VIABILITY OF LIGHTNING ENERGY HARNESSING THROUGH ANNUAL DISTRIBUTION ANALYSIS USING THREE SPECIFIC LOCATIONS IN NIGERIA

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Abstract
The ever increasing demand for energy has led to the advancement of power supply research into sufficient clean renewable energy sources. This has led to awaking scientific minds into available natural renewable Energy sources around us. One of such sources is lightning energy, which is a very fast electrostatic discharge from Columbus cloud and hence gives off very high intensity flash of light and very loud sound called thunder. It has an enormous amount of energy (about 1 billion watt) and occurs in a fraction of a second. There are some setbacks to harnessing this enormous energy and one is it's unpredictability nature which was looked into by this paper using lightning occurrence data from John Afa for three locations in Nigeria. The information was analyzed to ascertain the viability of harnessing lightning in these locations and to know the periods / months with low and high probability of catching lightning strike. The three locations were Brass, Bonny island and Port-Harcourt and analysis showed that Brass has the highest probability of harvesting lightning strike with annual periods of high frequency between March and June and between August and November. The months with peak frequency are April, May and October. In conclusion, as lightning frequency varies from different locations, putting a lightning harvesting farm in these locations would increase the possibility of arresting lightning strike.

Introduction
Over the years, there has always been a need for technological advancement in power generation to meet the ever growing demand. Research is concurrently being carried out for advancement and discoveries of more efficient non-polluting sources of energy, which has led to advancement in renewable energy. There are various source which has fewer research in harnessing due to it characteristics is lightning. Lightning has proven to be an interesting field of study with lots of on going research work. It has been witnessed or seen by all as its effects are felt during thunderstorms. It is initialized in the clouds, specifically a charged cloud (Columbus cloud). Lightning strike is an electrostatic discharge between oppositely charged bodies which gives off a high intensity flash of light and very loud sound called thunder (Rakov, 2013). This could occur between two oppositely charged clouds (intercloud lightning), between oppositely charged regions within a cloud (intracloud) and between cloud and ground/earth-surface (cloud-to-ground lightning). The lightning strike of most interest for harnessing is the cloud to ground (CG). The CG lightning enable a very high energy (about 1 billion watt) to flow between the cloud and ground and this energy can be harnessed and converted for use (Bouquegneau, 2011; Dwyer & Uman, 2014; Rakov & Uman, 2003; Tovar et al., 2014). But the harnessing of this enormous energy has some setbacks and one of which is the focus of this research paper. There is a certain perception that lightning doesn't strike a particular place twice and this isn't scientifically proven as this thought is based on the

unpredictability characteristics of lightning. Lightning occurrence has proven to be unpredictable in nature, but this can be assisted / handled by prior knowledge of specific areas with high frequency of occurrence to locate or position lightning harvesting farm. This research paper looks into lightning frequency analysis for three locations in Nigeria to determine the viability of harnessing lightning's energy and appropriate location for a lightning harvesting farm.

Overview Of Lightning Distribution In Nigeria

In order to harness lightning, the effective positioning of lightning arrestors or catchers is very important. This can only be achieved with knowledge of various lightning zones in Nigeria and specifically on the target zones or regions. The lightning zones involves areas with high frequency of lightning occurrence as this would help in effectively harvesting lightning. Lightning zones are directly proportional or dependent on cloud formation, when larger dense clouds are formed by integration of smaller clouds, which in-turn leads to lightning occurrence. These clouds could be as high as 5 – 10km in length (Dwyer & Uman, 2014). According to Dwyer and Uman (2014), cloud and cloud to ground lightning which has been virtually seen by everyone occurs about 30 – 100 discharge per second worldwide which is roughly 9 million discharge per day or 6 $km^{-2}yr^{-1}$ averaged over the earth (Dwyer & Uman, 2014). Lightning frequency is fairly high in tropical countries like Nigeria (Buba et al., 2012; Madueme, 2001). Various countries and regions have their varying frequencies and some research has been carried out to analyse lightning occurrence in some specific states in Nigeria.

