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RESEARCH ARTICLE OPEN ACCESS

Assessment of Lightning Ground Flash Density in the Niger Delta

Priye Kenneth Ainah, Danfebo Franklin Ayebagbalinyo John Tarilayon Afa

Department of Electrical and Electronic Engineering, Niger Delta University, Amassoma, Bayelsa State, Nigeria.

Email: ainahpriye@ndu.edu.ng

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Abstract:

The two important ingredients for thunderstorm formations are instability air mass (unstable air mass) and moisture. Apart from these conditions that favor the formation of thunderstorms in the area, several local conditions prevail due to the unstable air mass movement on rivers and seas to land mass. The influence of the ocean current in lightning formation is visible with incident, occurring along the coastlines. All these factors contribute to the high keraunic level of the coastal area in the Niger Delta. Twenty-two study areas were selected in the seven states of the Niger Delta. The meteorological data collected for the analysis is within 2005-2014 especially for the thunderstorm days. Some of the data were available in the Federal ministry of Aviation, and also from the aviation department of some oil companies in the area. The average cloud to ground flash was worked out and the ground flash density was calculated. Some influence of climatic effect on lightning frequency and distributions were observed and it was seen that the intensity of lightning activities varied as the area goes out of the delta coast.

Keywords — **Keraunic level, Meteorological data, Ground flash density, Inter Tropical Discontinuity.**

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I. INTRODUCTION

Lightning ground flash density refers to the frequency of lightning strikes that reach the Earth's surface within a specific area over a certain period, typically measured in flashes per square kilometer per year (flashes/km²/year). It's a crucial metric for understanding the prevalence and intensity of lightning activity in a particular region. Several factors influence lightning ground flash density, including geographical features, weather patterns, and climate conditions. Regions with warmer temperatures and high humidity tend to experience more lightning activity due to the convective processes that generate thunderstorms (Lavigne, T., et al., 2019). Additionally, topographical features such as mountains, plains, and coastlines can affect lightning patterns by influencing atmospheric circulation and moisture distribution. High lightning ground flash densities pose significant risks to human safety, infrastructure, and natural ecosystems (Shepherd, J. M., et al., 2010). Knowledge of lightning ground flash density informs the design and construction of buildings, power lines, and other infrastructure to withstand lightning strikes. It helps engineers determine the necessary precautions and standards to minimize damage and disruption caused by lightning. The warm, humid South-Western air mass and the warm, dry North-Eastern air mass are the two main surface air masses that influence the weather and climate of Nigeria. Two main pressure and wind systems interact to produce these air masses. In particular, the traits of their respective source regions have an impact on the trade winds that originate in the north-east from the Sahara and the south-west wind from south Atlantic (Ohwoghere-Asuma, et al., 2021). They also follow the sun's apparent path, which goes through Nigeria twice on its way to and from the tropic of cancer. Nigeria is affected all year long by both the warm, humid South-Western air mass and the warm, dry North-Eastern air mass. The Inter-Tropical Discontinuity

(ITD), which is the name given to the moisture discontinuity formed at the interface where these air masses converge (Udong, E., 2011). The climate of Nigeria is predominantly influenced by the seasonal movement of the ITD and it is associated with five distinct weather types. These weather types collectively shape Nigeria's climate. The occurrence of lightning is closely tied to weather and climate phenomena. Analyzing variations in lightning ground flash density over time provides valuable insights into climate change and its impact on atmospheric dynamics.

II. Lightning Current Distribution

Studies have gathered new statistical distributions of lightning current peak values from various countries. In Austria, for instance, (Diendorfer et al., 2009) conducted research from 2000 to 2007, collecting data on four hundred and fifty-seven upward negative flashes originating from the 100m Gaisberg tower. Similarly, in Japan, (Tokami & Okabe, 2007) analyzed one hundred and twenty current waveforms measured via sixty different transmission line towers. According to (Schoeme et al., 2009), data on 276 return stroke currents in the United States were examined using the triggered lightning equipment at the International Center for Lightning Research and Testing at the University of Florida (Rakov et al., 2003). Results from a statistical study based on lightning current measurements made on a 60-meter tower in the Belo Horizonde region were reported by Visacro et al. (2004) in Brazil. In earlier research, significant information on lightning peak current was also obtained by lightning locating systems (LLS) (Udo, 2006); (CIGRE, W.G C4.404, 2009); (Diendorfer et al., 2009). CIGRE (CIGRE WG. 33-01, 1991); EPRI Report 2006) adopted the frequency distribution of first return stroke lightning current peaks, which were derived from measurements of 388 negative downward flashes that were collected globally on a variety of structures, such as lines, masts, and chimneys. Berger's tower contributed one hundred and twenty-five measurements, with a lowest recorded current value of 3kA. The median value of the cumulative distribution of these present peaks is roughly 34 kA. With a median (μ) of 31.1 kA and a logarithmic standard deviation (σ) of 0.484, Berger estimated the lightning current distribution to have a log-normal distribution (Berger et al., 1980).

