Towards a Lightning Detection and Warning System in Zambia

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Abstract

Lightning is essentially an electromagnetic field phenomenon that can fundamentally be characterized using scientific methods. It would interest property designers and managers to have a facility of protection against lightning for property and life and one stage to effect the protection is an ability to predict the occurrence of lightning. In one type of approach, lightning alert regions can be configured around important assets such as buildings in different locations. Notifications about alerts in an area of interest can be sent via emails, SMS texts to phones and user interface (UI) platforms on personal computers. The meteorology industry can leverage real-time lightning information to improve forecasting, monitoring and safety of communities. This paper uses big data from 2016 to 2022 to show how much lightning Zambia experienced in the seven-year span. Big data was used to detect patterns and trends around the country. Big data is one common and contemporary factor that informs policy and decision in business sectors. The paper also shows how an alert region, Lusaka city, can be configured in order to send alerts and warnings to the users within the city about lightning threat developments. By employing AI-based analytics the results show that Zambia experienced a total of 89,826,330 lightning events from 2016 to 2022. By centering Lusaka city at coordinates 15.3875 ºS and 28.3228 ºE, 168 alerts were monitored using Thunderstorm Manager between 25 January 2023 and 24 February 2023. The longest lightning threat duration observed was 11 hours 20 minutes within Lusaka city.

Keywords

Buildings, Electromagnetic Fields, Forecasting, Lightning and Monitoring.

1. Introduction

The rainstorms that strike the African continent from October to April in the Southern hemisphere and April to October in the Northern hemisphere wreak havoc on life and property around the continent. Scientists and advocates of lightning protection have provided some information over the years that can help in the protection against this natural phenomenon. Such information is readily available in international standards such as IEC 62305 series, DHEN Lightning protection guide and NFPA 780 (Mpanga et al. 2021, 2022a, 2022b and 2022c). The impact of lightning occurrence is that it fixes the nitrates into the soil, it is the cause of the electrical rhythm of the earth and it can help explain the climate change patterns (EIT 2009, Williams 2009 and Williams et al. 2014). Thus, despite its manifestation in spectacular fashion such as damaging physical installations and presenting danger to life, lightning is essentially an electromagnetic phenomenon that can fundamentally be characterized using scientific methods. It would interest property designers and managers to have a facility of protection against lightning for property and life and one stage to effect the protection is an ability to predict the occurrence of lightning. In one type of approach, lightning alert regions can be configured around important assets and locations. Notifications about lightning threat development (LTD) in an area of interest can be sent via emails, SMS texts to phones and user interface (UI) platforms on personal computers.

Articulation of the spread of the electromagnetic fields due to lightning and taking steps to protect buildings and electrical and electronic systems can enhance safety of communities. This is now more significant because governments around Africa, Zambia included, are determined to install early warning systems for their citizens. A lightning detection and warning system (LDWS) can be one of such systems since lightning is one natural phenomenon not adequately addressed in Africa (Mpanga et al. 2021). It is not covered in national documents such as public health act and occupational health and safety (OHS) act (Gomes et al. 2016b). An LDWS would involve articulating the lightning occurrence statistics for a country like Zambia in order to advance the reasons for the need for a detection system of the phenomenon and fully describing areas that are more prone to lightning strikes around the country. The meteorology industry can leverage real-time lightning information to improve forecasting and safety of establishments.

1.1 Objectives

The objectives of this research were to (1) use big data to articulate the lightning characteristics around Zambia for the seven-year period from 2016 to 2022, (2) determine which regions of Lusaka are potential zones for lightning strikes, and (3) configure an LDWS for Lusaka city for the protection of life and property.

2. Literature Review

Holle (2010) determined that 90% of buildings in sub-Saharan Africa have occupants at risk of lightning strikes. The known effects of direct or indirect electromagnetic fields due to lightning strikes are injury to human beings, damage to property or a complete loss of lives and property (Cooper et al. 2019a, 2019b, Gomes et al, 2016c, 2019 and Lubasi et al. 2012). Mass casualty incidents due to lightning strikes inside buildings are reported every year in developing countries (Holle 2010 and Gomes et al. 2016c). Zambia has a good share of these events as they are reported in media. For instance, Zambia National Broadcasting Corporation (ZNBC) reported on 22 December 2022 that five people of the same family that comprised two parents and three children were struck to death inside their house by lightning on 19 December 2022 around 21:00 hours in Kabwe town. Three days earlier, on 16 December 2022, another family of five again that involved a father and four children lost their lives when lightning struck them as they sheltered from the rains under a tree around 12:00 hours in Siavonga town. This entails the need for developing countries in sub-Saharan Africa to ramp up their efforts with respect to lightning protection of their communities if they are to approach the levels of protection observed in developed countries. Some efforts seen on the African continent are spearheaded by Professor Mary Ann Cooper and her team through the African Centres for Lightning and Electromagnetics Network (ACLENet) and her endeavors are already bearing fruits in Uganda where even rural communities are getting protected (Cooper et al. 2018, Gomes et al. 2016 and The African Flash, 2023). Thus, each sub-Saharan country can learn from what ACLENet is doing by applying the established international standards such as the IEC 62305 series, carrying out lightning safety awareness and zeroing in on its own local environmental parameters in order to see how they can complement the existing standards.