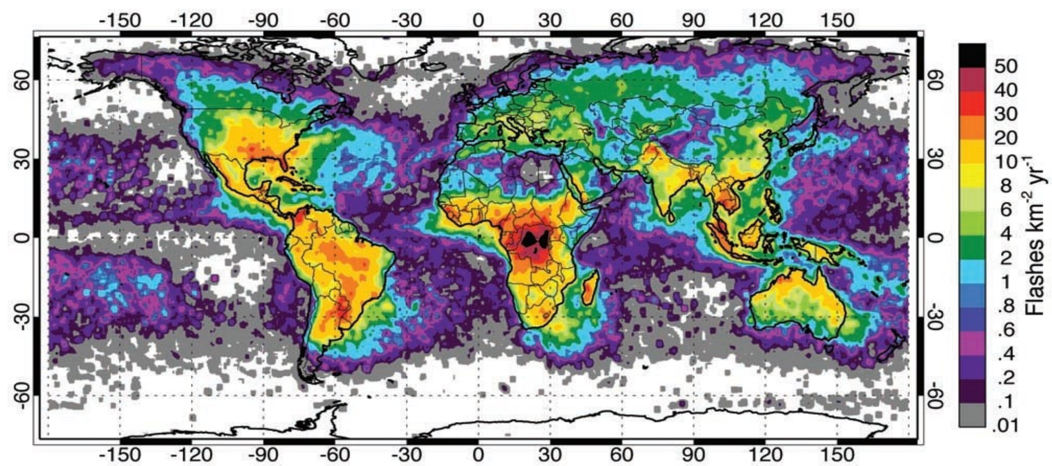

Figure 1 The annual distribution of total lightning activity worldwide (fl $km^{-1}y^{-1}$) (Christian et al., 2003)

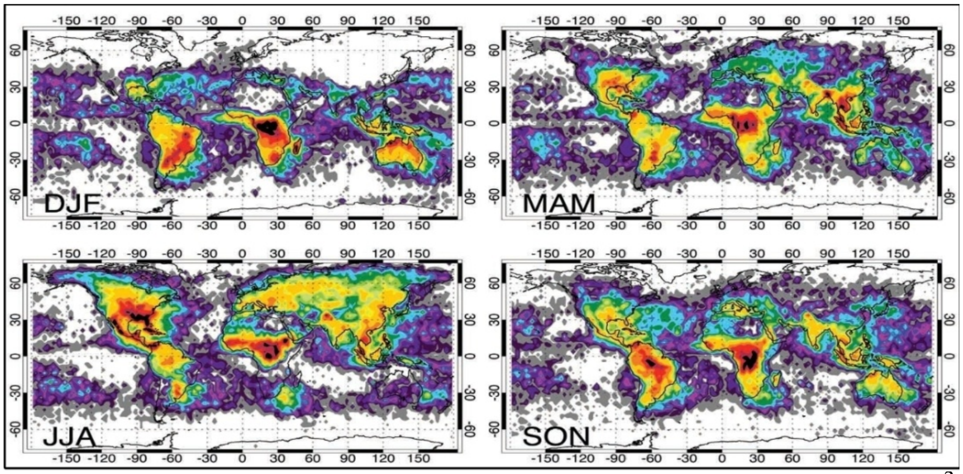

Figure 2 The annual seasonal distribution of lightning activity (in units of fl km^{-2} yr^{-1}) a) December, January, and February (**DJF**) (b) March, April and May (**MAM**) (c) June, July and August (**JJA**) (d) September, October and November (**SON**) (Christian et al., 2003)

Table 1 Optical transient detector (OTD) Mean Annual Flash Density: Africa (Christian et al., 2003)

