23,01% | 45,48% | 44,66% | Low-High |
| Naganraya-Sigli | 52,60% | 49,32% | 53,70% | 62,19% | 59,73% | High-Very High |
| Sigli-Banda Aceh | 30,41% | 35,89% | 30,41% | 31,23% | 23,84% | Low-Moderate |

**Rainfall Intensity Around the 150 kV Overhead Transmission Line**

High-spatial-resolution rainfall data are essential to support this study. The rainfall intensity data used in this research were obtained from CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data). CHIRPS data were utilized to derive the spatial distribution of rainfall over the study area, namely Aceh Province, by integrating the data into a Geographic Information System (GIS) using ArcGIS Pro. The data processing stages included data downloading, format conversion, coordinate system adjustment, spatial clipping to the study area, and zonal-based spatial analysis (zonal statistics). The output consists of a map of average rainfall distribution, which can be used for climatological analysis and spatial-based environmental planning.

Based on the overlay results between the rainfall intensity map and the coordinates of transmission towers operated by PLN UPT Banda Aceh, it was found that during the 2020–2024 period there was a shift in rainfall distribution patterns across different segments. This shift is likely to affect the lightning distribution patterns occurring around the 150 kV Overhead Transmission Line.The results of the overlay between rainfall intensity and the 150 kV transmission towers in Aceh Province are shown in Figure 2 until Figure 6, which consists of eight transmission segments: segment (a) is the Langsa–Pangkalan Brandan overhead transmission line, segment (b) is the Langsa–Lhokseumawe line, segment (c) is the Lhokseumawe–Arun–Bireuen line, segment (d) is the Bireuen–Takengon line, segment (e) is the Bireuen–Sigli line, segment (f) is the Nagan Raya–Sigli line, segment (g) is the Nagan Raya–Blangpidie line, and segment (h) is the Sigli–Banda Aceh line.