III. Ground Flash Density and Thunderstorm Day Analysis

Lightning parameters serve as indicators of lightning activity characteristics, encompassing factors such as thunderstorm occurrence, cumulative probability of lightning current magnitude, and the distribution of cloud-to-ground flash density. These fundamental lightning parameters play a pivotal role in traditional lightning performance analysis, particularly in the context of safeguarding power systems against lightning strikes (Sarajcev, P. et al., 2022). The features of lightning activity exhibit variations across different geographical regions and climates, leading to differing lightning parameter values (Galanaki, E., et al., 2015). Significant advancements have been made in the measurement of ground flash density over the years (Jayaratne & Kuleshov, 2006). Ground flash density directly impacts the lightning outage rate, demonstrating a linear relationship. An empirical equation of the form aT_d^b can be used to predict lightning ground flash density (Ng) from thunderstorm days (T_d) in situations where direct information on lightning activity from detectors is unavailable. In the empirical equation, a and b stand for empirically derived constants that are dependent on the local climatic circumstances. In the past, Mackerras (Mackerras, 1978) estimated these equations for Australia early on, producing values of a = 0.01 and b = 1.4. The constants a = 0.023 and b = 1.3 for South Africa were determined by (Anderson & Eriksson, 1980), who also developed what is now known as Eriksson's Formula. The values of a = 0.04 and b = 1.25, sometimes known as the CIGRE formula, were obtained in later research by (Anderson et al.,1984) using data from 62 stations collected over a five-year period. The CIGRE and Eriksson's equations are commonly employed in scholarly works to approximate the density of lightning strikes on earth.

$$N_g = 0.04T_a^{1.25} \qquad (1)$$

Another important step forward was when (Janischewskyj & Chisholm, 1986) published thunderstorm hour (TH) data rather than thunderstorm day (T_d) data for the indirect measurement of Ng based on thunder. TH data have been gathered consistently for at least 30 years, and they provide a temporal sample density 24 times higher than Td values. From TH, Ng can be calculated as follows:

$$N_g = 0.054\, T_H^{1.1} \tag{2}$$

IV. METHODOLOGY

A. Description of Study Area

The Niger Delta is situated in the southern portion of Nigeria, and it comprises of nine states. The region is distinguished by its substantial oil and gas resources, which are shared by all of these states. Approximately 60% of the overall area is made up of its vast coastal region, which is divided into upland and coastal zones. Because of the complex system of rivers, oceans, tributaries, and the influence of oceanic winds on the topography, this area has unusually high keraunic levels.

B. Method of Analysis

Due to the limited information and lack of modern lightning detectors the lightning days per year were collected for various sources for 2005 through 2014. Also, observations were made to know the lightning distributions and as its affects various seasons of the year.

The following procedure was used to evaluate the lightning ground flash density of the Niger Delta Region;

- Collection of Meteorological data.

The data sources are;

- Federal Ministry of Aviation,
- The Niger Delta Development Commission (NDDC)
- Land and people of Rivers and Bayelsa States

The monthly occurrences of thunderstorms and lightning days spanning from 2005 to 2014 are provided as a sample calculation for one of the sites, specifically the Brass Site. The monthly records for these years are detailed in Table 1. The analysis pattern of thunderstorm days and ground flash density (GFD) was conducted utilizing the Brass site, as outlined in Table 2.

If the ratio of cloud-cloud CC and cloud ground CG flashes is 3:1, Then the cloud to ground flash = 560/4 = 140. The ground flash density can be calculated from $N_g = 0.04T^{1.25}$. $N_g = 0.04 \times 140^{1.25} = 19.4$ flashes/ km/yr.