Rank	Place name	OTD, fl km^{-2} yr^{-1}	Lat (N)	Lon (E)	Thunder days
1	Kamembe, Rwanda	82.7	−1.25°	27.75°	221
2	Boende, Dem. Rep. Congo	66.3	0.25°	20.75°	118
3	Lusambo, Dem. Rep. Congo	52.1	−4.75°	24.25°	119
4	Kananga, Dem. Rep. Congo	50.3	−5.75°	18.75°	139
5	Calabar, Nigeria	47.4	5.25°	9.25°	216
6	Franceville, Gabon	47.1	−2.25°	14.25°	–
7	Miandrivazo, Madagascar	35.9	−19.25°	45.75°	146
8	Mamfe, Camaroon	35.6	5.7°	8.3°	201
9	Kindia, Guinea	35.0	10.75°	−12.75°	111
10	Bahar Dar, Ethiopia	33.1	12.25°	36.75°	–
11	Ouanda Djalle, Central African Republic	31.5	8.25°	22.25°	–
12	Macenta, Guinea	31.4	8.25°	−10.25°	151
13	Jos, Nigeria	29.4	9.25°	8.25°	139
14	Kumasi, Ghana	26.1	6.25°	−1.25°	157
15	Entebbe, Uganda	23.4	0.0°	32.6°	206
16	Sikasso, Mali	23.0	10.75°	−5.75°	123
17	Bloemfontein, South Africa	23.0	−29.75°	28.75°	60

Figure 1, figure 2 and table 1 were obtained due to optical sensing and lightning detection from the satellite view, which shows lightning occurrence frequency of the world with range specification. Figure 1 shows an overall annual lightning distribution worldwide map with range in flash per square kilometer per year. It shows that most part of Nigeria has 10 – 20 flash per kilometer per year, but the central and southern part has higher lightning frequency from 20 – 30 fl/Km/yr. Figure 2 shows quarterly lightning frequency distribution map (DJF, MAM, JJA, and SON) which indicates variation in intensity. The four-quarter duration represents weather seasonal shift. From observation of figure 2, it is noticed that DJF map has the lowest lightning frequency with the highest periods being JJA followed by MAM (with black spots –highest frequency- noticed at the bottom left of Nigeria) and then SON. This is in line with the weather seasons in Nigeria in which the JJA, SON and MAM periods have higher rainy and cloudy periods. It is also observed from the map that lightning occurs more at the southern and central part of Nigeria.

Mowete and Adelabu (2009) conducted a study to determine the frequency of lightning in selected locations along the coastal area of Lagos, and some cities in South West, Nigeria; including high tension power transmission facilities (132kV, 330kV), power sub-stations, the airport and similar institutions. Afa & Kelvin (2013) conducted research on the frequency of lightning in the coast of Brass, Bayelsa state. They collected lightning information between 2008 and 2012 which enabled them determine the lightning density of 10 – 15 flashes per km^2 per year. Melodi & Oyeleye (2017) also conducted a study to model the frequency of lightning in the south-west coast and its impact to power lines. In same view, Buba et al., (2012) conducted research to determine the frequency of lightning in Nigeria using the high rate of lightning accidents especially for the aviation sector which proved to be high (about 30 – 40 strikes per km^2 per year). All these research shows that Nigeria is a country with high lightning frequency, especially at the coastal areas as mentioned by (Buba et al., 2012). Lightning occurrence distribution data has been computed by different authors for some few locations in Nigeria. All computation carried out were done by obtaining lightning data from the Nigerian meteorological agency database at the different airports locations. These locations has also been investigated to have averagely high lightning occurrence frequency. These are;

a) Lokoja, kogi state
b) Brass, PH and Bonne
c) Lagos west coast
d) Owerri, Imo state
e) Enugu
f) Jos
g) Zaria
h) Cross river

(Afa, 2012; Afa & Kelvin, 2013; Mowete & Adelabu, 2009; Melodi & Oyeleye, 2017; Adepitan & Ogunsanwo, 2012; Audu et al., 2024)