Determination of local environmental lightning flash density, N_g values, is important because lightning activities are not uniformly distributed around the globe (Christian et al. 2003, King 2023 and Nyambe et al. 2014). These N_g values are a necessity for lightning risk assessment (LRA) of any infrastructure and the subsequent appropriate lightning protection system (LPS) design. The current trend is to estimate the N_g values from the existing lightning flash density maps established by orbiting satellites which put Zambia in the range of 8 to 25 flashes/km^2/year (King 2023). Each country has its own flash density map and thanks to Vaisala Inc. and other lightning detection network companies for serving the world in this aspect. However, local studies of the lightning phenomenon can result in improved parameters for both LRA and LPS designs of infrastructure in the country (Mpanga et al. 2021, 2022a, 2022b and 2022c). The infrastructure in this case could be buildings such as houses, office complexes, shopping malls and overhead power transmission lines which are usually exposed to the atmosphere. Low and high energy systems being widely studied in Zambia now (Kaoma et al. 2017, Lubobya et al. 2018, Mpanga et al. 2013, 2014 and 2016) must also be protected against lightning electromagnetic impulses (LEMP).

LEMP effects can be avoided by leveraging lightning detection information from LDWSs. The sequence and principle of lightning detection are described according to Figure 1 where (1) is the sensor that detects the lightning flashes and transmits the data to a satellite (2). From the satellite, data is transmitted to an earth station (3). From the earth station data gets transmitted to a national control center (NCC) at no. 4 for processing. After processing the data is relayed back to the satellite through 3 and 5 after which the lightning data is displayed on a UI platform at 6 within seconds of occurrence. Examples of networks that operate on this principle are the National Lightning Detection Network (NLDN) and the Global Lightning Dataset (GLD360), both owned and operated by Vaisala Inc., a Finnish company based in Arizona, USA (EIT 2009).

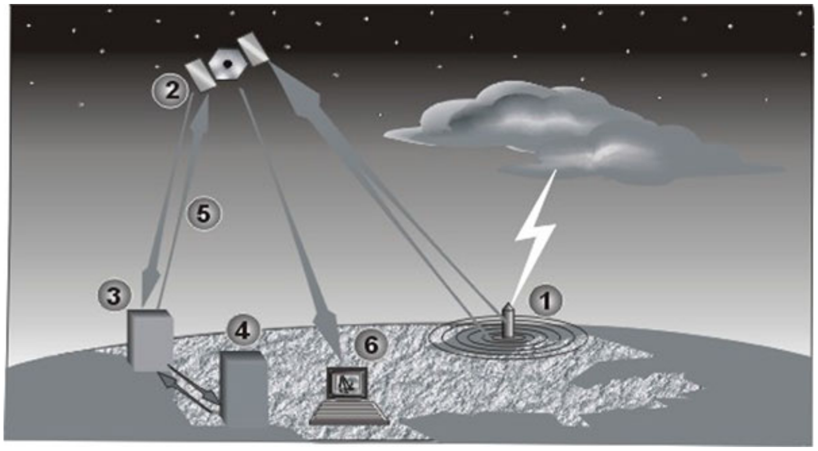


Figure 1. Lightning detection and warning system (EIT 2009)

3. Methods

Raw lightning data for a seven-year period from 2016 to 2022 was accessed from Global Lightning Dataset (GLD360) whose working principle is based on Figure 1. The data was then exported to a spreadsheet, Microsoft Power BI, for statistical analysis of trends over the seven-year period. After the trend analysis, the data was exported to ArcGIS software to determine the heat maps and the lightning flash densities (N_g) per province.

Next was the determination of the lightning strike potential zones (LSPZs) in the capital city, Lusaka, since this is the most densely populated town in Zambia and lightning safety of lives and property is paramount. Figure 2 shows the map of Zambia and the location of Lusaka city whereas Figure 3 shows the division of Lusaka city into geopolitical constituencies.

