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Characteristics of Cloud to Ground (CG) Lightning and Heavy Rainfall in Medan and Deli Serdang

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Abstract

The areas of Medan and Deli Serdang have complex topography, stretching from the slopes of Bukit Barisan Mountains to the east coast of North Sumatera. This condition causes Medan and Deli Serdang areas frequently form convective clouds that produce rain and lightning. This research utilizes Cloud to Ground (CG) lightning data and rainfall from 2019-2022 to analyse the characteristics and relationship between lightning and rainfall in Medan and Deli Serdang. CG lightning data is obtained from Lightning Detector equipment with a 10 km radius to avoid noise and obtain better data. Rainfall data above 50 mm/day (heavy rain) is used, which is obtained from 3 rain gauges locations. The study results showed that there was an increase in lightning events along with an increase of rainfall which showed almost the same pattern of peak activity from lightning and rainfall. The correlation between heavy rainfall and CG lightning, in the Medan and Deli Serdang areas are moderate positive, around r=0.566 for CG-, r=0.567 for CG+ and r= 0.576 for total CG. The highest correlation in Sunggal Rain Station is r = 0.947, in Deli Serdang Climatological Station is r = 0.950 and in the Kualanamu Meteorological Station is r = 0.932.

Keywords: Cloud to Ground, Correlation, Lightning Detector, Rainfall

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INTRODUCTION

Indonesia is a maritime continent where the cloud growth is mostly caused by convection process. Strong convective clouds such as Cumulonimbus can cause heavy rain, hail, lightning, thunderstorm and tornadoes. Thunder days in Indonesia occur at least 100 times each year, while in subtropical areas around 50 times each year (Tjasyono, 2008). Cumulonimbus clouds containing electric currents are often compared to natural giant capacitors, which can produce lightning and thunder, upward and downward air flows, as well as windshear (strong winds with sudden changes), so cumulonimbus clouds are very feared (Pertiwi B.D., 2018). According to Doswell (1985), convective clouds, in this case cumulonimbus clouds, have three stages of evolution, namely the growth stage (towering cumulus stage), the mature stage, and the dissipation stage.

Lightning is an electrical condition in the atmosphere that can cause danger in a short time period and its energy can make the sky appear bright (Byers, 1997). Lightning based on the discharge of its charge according to Husni (2002) is divided into several types, discharge from the cloud to the ground or Cloud to Ground (CG), discharge between clouds known as Cloud to Cloud (CC), discharge from the cloud into the air around what is called Cloud to Atmosphere (CA) and discharge within the cloud or Intra Cloud (IC). Lightning is closely related to atmospheric dynamic processes, especially cloud microphysics, so lightning can be used to determine the characteristics and identify weather conditions (Septiadi and Hadi, 2011). According to Wu et al. (2017), lightning activity is closely related to heavy rainfall in a short time. Based on BMKG provisions, the criteria for heavy rain in Indonesia is 10.0 - 20.0 mm/hour or 50 - 100 mm/day.

According to MacGorman and Rush (1998), by using optical sensors, electrical radio waves and magnetic waves produced by the electric discharge process at a certain frequency, lightning events can be detected both from the surface of the earth and from the air. CG lightning produces strong emissions near the surface of low frequency (LF) radio waves (Suszcynsky, et al, 2000). The lightning detector equipment located at Deli Serdang Geophysical Station has been widely used. Based on research conducted by Pandiangan et al in 2010, the increasing number of BTS buildings affects the intensity of CG lightning strikes in Medan and high lightning intensity occurs in sub-districts where there are many BTS buildings. Furthermore, based on research conducted by Prasetyo et al in 2019, it is known that the correlation between lightning and rainfall is quite significant, namely 0.90 for CG+ and 0.85 for CG-. The mature phase of convective clouds in the Medan area lasts for 6 hours, ranging from 15.00 - 21.00 Local Time.