Table: 1 Ten Years Monthly Lightning Records for Brass Site

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Month	Year
15	30	71	89	76	67	35	28	51	78	20	9	2005	569
10	20	60	97	66	57	38	30	60	82	15	6	2006	541
10	25	55	91	70	51	40	25	54	80	25	12	2007	538
9	32	68	85	71	61	41	25	60	75	28	11	2008	561
16	34	70	81	79	59	39	31	63	67	30	13	2009	542
7	30	78	82	66	64	40	30	59	80	29	15	2010	580
12	32	77	80	76	60	31	29	64	68	22	16	2011	557
8	30	70	75	72	61	38	32	62	79	28	11	2012	566
9	20	63	85	72	52	40	33	67	80	21	10	2013	552
12	20	70	95	66	69	35	30	51	80	26	9	2014	561

Table 2: Climatic and Lightning days of the Niger Delta

S/N	State	Location	Average Lightning Days T_d	Ground Flash Density km/yr	Ave. Temp variation °C		Average Humidity mm H_g		Mean Annual Rainfall mm
					Wet Season	Dry Season	Wet Season	Dry Season	
1	Akwa-Ibom	Uyo	90	11.0	23	32	80	55	1670
		Ikot-Ekpene	100	12.7	22	34	81	58	1810
		Ikot-Abasi	130	17.6	22	33	84	60	2010
2.	Bayelsa	Yenagoa	105	13.4	24	35	88	63	2450
		Gbarain	110	14.3	23	34	86	64	2380
		Brass	141	19.4	22	34	93	65	3450
3	Cross River	Calaba	150	21	22	33	90	61	3840
		Akamkpa	65	7.4	23	35	78	51	1560
4	Delta	Warri	125	16.7	23	33	85	58	2870
		Sapele	101	12.8	22	34	77	52	2200
		Ugelli	111	14.4	23	35	81	57	2010
		Asaba	85	10.3	25	33	81	54	2420
5	Edo	Bennin	85	10.3	24	34	77	52	2000
		Irua	56	6.1	24	35	72	50	1650
6	Rivers	Port Harcourt	110	14.3	23	34	82	52	2810
		Afam	108	14	22	34	82	58	2640
		Ahoada	90	11.1	23	34	78	56	2645
		Bonny	135	18.4	22	33	90	61	3260

V. RESULTS AND DISCUSSION

The monthly occurrences of thunderstorms and lightning days spanning from 2005 to 2014 (ten years) are presented as a sample calculation for one of the sites, specifically the Brass Site. The spread of ground flash density for the stations is depicted in the map shown in Figure 2, while the monthly records for these years are detailed in Table 1. The geographical distribution of ground flash density, as shown in Figure 2, which illustrates the variation in lightning activities across the Niger Delta. Notably, the highest ground flash densities are recorded within the coastal towns. For instance, Calabar records (Td = 150) a ground flash density of 21 km-2yr-1, while Bonny (Td = 139) and Brass (Td = 140) record 19 km-2yr-1 and 20 km-2yr-1, respectively. As mentioned before, the inter-tropical discontinuity (ITD) boundary's seasonal migration is the main factor influencing Nigeria's climate. In August, the ITD is positioned at its northernmost position at about latitude 20° N, while in February, it resides at the southernmost position at latitude 7° N. The rainfall amount, seasonal distribution, type of rainfall, duration of wet and dry seasons, and general weather conditions in any location within the country largely depend on the location of the migrating ITD zone. This migrating ITD delineates the Nigerian weather into distinct dry and wet seasons of varying durations.

In the Niger Delta, the wet season typically extends from late March or April to October or early November, while dry season spans from November to March, with the occurrence of the Harmattan in late December. Observationally, lightning and thunderstorm activities are more prevalent during the transitional periods between two main weather seasons, namely April to June and October to early November. This phenomenon may be attributed to the interplay between cold fronts and warm, moist air masses. In the Niger Delta, humidity levels range from 65mmHz to 95mmHz.