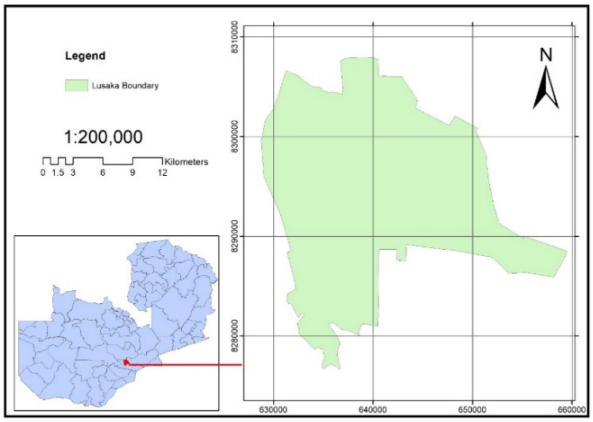


Figure 2. Location of Lusaka city on the map of Zambia

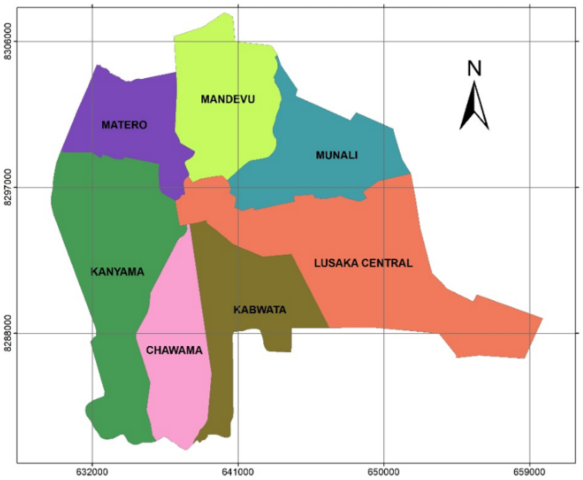


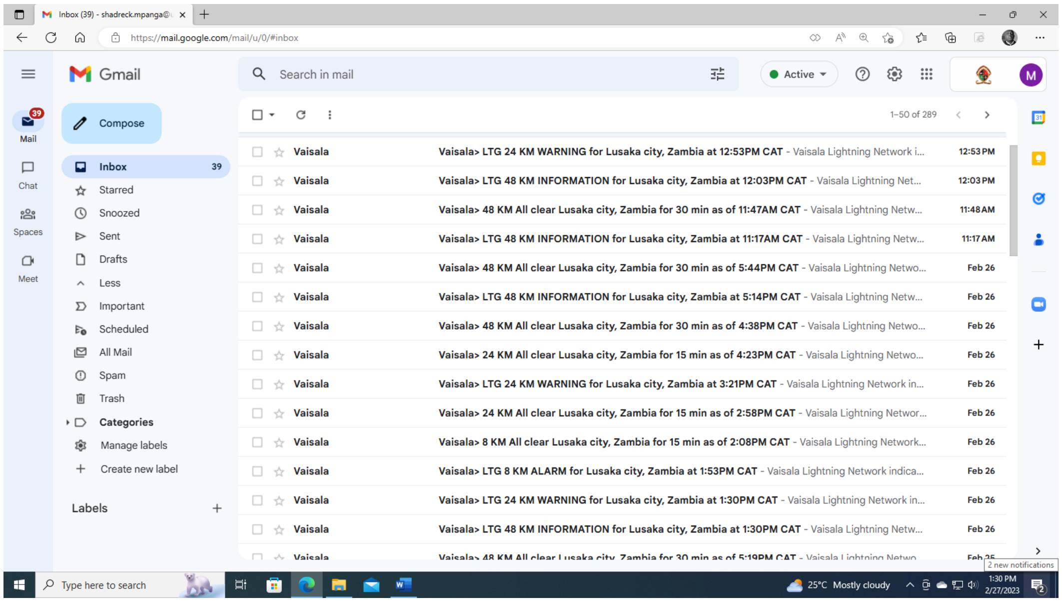
Figure 3. Seven geopolitical constituencies in Lusaka

Remote sensing technology (Cai et al. 2019 and Cihlar 2000) was used to determine the land use and land cover (LULC) structures such as built-up, trees, shrubs, water and bare ground. The analytical hierarchy process (AHP) was used to assign weights to LULC structures, elevation, soil map, and drainage density with respect to a machine learning algorithm done in Google earth engine of how these parameters were thought to affect lightning occurrence. The final analysis was performed in ArcGIS software using the weighted overlay tool to determine LSPZs in the city. The validation of the results from this modeling was done using Thunderstorm Manager.

An LDWS for Lusaka town was configured using Thunderstorm Manager, an Xweather software designed by Vaisala Inc. and leverages GLD360 data to monitor lightning threat developments (LTDs) around the globe. For Lusaka town center the coordinates used were 15.3875 ^{o}S and 28.3228 ^{o}E and an 'alarm' alert was configured for LTD within a radius of 0-8 km, a ‘warning’ alert for LTD within a radius of 8-24 km, and an ‘info’ alert for LTD within a radius of 24-48 km.

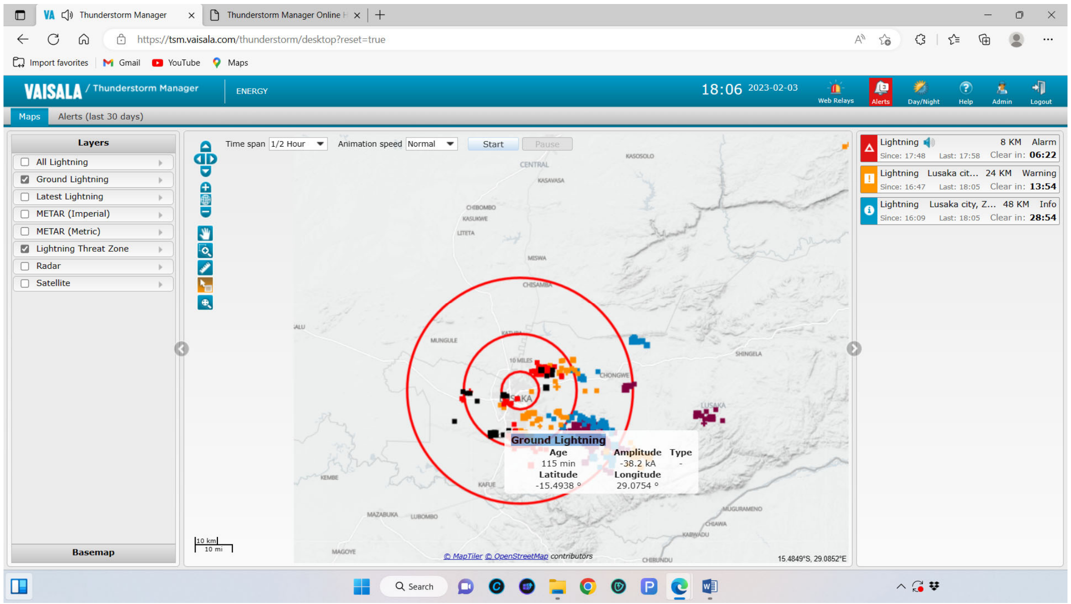
4. Data Collection

Apart from the data accessed from the GLD360, data was also collected during the monitoring of the LTDs from 25 January 2023 to 24 February 2023. Data was collected in form of email alerts as shown in Figure 4, in form of maps as shown in Figure 5 on a UI, and in table format on the same UI as shown in Figure 6.