The areas of Medan and Deli Serdang have complex topography, stretching from the slopes of the Bukit Barisan Mountains to the east coast of North Sumatera. Medan is surrounded by Deli Serdang Regency. This condition causes Medan and Deli Serdang area frequently form the confective clouds that produce heavy rain and lightning. Medan and Deli Serdang areas are also strategic areas because there are many important places in the area,such as densely populated urban areas, Kualanamu International Airport, Belawan Harbor, office areas, as well as various tourist locations that are densely visited by people. This study was conducted to determine the characteristics of CG lightning during heavy rain events in Medan and Deli Serdang. It is hoped that this study can become the basis for information on lightning hazard mitigation in the Medan and Deli Serdang.

METHOD

The study is located in the Medan and Deli Serdang areas which are located at 2° 57' - 3° 16' North Latitude and 98° 33' - 99° 27' East Longitude. The time periode of this study is from 2019-2022. Analysis of CG lightning characteristics and rainfall during heavy rain events was carried out on case studies in the 2019-2022 time period.

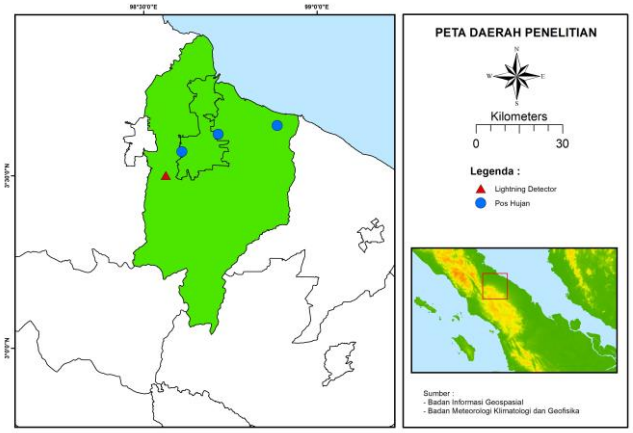

Figure 1. Research Area

Near real time lightning data for 4 years from 2019 - 2022, with a resolution of 15 minutes from the Lightning Detector tool obtained from the Deli Serdang Geophysical Station, North Sumatera. The heavy rainfall data used are from the ARG (Automatic Rain Gauge) obtained from the Kualanamu Meteorological Station, North Sumatera Climatological Station and Sunggal Rain Station.

This study use several aplications to process data, such as Nextstorm, Matlab, and Microsoft Excel. Nexstorm software records lightning events throughout the North Sumatera region. The Matlab program is used to process lightning data formed in the Nexstorm application to be analyzed in Microsoft Excel.

The Pearson Correlation Test is carried out to obtain the correlation coefficient (r) value which is used to determine the linear relationship between 2 variables continuously. Pearson correlation produces a correlation coefficient which functions to measure the strength of the linear relationship between two variables (Smith, 2018). Correlation tests were carried out to see the relationship between lightning strikes and rainfall and the geospatial factors that influence it. Pearson correlation The correlation formula is as follows:

$$r = \frac{n\sum_{i=1}^{n} X_i Y_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{\sqrt{n\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i^2\right)^2}\sqrt{\sum_{i=1}^{n} Y_i^2 - \left(\sum_{i=1}^{n} Y_i^2\right)^2}} \quad (1)$$

Descriptions :
x = first variable
y = second variable
n = number of observations

This correlation coefficient value is between 1 and -1. If the value of *R* is positive, then for the variable *X* the value increases, the value of variable *Y* also increases. On the other hand, if the value of *R* is negative, then for variable *X* the value increases, variable *Y* will have the value decrease. vice versa. In this study there were 2 correlation tests. The first is to look for the relationship between rainfall and lightning, and the second is to look for the relationship between lightning and geospatial factors. The classification for the correlation coefficient (r) value is as follows.

Tabel 1. Range of correlation values (r)

Correlation Coeffiecient (r)	Classification
-1	Perfect Negative
-1 < r ≤ -0.9	Strong Negative
-0.9 < r < -0.5	Moderate Negaive
-0.5 ≤ r < 0	Weak Negative
0	No Correlation
0 < r ≤ 0.5	Weak Positive
0.5 < r < 0.9	Moderate Positive
0.9 ≤ r < 1	Strong Positive
1	Perfect Positive

RESULTS AND DISCUSSION

During the time period 2019 to 2022, there were several heavy rain events with rainfall more than 50 mm per day at the research location. These values are shown in Tabel 2 for the Sunggal Rain Post location, Tabel 3 for the North Sumatera (Sampali) Climatological Station location, and Tabel 4 for the Kualanamu Meteorological Station location.