The interplay of warm, moist air rising due to convection and cool air replacing it plays a crucial role in thunderstorm formation. As moist air ascends, it cools, leading to condensation of water vapor and release of latent heat, allowing the air parcel to continue ascending, thus forming cumulonimbus clouds conducive to lightning and thunderstorm activities. During the period from July to September, lightning activity intensifies, accompanied by heavy rain and intense lightning within the rainfall duration. This period corresponds to the latitude 20° N positioning of ITD and dominance of the south-west trade wind from the South Atlantic, resulting in higher moisture content and increased prevalence of thunderstorm activities in the Niger Delta. Figure 1 illustrates that nearly 85% of recorded thunder days occur within this period. In addition to these conditions, several local factors influence thunderstorm development, including the influence of the ocean, seas, and rivers.

Air masses across certain areas experience variations in temperature throughout the day, providing a conducive environment for thunderstorm development. Convection, triggered by the presence of moisture, instability, and triggering mechanisms, plays a significant role in thunderstorm initiation. One major factor influencing severe thunderstorm and lightning activity along the coast of the Niger Delta is the influence of the ocean.

Thunderstorm records spanning the ten-year period were used to create a keraunic map of the Niger Delta, depicted in Figure 3. Analysis of Figure 3 revealed that lightning predominantly occurred over land masses rather than over the ocean, thus confirming the findings of Orville and Henderson in 1986. The influence of ocean currents on lightning activity is evident, with a higher incidence observed along coastlines where warm currents prevail, while cooler currents tend to suppress lightning activity. This pattern is particularly noticeable within the coastal areas of the Niger Delta. Thunderstorm and lightning activities occur consistently throughout the year in this zone, with lightning peaks varying across different months.

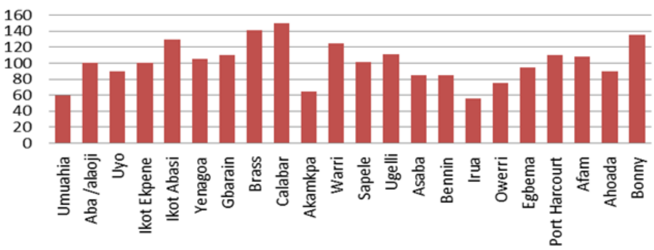

Figure: 1: Variation in the number of thunderstorm days across 22 states

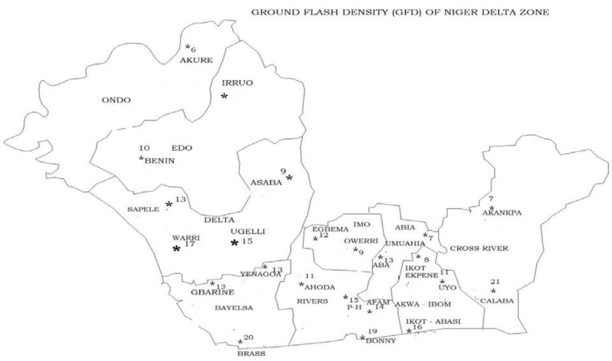

Figure 2: Dispersion of Ground Flash Density in the Niger Delta

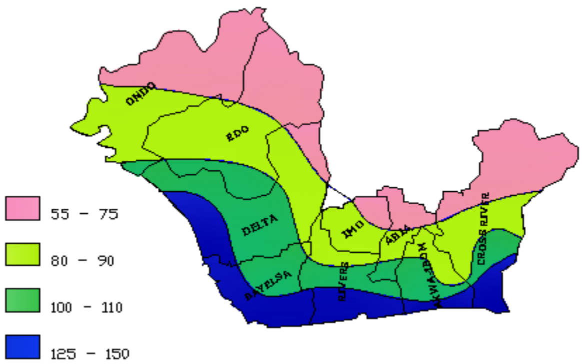

Figure: 3: Keraunic Niger Delta Map

VI. Conclusion

The Inter-Tropical Convergence Zone's (ITCZ) location largely determines where lightning strikes in the nation. About ten months of the year, the Niger Delta is greatly affected by the maritime (humid) air mass that originates from the Atlantic Ocean and the south-western wind known as the south-west monsoon, though to differing degrees. This south-westerly wind plays a predominant role in thunderstorm formation. Due to the systematic heating of continental land surfaces compared to the sea, there is a greater convective potential energy (CAPE), atmospheric instability, and stronger air movements, all of which are crucial for the formation of deep convection and thunderstorms. It's well-established that lightning activity over land is typically an order of magnitude greater than over the ocean. The coastal region of the Niger Delta, bound by rivers and seas and influenced by the Atlantic coast, is particularly susceptible to intense lightning activity. This susceptibility is further confirmed by observations in coastal sites, particularly during January and February when the ITD zone reaches latitude 70° N. During this period, thunderstorms and lightning flashes are notably prevalent, especially during the early hours of the morning.