Methodology

Nigeria as a country has high frequency of lightning occurrence from a global standpoint. An average lightning frequency for the world is 6 per km square per year, but Nigeria has averagely 30 flashes per km square per year. In Nigeria, there are areas which constitute for that high average frequency of lightning occurrence. This denoting that lightning frequency vary from location to location. The frequency of a certain community could differ from the neighboring community depending on some certain factors. Some of such factors which effect variations are;

a) High pollution load (like particle matter)
b) Urban heat island (UHI) induced differential heating
c) Increased surface roughness
d) Local tropical factors like sea breeze
e) High total aerosol optical depth
(Dewan et al., 2024; Westcott, 1995; Wang et al., 2021; Shi et al., 2023; Bourscheidt et al., 2016; Bentley et al., 2021;)

And for coastal areas, these additional factors are important;

f) High humidity (moisture) and pressure of the area
g) The influence of the ocean current on lightning activities
h) The trajectory nature of discharges on coastlines
(Afa, 2012; Afa & Kelvin, 2013)

But this paper carries out analysis using three locations in Nigeria; Brass coast, Port Harcourt and Bonny island. Brass is a local government in Bayelsa state, situated close to the Atlantic Ocean. The data obtain for brass was at the coastal region. While PH and Bonny island are both located in river state with Port Harcourt an inland being the capital city and bonny island is a riverine community. These are all depicted in figure 3 below.

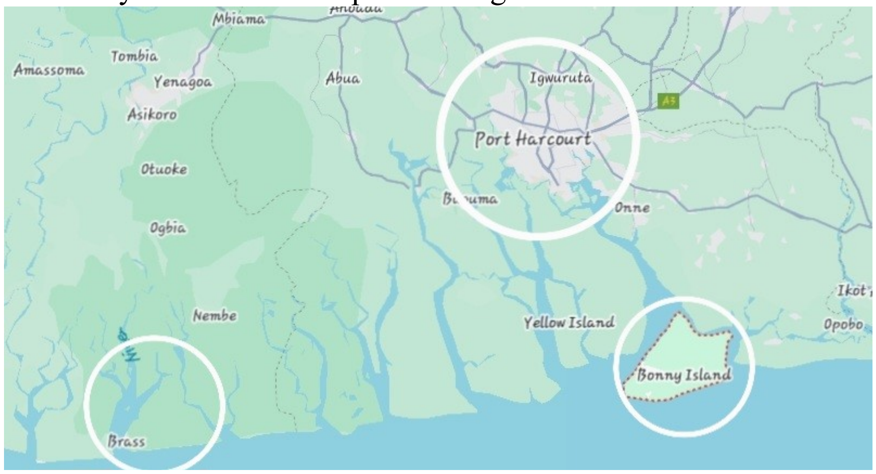

Figure 3 Google map showing Port-Harcourt, Brass and Bonny Island in the south-south of Nigeria

Data Source

The lightning data were obtained from John Afa (Afa, 2012; Afa & Kelvin, 2013), which was summarized in table 2. This entails lightning days for 2010 and 2011 (January to December) from three locations in the Niger delta region (brass coast, Port Harcourt, and bonne).

Data Presentation and Analysis

Statistical analysis can be carried out to ascertain convenient lightning harvesting periods. This is essential in-order to know the periods in which lightning harvesting is deficient or at its peak. As already stated in section 3.0, that Nigeria does not have a lightning map showing its frequency but some research has been conducted in some few areas to obtain lightning frequency.

The data presented in table 2 are the lightning days values for each month for each location.