Vaisala	**Vaisala> LTG 24 KM WARNING for Lusaka city, Zambia at 12:53PM CAT** - Vaisala Lightning Network i...	12:53 PM
Vaisala	**Vaisala> LTG 48 KM INFORMATION for Lusaka city, Zambia at 12:03PM CAT** - Vaisala Lightning Net...	12:03 PM
Vaisala	**Vaisala> 48 KM All clear Lusaka city, Zambia for 30 min as of 11:47AM CAT** - Vaisala Lightning Netw...	11:48 AM
Vaisala	**Vaisala> LTG 48 KM INFORMATION for Lusaka city, Zambia at 11:17AM CAT** - Vaisala Lightning Netw...	11:17 AM
Vaisala	**Vaisala> 48 KM All clear Lusaka city, Zambia for 30 min as of 5:44PM CAT** - Vaisala Lightning Netwo...	Feb 26
Vaisala	**Vaisala> LTG 48 KM INFORMATION for Lusaka city, Zambia at 5:14PM CAT** - Vaisala Lightning Netw...	Feb 26
Vaisala	**Vaisala> 48 KM All clear Lusaka city, Zambia for 30 min as of 4:38PM CAT** - Vaisala Lightning Netwo...	Feb 26
Vaisala	**Vaisala> 24 KM All clear Lusaka city, Zambia for 15 min as of 4:23PM CAT** - Vaisala Lightning Netwo...	Feb 26
Vaisala	**Vaisala> LTG 24 KM WARNING for Lusaka city, Zambia at 3:21PM CAT** - Vaisala Lightning Network in...	Feb 26
Vaisala	**Vaisala> 24 KM All clear Lusaka city, Zambia for 15 min as of 2:58PM CAT** - Vaisala Lightning Networ...	Feb 26
Vaisala	**Vaisala> 8 KM All clear Lusaka city, Zambia for 15 min as of 2:08PM CAT** - Vaisala Lightning Network...	Feb 26
Vaisala	**Vaisala> LTG 8 KM ALARM for Lusaka city, Zambia at 1:53PM CAT** - Vaisala Lightning Network indica...	Feb 26
Vaisala	**Vaisala> LTG 24 KM WARNING for Lusaka city, Zambia at 1:30PM CAT** - Vaisala Lightning Network in...	Feb 26
Vaisala	**Vaisala> LTG 48 KM INFORMATION for Lusaka city, Zambia at 1:30PM CAT** - Vaisala Lightning Netw...	Feb 26
Vaisala	**Vaisala> 48 KM All clear Lusaka city, Zambia for 30 min as of 5:19PM CAT** - Vaisala Lightning Netwo	Feb 25

Figure 4. Alerts sent to emails



Layers:
- ☐ All Lightning
- ☑ Ground Lightning
- ☐ Latest Lightning
- ☐ METAR (Imperial)
- ☐ METAR (Metric)
- ☑ Lightning Threat Zone
- ☐ Radar
- ☐ Satellite

Lightning 8 KM Alarm
Since: 17:48 Last: 17:58 Clear in: **06:22**

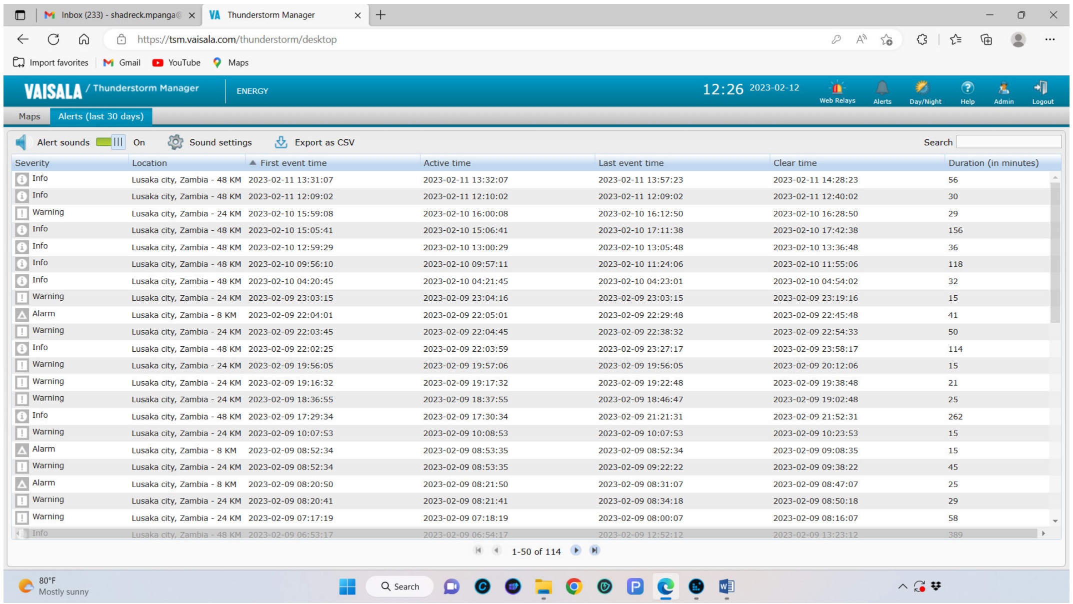
Lightning Lusaka cit... 24 KM Warning
Since: 16:47 Last: 18:05 Clear in: **13:54**