Heavy rain events in the Medan and Deli Serdang vary throughout the year. When the location closer to the mountainous areas in Deli Serdang, heavy rain events occur more frequently compared to urban and coastal areas on the east coast of Sumatera. This can be seen from the heavy rain events recorded at the Sunggal Rain Station which is near the slopes of Bukit Barisan, the North Sumatera Climatological Station (Sampali) which is near urban areas, and the Kualanamu Meteorological Station which is on the east coast of Sumatera. There were 17 heavy rain events with more than 50 mm per day at the Sunggal Rain Post, 16 heavy rain events at the Sampali Climatological Station, and 10 heavy rain events at the Kualanamu Meteorological Station.

Tabel 2. CG lightning events and total daily rainfall over 50mm a day during 2019-2022 in Sunggal Rain Station

Date	Lightning Events			Rainfall (mm)
	CH -	CG +	CG Total	
27/01/2019	349	169	518	69
27/05/2019	123	65	188	52,8
25/12/2020	708	168	876	74,8
08/02/2021	185	42	227	56,6
25/04/2021	360	312	672	55,4
12/06/2021	189	125	314	63
24/06/2021	27	9	36	50,2
26/10/2021	218	201	419	54,8
23/11/2021	193	52	245	71,8
27/02/2022	178	130	308	116,2
06/06/2022	133	77	210	62,8
22/06/2022	736	368	1104	60,4
15/07/2022	101	78	179	97,4
15/08/2022	566	342	908	78,8
17/08/2022	1080	629	1709	158,2
03/11/2022	75	36	111	78,8
18/11/2022	2125	1585	3710	138,1
18/12/2022	224	113	337	51,4

Tabel 3. CG lightning events and total daily rainfall over 50 mm a day during 2019-2022 in North Sumatera Climatological Station

Date	Lightning Events			Rainfall (mm)
	CH -	CG +	CG Total	
04/05/2019	627	317	944	143,6
29/08/2019	71	30	101	65,4
03/09/2019	478	257	735	101,8
28/01/2020	337	138	475	142,2
07/05/2020	246	208	454	79,2
14/06/2020	276	258	534	51,6
11/08/2020	561	318	879	83,2
25/12/2020	708	168	876	71,6
15/02/2022	166	61	227	53,8
27/02/2022	178	130	308	94,2

Date	Lightning Events			Rainfall (mm)
	CH -	CG +	CG Total	
09/03/2022	965	400	1365	111
22/06/2022	736	368	1104	127,2
17/08/2022	1080	629	1709	66,2
31/08/2022	277	293	570	60
18/10/2022	499	261	760	69,4

Tabel 4. CG lightning events and total daily rainfall over 50 mm a day during 2019-2022 in Kualanamu Meteorology Station

Date	Lightning Events			Rainfall (mm)
	CH -	CG +	CG Total	
27/03/2019	217	237	454	58,6
04/05/2019	627	317	944	52,2
29/05/2019	907	475	1382	57,8
08/09/2019	127	62	189	50,8
27/10/2019	30	5	35	54,6
14/09/2020	682	233	915	64,8
22/06/2022	736	368	1104	111
23/06/2022	234	158	392	86,6
29/07/2022	131	118	249	72,8
21/10/2022	13	28	41	72,6

Based on Figure 2, 3 and 4, it can be seen that in general when there is an increase in lightning events at the 3 research locations, the rainfall also increases. This is because, at the growth stage of cumulonimbus clouds, lightning generally occurs at the mature stage. At this stage, cumulonimbus clouds experience an updraft and downdraft process and raindrops have formed at this stage. So when the downdraft process (air flow is pushed downwards), the saturated raindrops are also pushed down towards the earth's surface. So, in line with the massive lightning events in mature cumulonimbus clouds, heavy rain also occurred almost at the same time period.