Table 2 Lightning days for 2010 and 2011 from brass coast, bonny an Port Harcourt

	Bonny, Onne		**Port Harcourt**		**Brass coast**	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**
January	5	7	2	1	15	10
February	20	24	15	18	30	20
March	43	45	38	35	71	60
April	49	71	42	58	89	97
May	68	72	57	61	76	66
June	35	40	35	28	67	57
July	31	29	28	18	35	38
August	6	10	15	18	28	30
September	40	42	25	25	51	60
October	54	61	40	48	78	82
November	18	15	6	8	20	15
December	7	6	5	2	9	6
TOTAL	**376**	**422**	**308**	**320**	**569**	**541**

The lightning days data expressed in table 2 for bonny, brass coast and PH represents the average number of days in which at least a single lightning strike is witnessed in a certain

location for a certain period of time. The lightning data which was obtained for 2010 and 2011 was grouped monthly (January to December), showing changes between months.
From (Contributor, 2021; Uman, 1986;), the ratio of intra-cloud (IC) and cloud-to-cloud (CC) lightning to cloud-to-ground (CG) lightning is 3:1. Hence;
(IC + CC) : CG = 3 : 1
The total amount of lightning days for each year (table 2) consist of IC, CC and CG lightning flashes all together, and the average number of CG lightning strike can be obtained using the equation.

$$\text{Number of CG Lightning} = \frac{\text{Total number of thunderstorm days}}{n}$$

n = total ratio number = 4
The mean or average of lightning flash for a period of time also known as ground flash density (GFD) or lightning frequency can be calculated from the total lightning flash for a period. This can be obtained using;
$N_g = 0.04T_a^{1.25}$ flashes/km^2/yr
Where
N_g is the ground flash density (flashes/km^2/yr)
T_a is the total number of thunderstorm days
Table 3 shows the GFD (ground flash density) and AGFD (average ground flash density) and the AGFD is calculated for every site. The AGFD for a location can be used to determine the probability of lightning strike in that area.

Table 3 Total Lightning days for 2010 and 2011 from brass, bonny and Port Harcourt showing CG, GFD and AGFD

	Bonny, Onne		**Port Harcourt**		**Brass coast**	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**
TOTAL	376	422	308	320	569	541
IC + CC	282	316.5	231	240	426.75	405.75
CG	94	105.5	77	80	142.25	135.25
GFD	11.70765	13.52464	9.12375	9.570232	19.65058	18.44937
AGFD	12.61614374		9.346991322		19.04997505	

The probability for getting a lightning strike per day in a month can be obtained using the probability formula.

$$p(\text{a lightning per day per month}) = \frac{\text{Total lightning occurrence in a month}}{\text{Total number of days in a month}}$$

Table 4 Monthly lightning distribution showing probability, CG and GFD

	Bonny, Onne					**Port Harcourt**					**Brass coast**				
	2010	**2011**	**ACG**	**Prob. CG**	**AGFD**	**2010**	**2011**	**ACG**	**Prob. CG**	**AGFD**	**2010**	**2011**	**ACG**	**Prob. CG**	**AGFD**
Jan	5	7	1.5	0.05	0.796811	2	1	0.375	0.0125	0.140858	15	10	3.125	0.104167	1.994361
Feb	20	24	5.5	0.183333	4.042915	15	18	4.125	0.1375	2.821767	30	20	6.25	0.208333	4.743416
Mar	43	45	11	0.366667	9.615726	38	35	9.125	0.304167	7.612588	71	60	16.375	0.545833	15.81131
Apr	49	71	15	0.5	14.16953	42	58	12.5	0.416667	11.28181	89	97	23.25	0.775	24.50586
May	68	72	17.5	0.583333	17.18062	57	61	14.75	0.491667	13.87494	76	66	17.75	0.591667	17.48796
Jun	35	40	9.375	0.3125	7.87418	35	28	7.875	0.2625	6.332197	67	57	15.5	0.516667	14.76236
Jul	31	29	7.5	0.25	5.957552	28	18	5.75	0.191667	4.273917	35	38	9.125	0.304167	7.612588
Aug	6	10	2	0.066667	1.141639	15	18	4.125	0.1375	2.821767	28	30	7.25	0.241667	5.710363
Sept	40	42	10.25	0.341667	8.803311	25	25	6.25	0.208333	4.743416	51	60	13.875	0.4625	12.85383
Oct	54	61	14.375	0.479167	13.43541	40	48	11	0.366667	9.615726	78	82	20	0.666667	20.30153
Nov	18	15	4.125	0.1375	2.821767	6	8	1.75	0.058333	0.966137	20	15	4.375	0.145833	3.037133
Dec	7	6	1.625	0.054167	0.880659	5	2	0.875	0.029167	0.406211	9	6	1.875	0.0625	1.053156