Lightning Lusaka city, Z... 48 KM Info
Since: 16:09 Last: 18:05 Clear in: **28:54**

Ground Lightning

Age	Amplitude	Type
115 min	-38.2 kA	-
Latitude	**Longitude**	
-15.4938 °	29.0754 °	

Figure 5. Alerts in form of maps on a UI platform



Severity	Location	First event time	Active time	Last event time	Clear time	Duration (in minutes)
Info	Lusaka city, Zambia - 48 KM	2023-02-11 13:31:07	2023-02-11 13:32:07	2023-02-11 13:57:23	2023-02-11 14:28:23	56
Info	Lusaka city, Zambia - 48 KM	2023-02-11 12:09:02	2023-02-11 12:10:02	2023-02-11 12:09:02	2023-02-11 12:40:02	30
Warning	Lusaka city, Zambia - 24 KM	2023-02-10 15:59:08	2023-02-10 16:00:08	2023-02-10 16:12:50	2023-02-10 16:28:50	29
Info	Lusaka city, Zambia - 48 KM	2023-02-10 15:05:41	2023-02-10 15:06:41	2023-02-10 17:11:38	2023-02-10 17:42:38	156
Info	Lusaka city, Zambia - 48 KM	2023-02-10 12:59:29	2023-02-10 13:00:29	2023-02-10 13:05:48	2023-02-10 13:36:48	36
Info	Lusaka city, Zambia - 48 KM	2023-02-10 09:56:10	2023-02-10 09:57:11	2023-02-10 11:24:06	2023-02-10 11:55:06	118
Info	Lusaka city, Zambia - 48 KM	2023-02-10 04:20:45	2023-02-10 04:21:45	2023-02-10 04:23:01	2023-02-10 04:54:02	32
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 23:03:15	2023-02-09 23:04:16	2023-02-09 23:03:15	2023-02-09 23:19:16	15
Alarm	Lusaka city, Zambia - 8 KM	2023-02-09 22:04:01	2023-02-09 22:05:01	2023-02-09 22:29:48	2023-02-09 22:45:48	41
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 22:03:45	2023-02-09 22:04:45	2023-02-09 22:38:32	2023-02-09 22:54:33	50
Info	Lusaka city, Zambia - 48 KM	2023-02-09 22:02:25	2023-02-09 22:03:59	2023-02-09 23:27:17	2023-02-09 23:58:17	114
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 19:56:05	2023-02-09 19:57:06	2023-02-09 19:56:05	2023-02-09 20:12:06	15
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 19:16:32	2023-02-09 19:17:32	2023-02-09 19:22:48	2023-02-09 19:38:48	21
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 18:36:55	2023-02-09 18:37:55	2023-02-09 18:46:47	2023-02-09 19:02:48	25
Info	Lusaka city, Zambia - 48 KM	2023-02-09 17:29:34	2023-02-09 17:30:34	2023-02-09 21:21:31	2023-02-09 21:52:31	262
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 10:07:53	2023-02-09 10:08:53	2023-02-09 10:07:53	2023-02-09 10:23:53	15
Alarm	Lusaka city, Zambia - 8 KM	2023-02-09 08:52:34	2023-02-09 08:53:35	2023-02-09 08:52:34	2023-02-09 09:08:35	15
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 08:52:34	2023-02-09 08:53:35	2023-02-09 09:22:22	2023-02-09 09:38:22	45
Alarm	Lusaka city, Zambia - 8 KM	2023-02-09 08:20:50	2023-02-09 08:21:50	2023-02-09 08:31:07	2023-02-09 08:47:07	25
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 08:20:41	2023-02-09 08:21:41	2023-02-09 08:34:18	2023-02-09 08:50:18	29
Warning	Lusaka city, Zambia - 24 KM	2023-02-09 07:17:19	2023-02-09 07:18:19	2023-02-09 08:00:07	2023-02-09 08:16:07	58
Info	Lusaka city, Zambia - 48 KM	2023-02-09 06:53:17	2023-02-09 06:54:17	2023-02-09 12:52:12	2023-02-09 13:23:12	389

Figure 6. Alerts in form of a spreadsheet on a UI platform

Each row in Figure 6 represents a ground lightning event in an area of interest and it shows the alert time and the clear time. Alerts were monitored through the Thunderstorm manager (TM) software, emails and SMSs to cell phones. The TM data was exported as a CSV file to a spreadsheet for further analysis.

5. Results and Discussion

5.1 Numerical Results

Table 1 shows the lightning occurrence statistics from 2016 to 2022 where total lightning is presented in column 3 and expected cloud-to-ground (C-G) lightning is presented in column 4 according to IEEE Std. 1410-2010 that stipulates that one-third of total lightning is equal to C-G lightning.