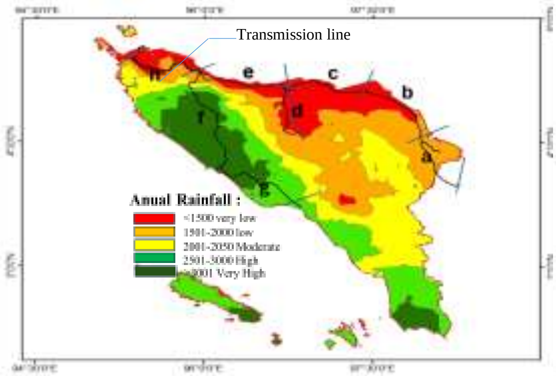


**Fig 2.** Rainfall Intensity in 2020

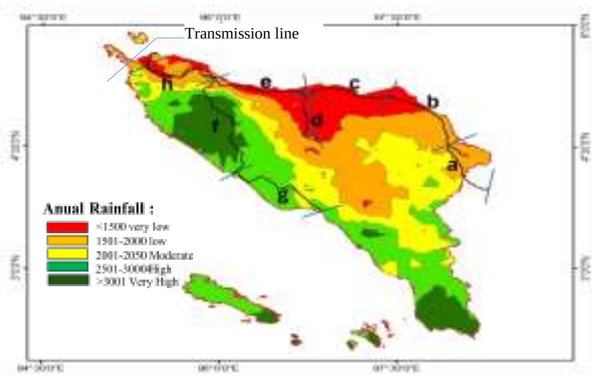


**Fig 3.** Rainfall Intensity in 2021

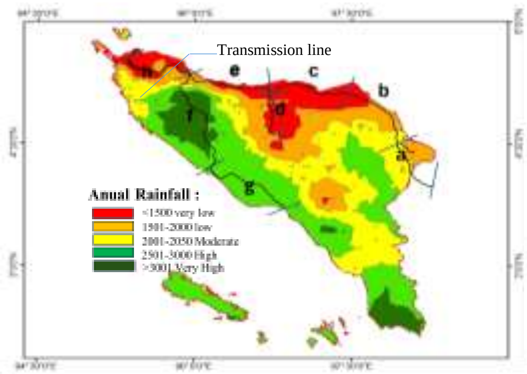


**Fig 4.** Rainfall Intensity in 2022

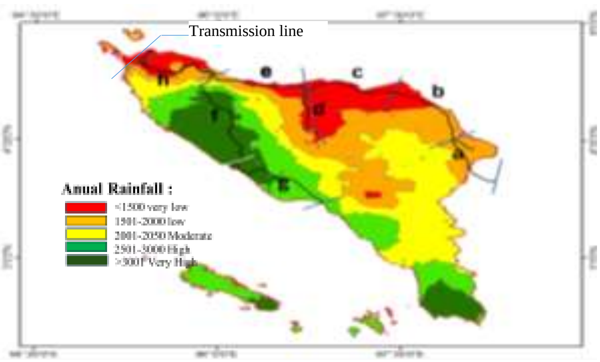


**Fig 5.** Rainfall Intensity in 2023

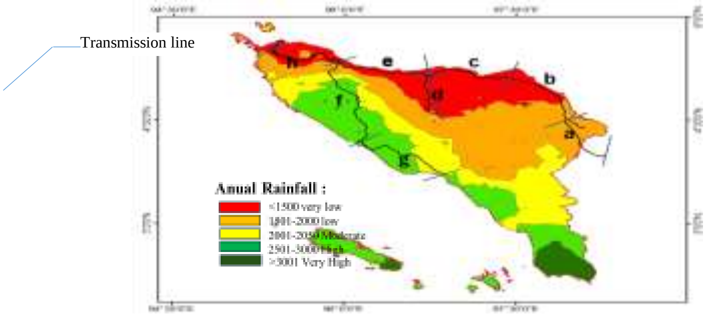


**Fig 6.** Rainfall Intensity in 2024

Based on the overlay results between the rainfall intensity map and the transmission tower locations, the annual rainfall intensity conditions for each 150 kV overhead transmission line segment were obtained, as presented in Table 6.

**Table 6.** Rainfall Intensity

| No | Segment | Rainfall Intensity | | | | |
|---|---|---|---|---|---|---|
| | | 2020 | 2021 | 2022 | 2023 | 2024 |
| 1 | Bireun-Sigli | Very Low | Very Low | Very Low | Very Low | Very Low |
| 2 | Bireun-Takengon | Very Low–Low | Very Low–Low | Very Low–Low | Very Low–Low | Very Low–Low |
| 3 | Langsa-Lhokseumawe | Very Low–Low | Low | Low-Moderate | Low | Very Low–Low |
| 4 | Langsa-Pangkalan Brandan | Low | Low | Low-Moderate | Low | Low |
| 5 | Lhokseumawe-Arun-Bireun | Low | Low | Low | Low | Low |
| 6 | Naganraya-Blangpdie | High-Very High | Moderate-High | High | High | Moderate-Hgh |
| 7 | Naganraya-Sigli | Very High | High-Very High | High-Very High | Very High | Moderate-Hgh |
| 8 | Sigli-Banda Aceh | Very Low–Low | Very Low–Low | Very Low–Low | Very Low–Low | Very Low |

Several transmission segments experienced shifts in rainfall intensity levels. These include the Langsa–Lhokseumawe segment, where in 2020 the intensity was very low–low; during 2021–2023 it increased to low and moderate levels, but in 2024 it returned to very low–low intensity, similar to conditions in 2020. The Langsa–Pangkalan Brandan segment, which is a segment with high lightning intensity, also experienced a shift in rainfall activity in 2022. In the previous years (2020–2021), rainfall intensity was low, then increased to moderate in 2022, although in 2023–2024 it returned to low levels. The Nagan Raya–Sigli segment also showed fairly varied shifts in rainfall intensity, from very high in 2020 to high–very high in 2021, high in 2022, then very high in 2023, and moderate–high in 2024. The Nagan Raya–Blangpidie segment experienced changes in rainfall intensity almost every year: in 2020 it was at high–very high levels, in 2021 moderate–high, in 2022 high–very high, in 2023 high, and in 2024 moderate–high.