From table 4, the probability for obtaining a lightning in a month is higher in the months of March, April, May, September and October.

Result and Discussion

This section highlights graphical representation of the analysis from section 6.0.

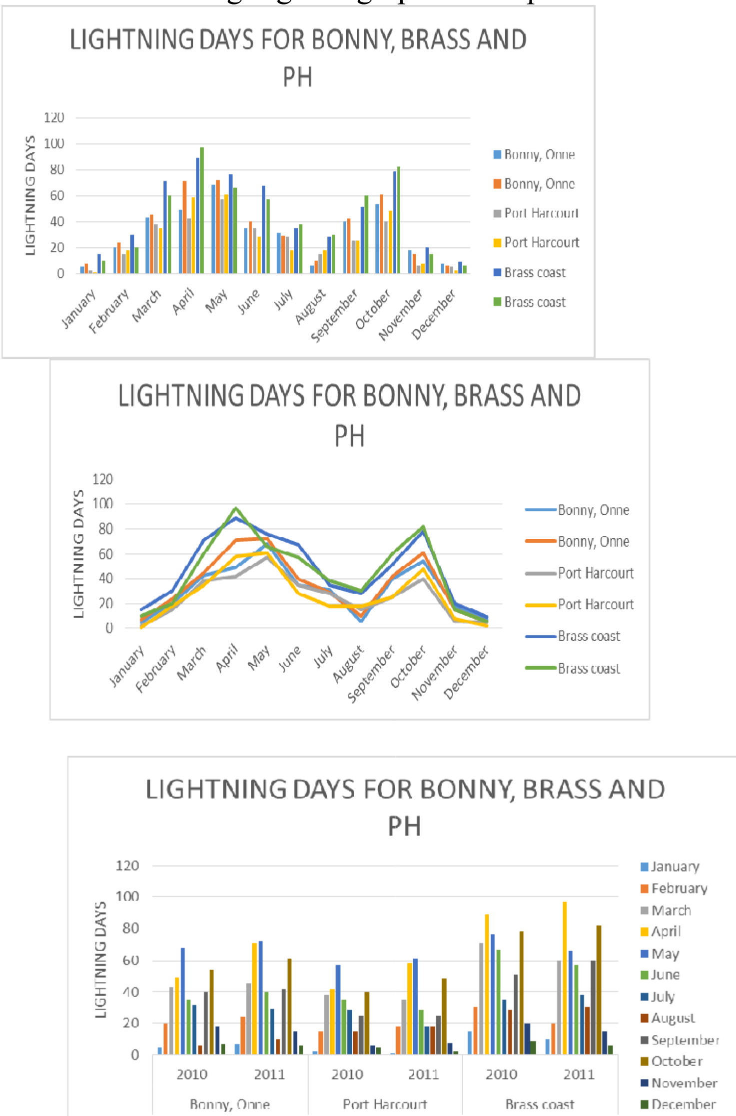

Figure 4 (a, b & c) Lightning days for bonny, brass coast and Port Harcourt

Figure 4 (a, b & c) shows different plot patterns signifying the variation of lightning days for the three location from January to December. Figure 4 (a) shows a histogram of the lightning days distribution across the year. This showed that Brass coast location for 2010 and 2011 has more lightning days distribution, and also indicated the periods in a year which has more lightning days. The periods with high lightning days are between March and June and then between September and November.