Table 1. Lightning statistics from 2016 to 2022

No.	Year	Number of events	C-G events
1.	2016	6,637,324	2,212,441
2.	2017	12,101,048	4,033,683
3.	2018	14,825,779	4,941,926
4.	2019	16,954,455	5,651,485
5.	2020	12,647,634	4,215,878
6.	2021	13,193,767	4,397,922
7.	2022	13,466,323	4,608,777
TOTALS		89,826,330	29,942,110

Table 1 results show that 89,826,330 lightning events occurred in the Zambia's airspace out of which 29,942,110 events were C-G lightning strikes. The trend in column 4 shows that on average Zambia experiences 4,600,000 C-G lightning events per year and these clean up the earth's atmosphere, fix nitrates into the soil, impart the electrical rhythm to the earth (Schumann resonance) and for engineering applications, they are the starting point for lightning flash density analysis. One noteworthy observation in the Table is the departure from what seems to be the average occurrence per year of lightning strikes in 2016. The number of events was uncharacteristically lower than in the other years and historically this is one year when Zambia experienced low rainfall levels as it can be remembered from massive load shedding around the country due to low water levels at the hydropower power stations. Hence, one application of lightning studies is the ability to explain climate change effects. However, the main focus of this paper is to monitor areas affected by the C-G events in column 4. Figure 7 shows the lightning strike pattern around the country with more C-G events happening in purple-colored areas than blue areas. This can help stakeholders visualize areas that require urgent attention with respect to LPSs.

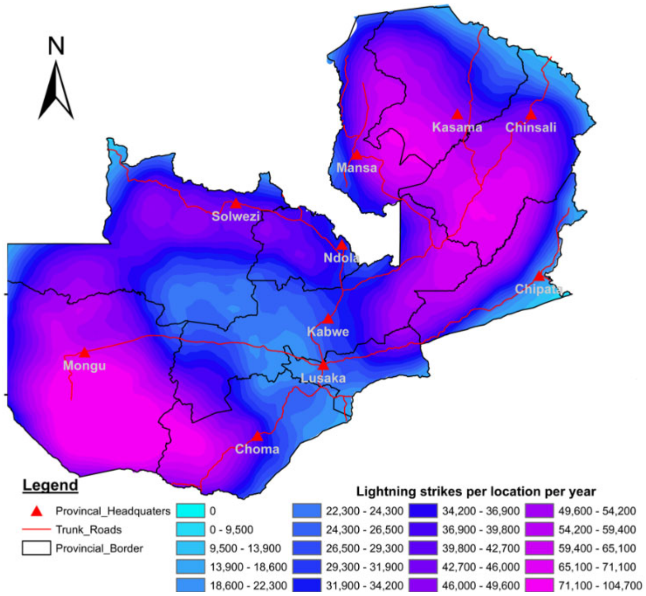


Figure 7. GLD360-detected lightning strike distribution around the country

Figure 8 shows the actual lightning flash density values per province in flashes/km^2/year. These are important for the lightning risk assessment (LRA) of any infrastructure. After an LRA, it can be determined what class of LPS is suitable for a particular building. The resulting LPS classification guides how the technology conducts the lightning current and its electromagnetic field safely to ground.

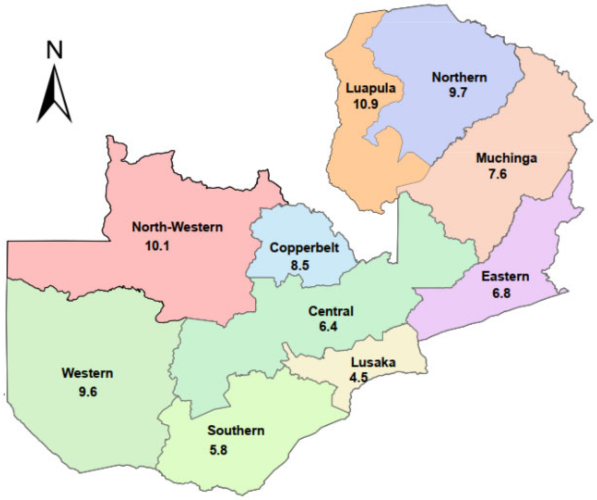


Figure 8. Determined lightning flash densities (N_g) per province in Zambia

By zeroing in on Lusaka city geopolitical constituencies and determining the lightning strike potential zones (LSPZs), the analytical hierarchy process (AHP) (Das et al. 2020) was used to determine the weighting factors as presented in Table 2. It can be seen in Table 2 that N_g values have a more bearing on the likelihood of strikes in a particular region. Figure 9 shows the LSPZs in the seven constituencies selected and it was observed that Chawama, Kabwata and Lusaka central constituencies experience more lightning of the seven regions. This revelation is a wake-up call for authorities having jurisdiction (AHJ) to monitor the buildings in these areas in order to assess how they stand against this natural phenomenon. An audit on the lightning effects on lives and property can thus be made and the exercise can be extended to other towns in the country.