**Correlation Analysis of the Vulnerability of 150 kV High Voltage Transmission Lines to Lightning**

At this stage, lightning data obtained from LDS station records were overlaid with rainfall intensity data from CHIRPS for the period 2020–2024. The overlay results were then used to establish a correlation between rainfall intensity and lightning intensity occurring around the 150 kV towers. The correlation is defined as neutral if the rainfall intensity level does not correspond to the lightning hazard level based on the ISL value; conversely, the correlation is considered positive if the rainfall intensity level corresponds to the lightning hazard level based on the ISL value. A neutral correlation indicates the absence of a direct relationship, whereas a positive correlation indicates a direct relationship between rainfall intensity and the level of lightning hazard. The results of the overlay between rainfall intensity and lightning intensity can be seen in the figure 7.Based on Figure 7, a correlation can be established between rainfall intensity and lightning intensity occurring around the 150 kV HVTL towers. The correlation is considered neutral when the rainfall intensity and the level of lightning vulnerability based on the ISL value do not correspond in magnitude, and vice versa. A positive correlation exists when the rainfall intensity and the level of lightning vulnerability based on the ISL value correspond in magnitude. A neutral correlation indicates the absence of a direct relationship, whereas a positive correlation indicates a direct relationship between rainfall intensity and the level of lightning vulnerability.