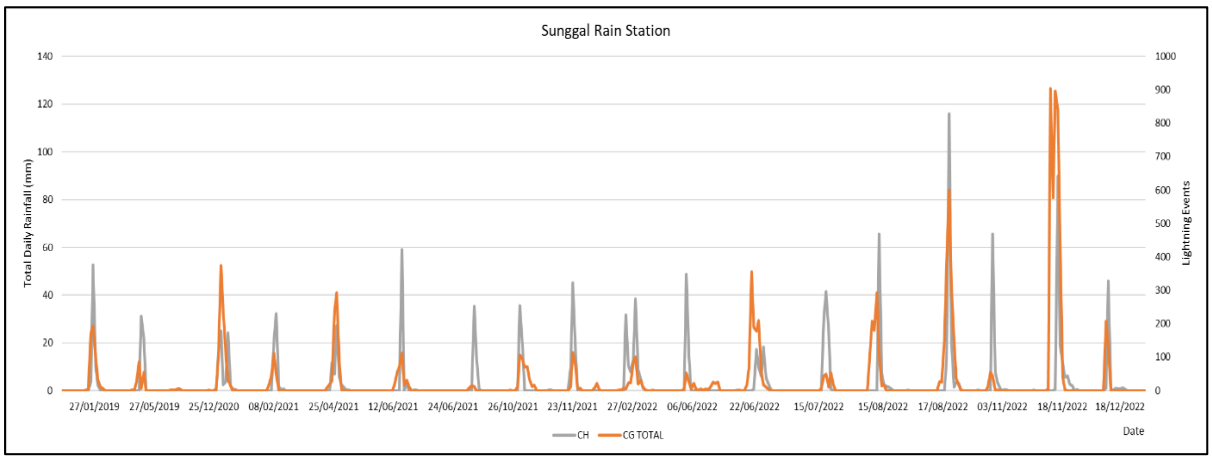

Figure 2. The Diurnal Analysis of CG Lightning and Heavy Rainfall in Sunggal Rain Station

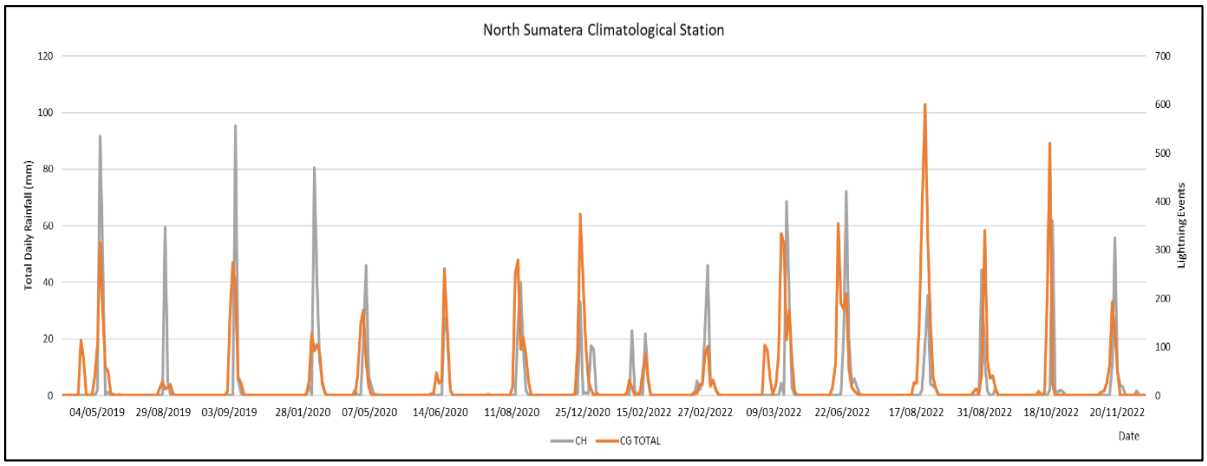

Figure 3. The Diurnal Analysis of CG Lightning and Heavy Rainfall in North Sumatera Climatological Station