REFERENCES

Anderson, R. B., and A. J. Eriksson (1980), Lightning parameters for engineering application, Electra, 69, 65 – 102.

Anderson, R.B., Eriksson, A.J., Kroninger, H., Meal, D.V. and Smith, M.A. (1984). Lightning and Thunderstorm Parameters, Paper presented at IEEE Int. Conf. Lightning and Power System London, UK.

Berger, K., Anderson, R.B. and Kroninger, H. (1980). Parameters of lightning flash. Electra, No. 69;. 65 – 102.

CIGRE WG.C4. 404-G. Diendorfer, 2009.Cloud to Ground Lightning Parameters derived from lightning location system performance. Cigre Technical procedure Nr.376.

CIGRE, W.G. (33-01, 1991). Eriksson, Guide to Procedures for estimating the lightning Performance of Transmission Lines CIGRE Broclure 63.

Diendorfer, G., Pichler, H and Mair, M. (2009). Some parameters of negative upward initiated lightning to the Gaisberg tower 2000 – 2007 IEEE Trans on EMC, (51)3; 20-31.

EPRI Report 1013594, 2006, Guide for Transmission Line Grounding: A road map for Design, Test and Remediation: Part 1 – Theory Book, Palo Atto, C.A. 2006.

Galanaki, E., Kotroni, V., Lagouvardos, K., & Argiriou, A. (2015). A ten-year analysis of cloud-to-ground lightning activity over the Eastern Mediterranean region. Atmospheric Research, 166, 213-222.

Janischewskyj, W. and Chisholm, W.A.(1986). Second Interim Report of Lightning Ground Flash Density measurements in Canada. Canadian Electrical Association Report for Project 179T 382.

Jayaratne, E. R., & Kuleshov, Y. (2006). Geographical and seasonal characteristics of the relationship between lightning ground flash density and rainfall within the continent of Australia. Atmospheric Research, 79(1), 1-14.

Lavigne, T., Liu, C., & Liu, N. (2019). How does the trend in thunder days relate to the variation of lightning flash density?. Journal of Geophysical Research: Atmospheres, 124(9), 4955-4974.

Mackernas, D. (1978). Prediction of Lightning Incident and Effect in Electrical Systems.Elect. Eng. Trans. Int. Eng. Australia, 73 – 77.

Ohwoghere-Asuma, O., Aweto, E. K., Nwankwoala, H. O., & Akpokodje, E. G. (2021). Stable isotopic composition of precipitation in a tropical rainforest region of the Niger Delta, Nigeria. Isotopes in Environmental and Health Studies, 57(1), 94-110.

Sarajcev, P., Lovric, D., & Garma, T. (2022). Statistical Safety Factor in Lightning Performance Analysis of Overhead Distribution Lines. Energies, 15(21), 8248.

Schoeme, J., Uman, M. A., Rakov, V.A., Rambo, K.J., Jerauld, J., Mata C.T., Mata, A.G., Jordan, D.M. and Schnetzer, G.H. (2009). Characteristics of return stroke currents in rocket trigged lightning. J. Geophy. Res. 114, DO3106.

Shepherd, J. M., Stallins, J. A., Jin, M. L., & Mote, T. L. (2010). Urbanization: Impacts on clouds, precipitation, and lightning. Urban ecosystem ecology, 55, 1-28.

Tokami, J. and Okabe, S. (2007). Observational results of lightning current on transmission towers" IEEE Trans. on PWRD-(22)1; 547 – 556.

Udo, T. (2006). Study of the Winter Lightning Ground Flash Density Investigated by the Lightning Location Systems. IEEE Trans. on Power Delivery. 21(3); 1613-1620.

Udong, E. (2011). The quest for sustainable livelihoods: women fish traders in Ibaka, Niger Delta, Nigeria. Wageningen University and Research.

Visacro, S., Soares J. A., Schroeder, M.A.O., Cherchiglia, C.L. and De Souse, V.J. (2004).Statistical Analysis of Lightning current parameters: Measurements at Morro de Cachimbo Station. J. Geo Phy Res. (109) doi 105; 1 – 11