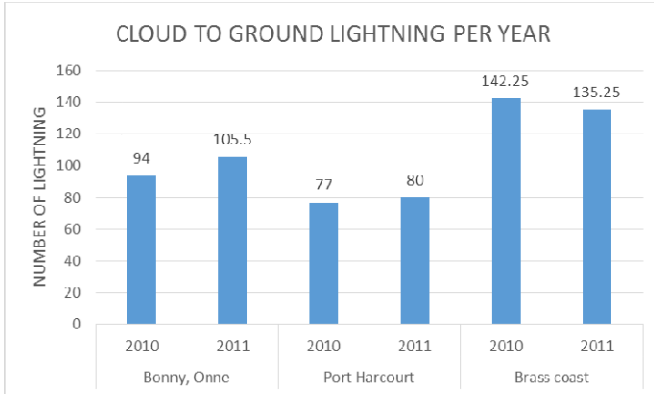

Figure 5 Cloud to ground lightning for a year

Figure 5 shows the total CG lightning for each year with the locations. It proves brass coast to have more CG lightning followed by bonny and the Port Harcourt.

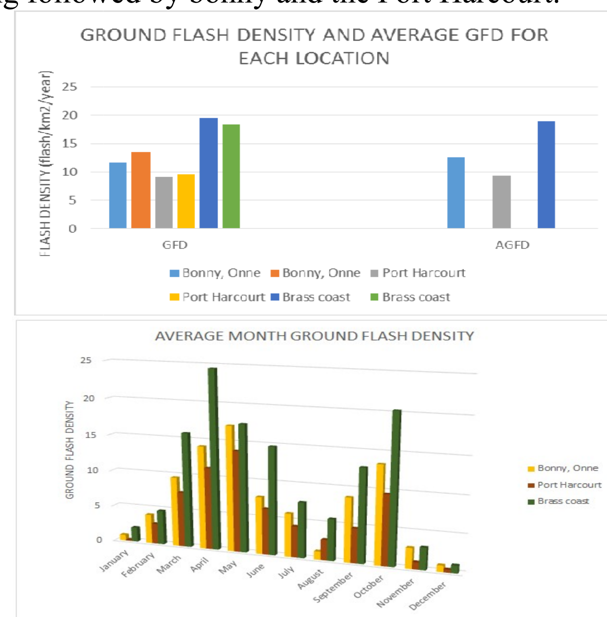

Figure 6 (a & b) GFD and AGFD for each location per year

Figure 6 shows the GFD and Average GFD (flash per kilometer square per year) for the individual years for each location, which differs from the number of lightning per year. This shows lightning occurrence for a year per kilometer square of the lightning location site considered. The AGFD is the average GFD for the both year per location. Meaning, the GFD for each year were added and halved to obtain the mean for the both year.

While (a) shows for year GFD, (b) shows for monthly GFD. When compared, brass still has higher readings for each month.