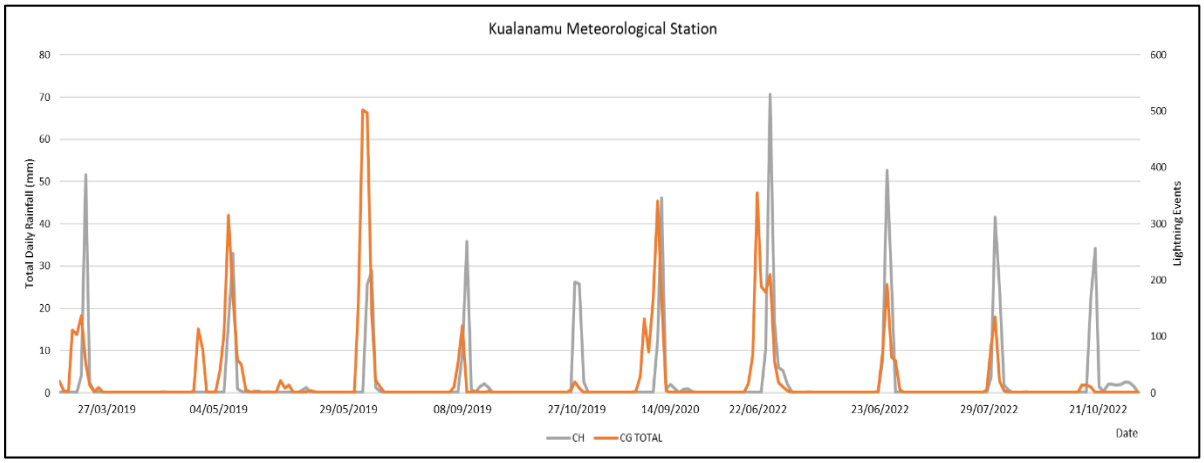

Figure 4. The Diurnal Analysis of CG Lightning and Heavy Rainfall in Kualanamu Meteorological Station

Based on Tabel 5, CG lightning events in the Sunggal Rain Station area generally occur 1 to 3 times the peak of the highest number of CG lightning with 1 to 2 peaks of rainfall. This means that it is possible that during heavy rain events, there will be repeated growth of cumulonimbus clouds so the number of lightning strikes also high and repeated, and the amount of rainfall also increases. The time period of lightning to occur is also quite long, around 2 to 5 hours for 1 peak CG lightning event, and 4 to 8 hours for 2 or 3 peak CG lightning events. Lightning around the Sunggal Rain Station usually come in the afternoon, evening and at night, starting at 06.00 UTC or 13.00 Local Time, 08.00 UTC or 15.00 Local Time, until 16.00 UTC or 23.00 Local Time.

The correlation value between heavy rainfall and CG lightning, both CG+ and CG – and combined CG (total) at the Sunggal Rain Post looks quite good, average correlation of CG- is r=0.615, r=0.626 for CG+ and r=0.633 for Total CG. The lightning and rainfall event with the highest correlation in the Sunggal Rain Station area take time on November 23 2021, , with a correlation value with CG total r = 0.947. The numbers of lightning on the time are CG- = 193, CG+ = 52, CG Total = 245, and daily rainfall of 71.8 mm. The lightning period lasts for 3 hours starting at around 12.00 UTC, or 19.00 Local Time with 1 peak of rain and 1 peak of CG lightning events.

Tabel 5. Characteristic of CG Ligtning and Heavy Rain in Sunggal Rain Station

Date	Number of Peak		Beginning of Lightning period (UTC)	Length of Lightning period (hours)	Correlation of Lightning and Rainfall		
	CG	Rainfall			CG-	CG+	Total
27/01/2019	1	2	12	2	0,811	0,706	0,779
27/05/2019	2	1	6	4	0,313	0,199	0,276
25/12/2020	1	2	15	3	0,634	0,720	0,652
08/02/2021	1	1	11	3	0,778	0,646	0,765
25/04/2021	1	2	10	4	0,809	0,877	0,847
12/06/2021	2	1	13	5	0,606	0,882	0,754
24/06/2021	1	1	19	2	0,489	0,544	0,529
26/10/2021	3	1	15	8	0,597	0,871	0,762
23/11/2021	1	1	12	3	0,932	0,965	0,947
27/02/2022	2	2	10	7	0,754	0,627	0,714
06/06/2022	1	1	9	3	0,776	0,654	0,762
22/06/2022	2	2	10	7	0,327	0,207	0,289
15/07/2022	2	1	16	6	0,710	0,686	0,703
15/08/2022	2	1	10	6	0,139	0,225	0,177
17/08/2022	1	1	16	4	0,762	0,929	0,843
03/11/2022	1	1	9	3	0,598	0,584	0,595
18/11/2022	2	1	10	6	0,563	0,333	0,479
18/12/2022	1	1	8	3	0,477	0,618	0,525
Average					0,615	0,626	0,633