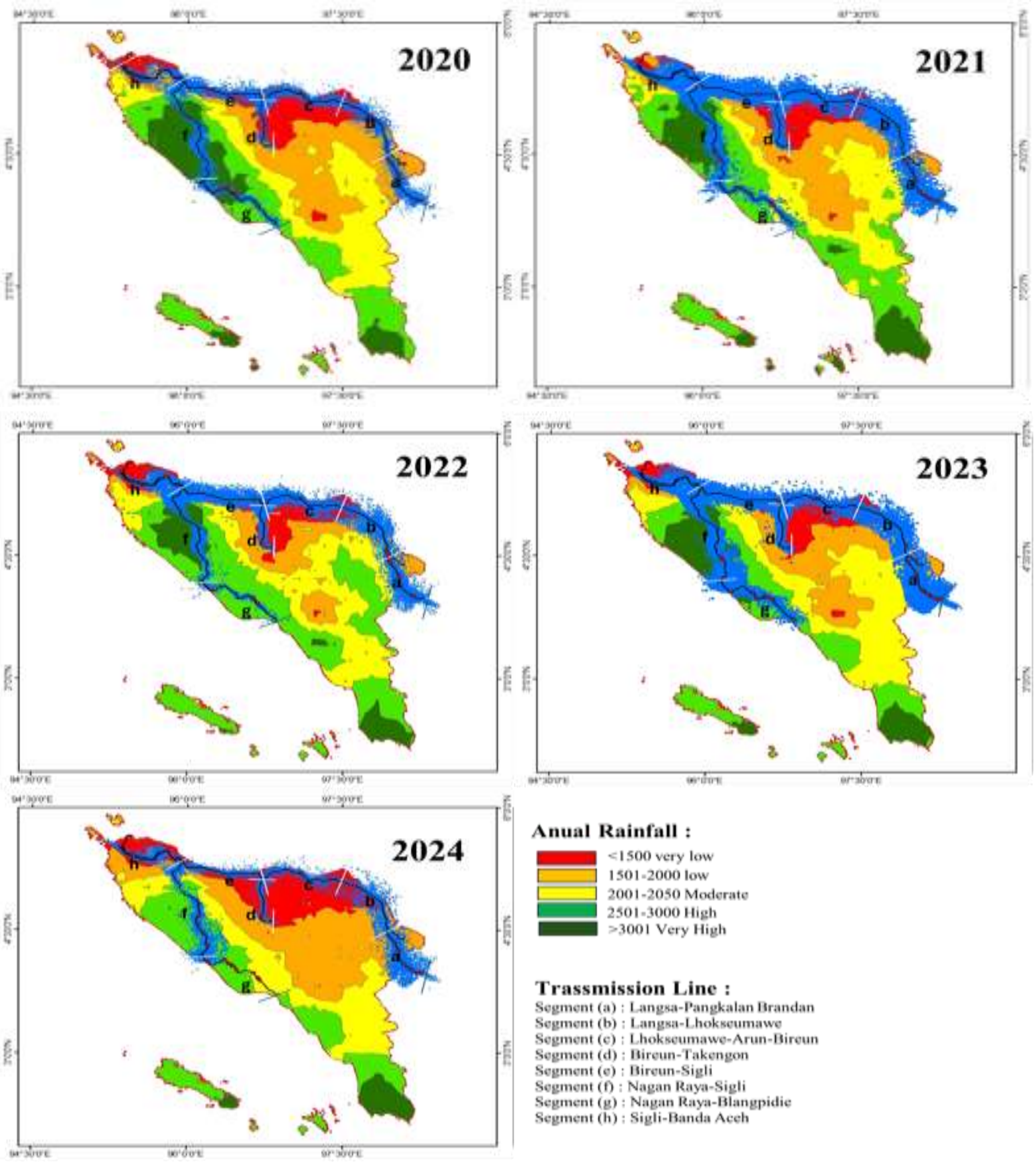


**Fig 7.** Overlay between annual rainfall with lightning vulnerability

The mapping data per segment of the 150 kV HVTL in Aceh Province are as follows:

**Table 6.** Correlation of Rainfall Intensity with IKL in 2020

| Segment | Year (2020) | | Correlation |
|---|---|---|---|
| | Rainfall Classification | IKL Classification | |
| Bireun-Sigli | Very Low | Moderate | Neutral |
| Bireun-Takengon | Very Low - Low | Moderate | Neutral |
| Langsa-Lhokseumawe | Very Low - Low | Moderate | Neutral |
| Langsa-Pangkalan Brandan | Low | High | Neutral |
| Lhokseumawe-Arun-Bireun | Low | Moderate | Neutral |
| Naganraya-Blangpdie | High-Very High | Moderate | Neutral |
| Naganraya-Sigli | Very High | Very High | Positive |
| Sigli-Banda Aceh | Very Low - Low | Moderate | Neutral |

**Table 7.** Correlation of Rainfall Intensity with IKL in 2021

| Segment | Year (2021) | | Correlation |
|---|---|---|---|
| | Rainfall Classification | IKL | |
| Bireun-Sigli | Very Low | High | Neutral |
| Bireun-Takengon | Very Low - Low | Moderate | Neutral |
| Langsa-Lhokseumawe | Low | High | Neutral |
| Langsa-Pangkalan Brandan | Low | Very High | Neutral |

| | | | |
|---|---|---|---|
| Lhokseumawe-Arun-Bireun | Low | Moderate | Neutral |
| Naganraya-Blangpdie | Moderate-High | Moderate | Positive |
| Naganraya-Sigli | High-Very High | High | Positive |
| Sigli-Banda Aceh | Low-Moderate | Moderate | Positive |

**Table 8.** Correlation of Rainfall Intensity with IKL in 2022

| Segmen | Tahun 2022 | | Korelasi |
|---|---|---|---|
| | Intensitas Hujan | IKL | |
| Bireun-Sigli | Very Low | High | Neutral |
| Bireun-Takengon | Very Low-Low | Moderate | Neutral |
| Langsa-Lhokseumawe | Low-Moderate | Very High | Neutral |
| Langsa-Pangkalan Brandan | Low-Moderate | Very High | Neutral |
| Lhokseumawe-Arun-Bireun | Low | Moderate | Neutral |
| Naganraya-Blangpdie | High | Low | Neutral |
| Naganraya-Sigli | High-Very High | Very High | Positive |
| Sigli-Banda Aceh | Very Low-Low | Moderate | Neutral |