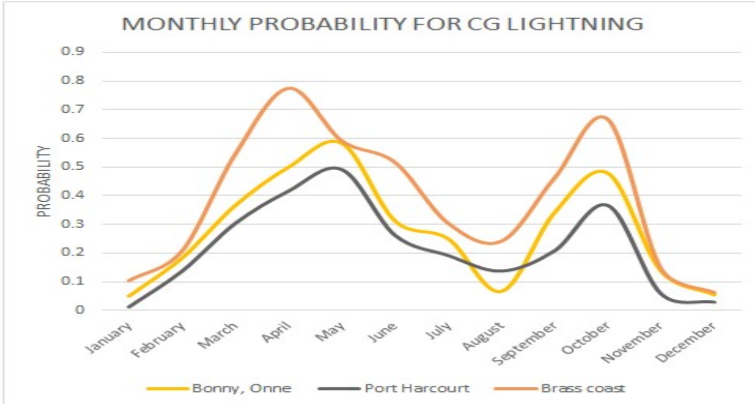

Figure 7 Monthly probability of lightning occurrence for the three locations

Figure 7 shows the probability of obtaining a single lightning strike per day in a month. Each location has two peak periods in a year signifying the two periods in a year in which lightning occurrence is at its peak even for harvesting. The first peak is during the second quarter of the year with a slope increase from the first quarter. The second peak period is observed in the month of October, sloping from September. The averaging months are March, June and July and even April for some locations. The abnormal periods showing low readings for lightning occurrence are January, February, August, November and December. From figure 7, brass coast has the highest of frequency and probability with high peaks during April and October. While Port Harcourt and Bonny have similar peaks during May and October with Port Harcourt having the lowest of the three readings.

The peak, normal and abnormal periods correlate with the season shift in Nigeria, which are the rainy season with high thundercloud and rainfall and dry season with less thundercloud activities. The dry season in Nigeria occurs in the months of November, December, January, and February with August seen as a break month for thundercloud activities. Some months with high rainfall activities are not observed to have the peak for lightning activities, this is because lightning occurrence has other influencing factors. As stated by John Afa, higher lightning occurrence are noticed at the end of the rainy season with other multiple influencing factors (Afa & Kelvin, 2013).

Discussion

The viability of harnessing lightning energy has been looked into, which has been streamlined to in-depth knowledge of zones in facilitating harvest process. With a larger goal of obtaining lightning map for Nigeria and also implementation of an harvest farm, two years lightning frequency data for three locations in Nigeria were obtained and analyzed.

From the results presented, there are periods of higher and lower lightning frequency or occurrence. According to John Afa, lightning occurrence is not totally dependent on rainfall intensity (Afa & Kelvin, 2013). This is evident from the results as the highest or peak frequency is not at periods of highest intense rainfall but rather after. It has been researched that the highest lightning frequency distribution are witnessed in coastal regions because of the moist atmospheric air condition. This is due to the presence of ocean/sea activities. (Christian, 2003). The moist atmospheric condition decreases the resistivity of the air medium, hence conductivity probability for lightning strike is increased. Similar coastal atmosphere could be seen from Lagos coastal research (Mowete & Adelabu, 2009).

From the view of the GFD, the three locations have averagely high lightning occurrence frequency as compared to the worldwide values (Christian et al., 2003) and the average Nigeria lightning value. This denotes that these are good locations for a lightning harness farm. As already shown from the tabulated values in section 5.0, lightning occurrence frequency is not fully dependent on rainfall as this is evident in the months of April, May and October. The graphical presentations shows higher lightning days before or after the major raining months. At such months with higher lightning days, this energy source could serve as the major source and at other months, it could be a backup or additional source of energy for communities within the region.

As mentioned by Afa, (2012) and Afa &Kelvin, 2013, more lightning data is required for the country to ascertain more possible locations for establishment of lightning harvest farms. With lightning enormous energy which has been explained in previous section, when fully harnessed would assist in Nigeria's energy supply to meet ever increasing demand.

Conclusion

The possibility of harnessing the enormous energy from lightning may seem slim due to its scarcity or unpredictable nature. But as already expounded in this paper, an in-depth knowledge of specific areas in the world with higher lightning frequency could facilitate trapping and harnessing of this energy through establishment of lightning harvest farms in lightning zones.

This was analyzed and shown using three specific locations in Nigeria (brass coast, bonny, and Port Harcourt). And in order to obtain more results, devices can be placed at more specific locations to determine lightning frequency at such areas. Hence producing lightning zone map for Nigeria. The lightning map has been hindered due to lack of funding and research into obtaining frequency for each town or village in Nigeria. This would facilitate lightning harnessing when large scale harvesting facilities are established.

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