Table 2. AHP determined weights

Item	Parameter	Weight [%]
1.	2019 lightning flash density map	33.4
2.	2020 lightning flash density map	33.4
3.	LULC map	16.5
4.	Digital elevation map	8.8
5.	Soil map	4.0
6.	Drainage density map	3.0
7.	Others	0.9

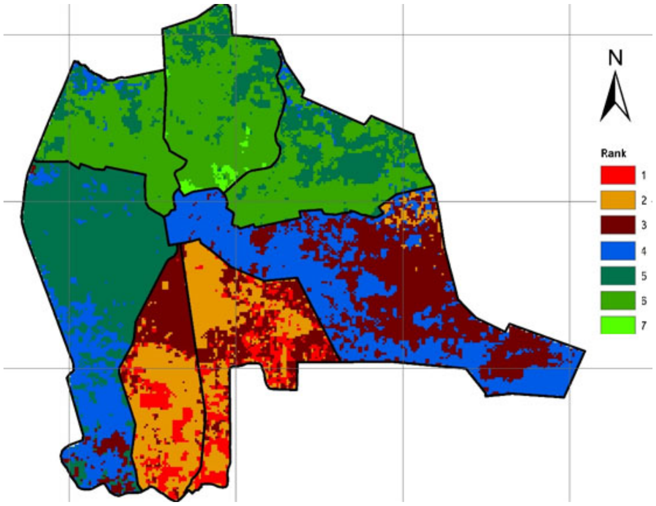


Figure 9. Determined lightning strike potential zones in Lusaka city

5.2 Graphical Results

Figure 10 gives insight into the lightning current levels experienced in the country as partly displayed in Figure 5 of data collection section.

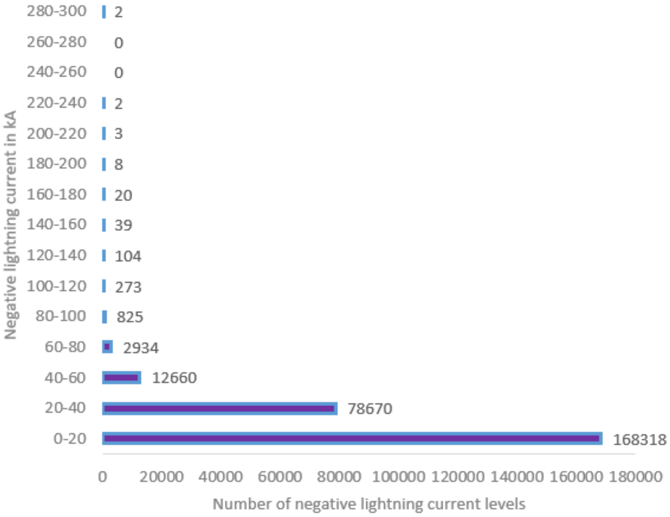


Figure 10. Negative C-G events for October 2019

Using Figure 10, it was observed that the current populations decrease exponentially from lower magnitudes to higher values. It was evaluated less than 1% of currents raining on Zambian soil go above 200 kA and this finding is in conformity to IEC 62305 standard series. The pattern which also fits the log-normal distribution as highlighted in IEEE Std. 1410-2010 and CIGRE working group C4.23 was observed for all the months that experience lightning from January to December in the seven-year period from 2016 to 2022.

The presented results on the lightning statistics in Zambia call for means to monitor the development of these threats to lives and property around the country. The results of one such monitoring activity are presented in Figure 11 as observed on 30 January 2023 at 11:34 AM Zambian local time. The alert region turns from grey to red when the lightning threat moves into the region and in Figure 11 the lightning threat was between 24 km and 48 km away from the town center. An example of all the three alerts, 'alarm', 'warning' and 'info' being present at the same time is shown in Figure 5 of the data collection section. The 'plus' sign on the figure represents positive lightning and these are the minority as it was observed. The square box represents negative lightning, the majority of the C-G events. These change colors from black-to-red-to-blue-to-orange and finally to purple as it can be seen in Figure 11. Black is an alert signifying that lightning can strike anytime between 0 and 15 minutes. From the record of events presented in Figure 6 of the data collection section, it struck after one minute of alert signal. After 15 minutes, the color changes to red for the next 15 minutes again. Blue color appears between 30 and 60 minutes, orange between 60 and 90 minutes, and purple between 90 and 120 minutes. These timings give an idea of how long ago an event occurred and they can help tell if an area is safe or not for resumption of activities outdoors.