**Table 9.** Correlation of Rainfall Intensity with IKL in 2023

| Segmen | Tahun 2023 | | Korelasi |
|---|---|---|---|
| | Intensitas Hujan | IKL | |
| Bireun-Sigli | Very Low | Moderate | Neutral |
| Bireun-Takengon | Very Low-Low | Moderate | Neutral |
| Langsa-Lhokseumawe | Low | Very High | Neutral |
| Langsa-Pangkalan Brandan | Low | Very High | Neutral |
| Lhokseumawe-Arun-Bireun | Low | Moderate | Neutral |
| Naganraya-Blangpdie | High | High | Positive |
| Naganraya-Sigli | Very High | Very High | Positive |
| Sigli-Banda Aceh | Very Low-Low | Moderate | Neutral |

**Table 10.** Correlation of Rainfall Intensity with IKL in 2024

| Segmen | Tahun 2024 | | Korelasi |
|---|---|---|---|
| | Intensitas Hujan | IKL | |
| Bireun-Sigli | Very Low | Moderate | Neutral |
| Bireun-Takengon | Very Low-Low | Moderate | Neutral |
| Langsa-Lhokseumawe | Very Low-Low | High | Neutral |
| Langsa-Pangkalan Brandan | Low | High | Neutral |
| Lhokseumawe-Arun-Bireun | Low | Moderate | Neutral |
| Naganraya-Blangpdie | Moderate-High | High | Positive |
| Naganraya-Sigli | Moderate-High | Very High | Positive |
| Sigli-Banda Aceh | Very Low | Low | Positive |

Periods of more intensive rainfall coincide with periods of higher lightning frequency, and the spatial distribution of lightning strikes and rainfall shows a consistent pattern. The correlation between lightning activity and rainfall was analyzed using linear regression, and the correlation coefficient between the two is 0.946 **[10]**. Table 6 shows the correlation between rainfall intensity and the level of lightning hazard in 2020, where out of 8 segments, 7 segments show a neutral correlation (87.5%). This neutral condition indicates that the rainfall intensity level or IKL does not fall within the same category; only 1 segment, namely Nagan Raya–Sigli, shows rainfall intensity and IKL at the same level, which is very high. Table 7 shows the correlation between rainfall intensity and the level of lightning hazard in 2021, where out of 8 segments, 5 segments show a neutral correlation (62.5%). Unlike the conditions in 2020, in 2021 the number of positive correlations increased to 3 segments, namely Nagan Raya–Blangpidie, Nagan Raya–Sigli, and Sigli–Banda Aceh. Table 8 shows the correlation between rainfall intensity and the level of lightning hazard in 2022, where out of 8 segments, 7 segments show a neutral correlation (87.5%).

This condition is the same as in 2020, with positive correlation occurring in only 1 segment, namely Nagan Raya–Sigli, where rainfall intensity and IKL are at the same level, i.e., very high. Table 9 shows the correlation between rainfall intensity and the level of lightning hazard in 2023, where out of 8 segments, 6 segments show a neutral correlation (75%). Positive correlation occurs in 2 segments, namely Nagan Raya–

Blangpidie and Nagan Raya–Sigli, where rainfall intensity and IKL are at the same level. Table 10 shows the correlation between rainfall intensity and the level of lightning hazard in 2024, where out of 8 segments, 5 segments show a neutral correlation (62.5%). This condition is relatively similar to that in 2021, where positive correlation increased to 3 segments, namely Nagan Raya–Blangpidie, Nagan Raya–Sigli, and Sigli–Banda Aceh. Overall, the correlation between rainfall intensity and IKL values in each segment during the 2020–2024 period tends to be neutral in 5 segments, namely Bireun–Sigli, Bireun–Takengon, Langsa–Lhokseumawe, Langsa–Pangkalan Brandan, and Lhokseumawe–Arun–Bireun, indicating that rainfall intensity does not tend to have a direct influence on lightning density along these 150 kV HVTL segments. However, one segment, Nagan Raya–Sigli, shows a positive correlation between rainfall intensity and IKL values throughout the 2020–2024 period. The other two segments, namely Nagan Raya–Blangpidie and Sigli–Banda Aceh, show positive correlation between rainfall intensity and IKL in 3 periods (60%) and negative correlation in 2 periods (40%).