Based on Tabel 6, CG lightning events in the Deli Serdang Climatological Station area generally occur 1 to 2 times the peak of the highest number of CG lightning with 1 to 2 peaks of rainfall. This means that it is possible that during heavy rain events, there will be repeated growth of cumulonimbus clouds so that the number of lightning strikes is high and the amount of rainfall also increases. The period of time for lightning to occur is also quite long, namely around 2 to 9 hours for 1 peak CG lightning event, and 6 to 11 hours for 2 peak CG lightning events. This condition occurred possibly because the cumulonimbus clouds that formed in the North Sumatera Climatological Station area were very large, so that a lot of lightning was produced and occurred over a long period of time. The start of lightning events around the North Sumatera Climatological Station usually occurs from afternoon to evening, namely from 07.00 UTC or 14.00 Local Time, until 17.00 UTC or 24.00 Local Time.

The correlation value between heavy rainfall and CG lightning, both CG+ and CG – and combined CG (total) at the North Sumatera Climatological Station looks quite good, namely an average of r=0.550 for CG-, r=0.567 for CG+ and r=0.560 for total CG. The lightning and rainfall event with the highest correlation in the Deli Serdang Climatological Station area occurred on February 22 2022, with a total of CG- = 178, CG+ = 130, CG Total = 308, and daily rainfall of 94.2 mm with a correlation value with CG total r = 0.950. The lightning period lasts for 9 hours starting at around 09.00 UTC, or 16.00 Local Time with 1 peak of rain and 1 peak of CG lightning events.

Tabel 6. Characteristic of CG Ligtning and Heavy Rain in Deli Serdang Climatological Station

Date	Number of Peak		Beginning of Lightning period (UTC)	Length of Lightning period (hours)	Correlation of Lightning and Rainfall		
	CG	Rainfall			CG-	CG+	Total
04/05/2019	2	1	7	11	0,884	0,893	0,889
29/08/2019	2	1	11	6	0,268	0,270	0,272
03/09/2019	1	1	12	4	0,491	0,583	0,527
28/01/2020	2	1	16	7	0,544	0,766	0,620
07/05/2020	1	1	9	5	0,474	0,539	0,504
14/06/2020	2	1	13	6	0,942	0,978	0,964
11/08/2020	1	1	17	7	0,609	0,464	0,562
25/12/2020	1	2	15	5	0,617	0,688	0,632
15/02/2022	2	2	9	9	0,619	0,697	0,646
27/02/2022	1	1	9	9	0,968	0,882	0,950
09/03/2022	2	1	13	8	0,208	0,462	0,281
22/06/2022	2	1	10	8	0,498	0,331	0,445
17/08/2022	1	1	15	7	0,692	0,676	0,695
31/08/2022	1	1	13	8	0,323	0,303	0,313
18/10/2022	1	1	14	2	0,009	0,019	0,013
20/11/2022	1	1	11	5	0,660	0,527	0,644
Average					0,550	0,567	0,560

Based on Tabel 7, CG lightning events in the Kualanamu Meteorological Station area generally occur 1 to 2 times the peak of the highest number of CG lightning with 1 peak of rainfall. This means that it is possible that during heavy rain events, there will be repeated growth of cumulonimbus clouds so that the number of lightning strikes is high and the amount of rainfall also increases. The period of time for lightning to occur is also quite long, namely around 4 to 6 hours for 1 peak CG lightning event, and 4 to 8 hours for 2 peak CG lightning events. The start of lightning events around the Kualanamu Meteorological Station usually occurs from evening to early morning, namely from 10.00 UTC or 17.00 Local Time, until 19.00 UTC or 01.00 Local Time.