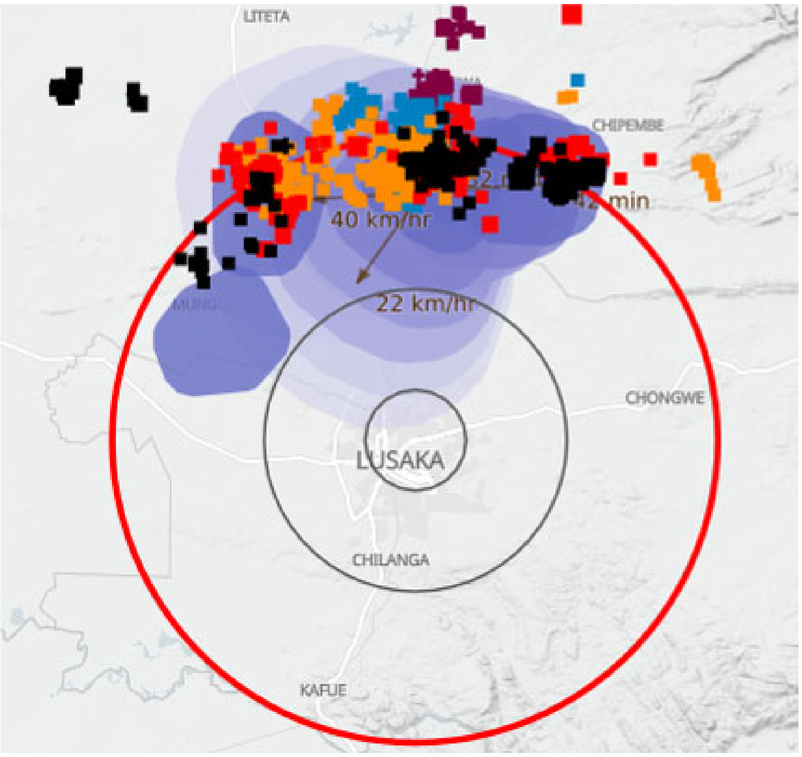


Figure 11. Configuration of Lusaka city with radii of 8 km, 24 km and 48 km centered at 15.3875 °S & 28.3228 °E

The blue cloud in Figure 11 shows the movement, direction and speed of the lightning threat development (LTD) and this is useful information for sending SMS to phones or broadcasting on radio about which areas must precautions be taken for safety against the phenomenon. The longest LTD was recorded on 9 February 2023 at radius between 24 km and 48 km from the town center that lasted 11 hours and 20 minutes. It started on 8 February 2023 at 18:24 hours with the first lightning occurring at 18:25 and stopped at 05:45 AM the following day after the last event was observed at 05:14 AM. Of the 168 monitored alerts from 25 January 2023 to 24 February 2023, 76 occurred between 24 km and

48 km from the center, 70 occurred between 8 km and 24 km from the town center, and 22 occurred within a radius of 8 km. These statistics help to see which infrastructure in which area are more exposed to lightning strikes.

5.3 Proposed Improvements

Lightning is a probabilistic event and thus there are places where it might not strike for several years. It might take even decades to prove the efficiency of the detection and warning systems. This implies that even the results presented in this paper require continued observations and analysis for the foreseeable future in order to arrive at more reliable figures. A period of at least ten years of data accumulation and analysis is proposed henceforth.

5.4 Validation

Figures 12 and 13 are validations of the result in Figure 9 about the LSPZs in Lusaka. Observations done between 25 January and 24 February 2023 revealed that Lusaka south and south-east are the more prone areas to lightning strikes. Lightning threats were seen to develop in the south-east region of Lusaka as shown in Figure 12 and sometimes from the western side as shown in Figure 13 and move towards the southern side of town as indicated.

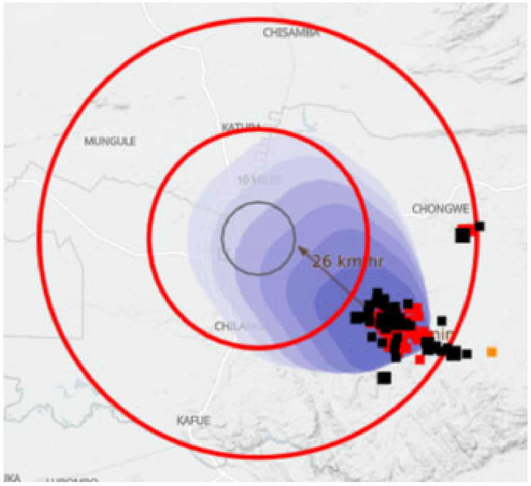


Figure 12. 3 February 2023 monitoring results

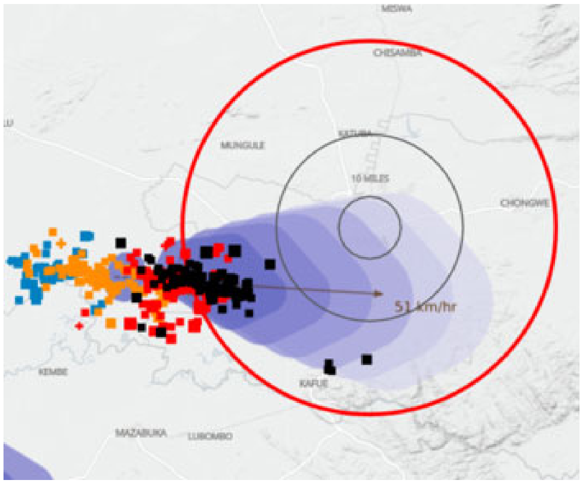


Figure 13. 18 February 2023 monitoring results

6. Conclusion

The objectives of this paper were to determine lightning statistics and characteristics for the seven-year period from 2016 to 2022, determine the lightning strike potential zones (LSPZs) in the capital city, and to configure a lightning detection and warning system (LDWS) for Lusaka. It was determined that Zambia as a whole experiences on average 4,600,000 lightning strikes per year and this translates to a lightning flash density of 7 flashes/km^2/year on average. The determined LSPZs in Lusaka were found to be more in Chawama, Kabwata and Lusaka Central constituencies than in the other four constituencies. The monitoring of the lightning threat developments (LTDs) within the capital from 25 January to 24 February 2023 showed that 13% of lightning flashes were experienced within a radius of 8 km from the town center, 42% occurred within 8-24 km radius, and 45% within the 24-48 km radius. The longest duration of LTD recorded was 11 hours 20 minutes on 8-9 February 2023. Further studies are needed to establish why the central business district experience fewer lightning events despite having the tallest buildings in the country.

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