## IV. CONCLUSION

The correlation between rainfall intensity and IKL (Isokeraunic Level) values for each segment shows a generally neutral relationship in five segments 150 kV High Voltage Transmission Lines, namely Bireun–Sigli, Bireun–Takengon, Langsa–Lhokseumawe, Langsa–Pangkalan Brandan, and Lhokseumawe–Arun–Bireun, where rainfall intensity tends not to have a direct effect on lightning density along the 150 kV segments. One segment, Nagan Raya–Sigli, shows a positive correlation between rainfall intensity and IKL values during the 2020–2024 period. The other two segments, Nagan Raya–Blangpidie and Sigli–Banda Aceh, show a positive correlation between rainfall intensity and IKL in three periods (60%).The vulnerability of the 150 kV High Voltage Overhead Transmission Lines in Aceh Province falls within the moderate IKL level (25.1%–37.5%), high (37.6%–50%), and very high (50%–100%). Segments with very high IKL values are Langsa–Nagan Raya–Sigli (55.51%) and Pangkalan Brandan (52.22%).

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## REFERENCES

[1] Rafael Alipio, Ana Clara Marques ; Pedro Regoto Luciano Ritter ; Thiago Ferreirad ,Fernando Diniz, "*Climate Changes and Detailed Characterization of Lightning Activity: Impact on Lightning Performance of Transmission Lines*" 37th International Conference on Lightning Protection

[2] Sanjit Kumar Mondal , Jinglong Huang, Yanjun Wang , Buda Su, Zbigniew W. Kundzewicz, Shan Jiang, Jianqing Zhai, Ziyan Chen, Cheng Jing, Tong Jiang,"*Changes in extreme precipitation across South Asia for each 0.5 ◦C of warming from 1.5 ◦C to 3.0◦C above pre-industrial levels*". Atmospheric Research 266 (2022)

[3] N.A.Ahmad, Iskandar Haszuan Ismail, Muhammad Abu Bakar Sidik, "*Correlation between Global Warming And Lightning Density In Kuala Lumpur and Johor Bharu*" International Conference on Electrical Engineering and Computer Science (ICECOS)

[4] Gavin Strelec, Robert Bell, Renier Van Rooyen, "*Trends between climate and lightning activity and the impact on transmission infrastructure*", IEEE Power and Energy System.

[5] Nagarjun.Y, "*Interrelation between Climate Change and Lightning and its Impacts on Power Sector*" ***Journal of Electrical and Electronics Engineering (IOSR-JEEE***, Volume 7, Issue 2 (Jul. - Aug. 2013), PP 01-05

[6] Mohammadbagher A, "*Improving tower grounding vs. insulation level to obtain the desired backflashover rate for HV transmission lines*" , ***International Journal of Electrical Power & Energy Systems Volume 123***

[7] Z. G. Datsios, "*Shielding Failure Current of Overhead Transmission Lines Generated through an ATPDraw Object*". International Conference on Power Systems Transients (IPST2011) in Delft, the Netherlands

[8] N.A.Ahmad, Iskandar Haszuan Ismail, Muhammad Abu Bakar Sidik, "*Correlation between Global Warming And Lightning Density In Kuala Lumpur and Johor Bharu*" International Conference on Electrical Engineering and Computer Science (ICECOS), 2019

[9] Rozikan dan Mira G. "*Analisa intensitas dan tingkat kerapatan petir dengan lightning detector di kabupaten pasuruan*". BMKG Tretes Pasuruan, 2013.

[10] Yuqing Mao, Jiao Liu, Youshan Jiang, Cong Li, Zhaoquan Han and Qu Chen. *Analysis of lightning activity characteristics and its relationship with precipitation in a strong convective weather process in Jiangsu Province,* Frontiers Enviromental Science