The correlation value between heavy rainfall and CG lightning, both CG+ and CG – and combined CG (total) at the Kualanamu Meteorological Station looks quite good, namely an average of r=0.532 for CG-, r=0.507 for CG+ and r=0.525 for Total CG. The lightning and rainfall event with the highest correlation in the Kualanamu Meteorological Station area occurred on June 23 2022, with a total of CG- = 234, CG+ = 158, CG Total = 392, and daily rainfall of 86.6 mm with a correlation value with CG total r = 0.932. The lightning period lasts for 5 hours starting at around 15.00 UTC, or 22.00 Local Time with 1 peak of rain and 1 peak of CG lightning events.

Table 7. Characteristic of CG Ligtning and Heavy Rain in Kualanamu Meteorological Station

Date	Number of Peak		Beginning of Lightning period (UTC)	Length of Lightning period (hours)	Correlation of Lightning and Rainfall		
	CG	Rainfall			CG-	CG+	Total
04/05/2019	2	1	7	11	0,884	0,893	0,889
29/08/2019	2	1	11	6	0,268	0,270	0,272
27/03/2019	2	1	3	5	0,275	0,167	0,227

Date	Number of Peak		Beginning of Lightning period (UTC)	Length of Lightning period (hours)	Correlation of Lightning and Rainfall		
	CG	Rainfall			CG-	CG+	Total
04/05/2019	1	1	13	6	0,701	0,703	0,703
29/05/2019	1	1	19	4	0,568	0,489	0,542
08/09/2019	1	1	17	3	0,179	0,164	0,174
27/10/2019	1	1	18	4	0,861	0,775	0,887
14/09/2020	2	1	10	5	0,512	0,524	0,516
22/06/2022	2	1	10	8	0,461	0,303	0,411
23/06/2022	1	1	15	5	0,926	0,937	0,932
29/07/2022	1	1	15	4	0,813	0,796	0,806
21/10/2022	1	1	11	4	0,023	0,210	0,155
Average					0,532	0,507	0,535

Generally, the begining period of lightning events in the Medan and Deli Serdang areas occurs at various times, but dominated by afternoon to evening and mid night Local Time. Lightning and heavy rain come about around 09.00 UTC or around 16.00 Local Time or at night around 12.00 UTC (19.00 Local Time) until 15.00 UTC (22.00 Local Time). The lightning period lasts for a quite long time, from 2 hours to 11 hours for 1 to 3 peaks of daily lightning events. This is in line with research by Septiadi and Hadi (2011), where diurnal analysis between CG lightning and rainfall shows almost the same pattern in both the time and number of peaks of lightning activity and rainfall.

Based on the beginning and duration of the lightning period, it can be seen that cumulonimbus clouds generally grow starting from the Sunggal Rain Station area, then move and grow back towards the North Sumatera Climatological Station area and then towards the Kualanamu Meteorological Station area. Due to the movement of air masses which generally occur from the slopes of the mountains towards the coast, air masses gather and supported by an unstable atmosphere and formed the cumulonimbus clouds.

The correlation value between heavy rainfall and CG lightning, both CG+ and CG– and combined CG (total) in the Medan and Deli Serdang areas looks quite good, about r=0.566 for CG-, r=0.567 for CG+ and r= 0.576 for total CG. The correlation value for each research point tends good, but decreases depends of the distance of the rain gauge and the lighning detector location. The best correlation was obtained at the closest location to the lightning detector.

CONCLUSION

Generally, when there is an increase of lightning events at the research location, the rainfall also increases. Diurnal analysis between CG lightning and rainfall shows the similar pattern in both the time and number of peaks of lightning activity and rainfall. The CG- lighning value is generally higher than the CG+ lighning value.

The correlation between heavy rainfall and CG lightning in the Medan and Deli Serdang areas looks quite good, with the average correlation about r=0.566 for CG-, r=0.567 for CG+ and r= 0.576 for total CG. The lightning and rainfall event with the highest correlation in the Sunggal Rain Station occured on November 23 2021 with total CG correlation r = 0.947. The lightning and rainfall event with the highest correlation in the Deli Serdang Climatological Station area occurred on February 22 2022 with total CG correlation r = 0.950. The lightning and rainfall event with the highest correlation in the Kualanamu Meteorological Station area occurred on June 23 2022 with total CG correlation r = 0.932.

The correlation value for each research point tends good, but decreases depends of the distance of the rain gauge and the lighning detector location. The best correlation was obtained at the closest location to the lightning detector.

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