Revista UIS Ingenierías
ISSN: 1657-4583
ISSN: 2145-8456
revistaingenierias@uis.edu.co
Universidad Industrial de Santander
Colombia

Lightning mortality rate in Colombia for the period 1997 - 2014

Cruz-Bernal, Audrey Soley; Torres-Sánchez, Horacio; Aranguren-Fino, Harby; Inampués-Borda, Juan Carlos

Lightning mortality rate in Colombia for the period 1997 - 2014
Revista UIS Ingenierías, vol. 17, no. 2, 2018
Universidad Industrial de Santander, Colombia
Available in: http://www.redalyc.org/articulo.oa?id=553756965007
DOI: https://doi.org/10.18273/revuin.v17n2-2018006

Artículos

Lightning mortality rate in Colombia for the period 1997 - 2014

Tasa de mortalidad por rayos en Colombia para el periodo 1997 - 2014

Audrey Soley Cruz-Bernal a.cruz@keraunos.co
Keraunos S.A.S, Colombia
Horacio Torres-Sánchez htorress@keraunos.co
Keraunos S.A.S, Colombia
Harby Aranguren-Fino daranguren@keraunos.co
Keraunos S.A.S,, Colombia
Juan Carlos Inampués-Borda juan.inampues@keraunos.co
Keraunos S.A.S, Colombia

Revista UIS Ingenierías, vol. 17, no. 2, 2018

Universidad Industrial de Santander, Colombia

Received: 10 November 2017
Accepted: 30 December 2017
Published: 26 February 2018

DOI: https://doi.org/10.18273/revuin.v17n2-2018006

Redalyc: http://www.redalyc.org/articulo.oa?id=553756965007

Resumen: En muchos países se ha estudiado el fenómeno natural del rayo teniendo en cuenta las condiciones climatológicas y geográficas. Estas descargas atmosféricas son responsables de la muerte de más de 6000 personas por año en el mundo. Colombia se encuentra ubicada en la zona de convergencia intertropical y posee una geografía caracterizada por llanuras y largas cadenas montañosas. Estas condiciones hacen que Colombia esté en la región con mayor actividad de rayos en el mundo, lo cual incrementa el número de muertos y heridos a causa de este fenómeno, especialmente, en las zonas rurales. Este artículo presenta un estudio sobre la cantidad de muertes y la tasa de mortalidad por rayos en Colombia para el periodo comprendido entre 1997 y 2014. La información de muertes fue tomada de las estadísticas del Departamento Administrativo Nacional de Estadísticas (DANE). Los resultados obtenidos se sintetizan para todo el país y se discriminan por departamentos y subregiones naturales. De esta manera, la tasa de mortalidad obtenida para toda Colombia fue de 1,51 muertes por millón de habitantes por año. Así mismo, se encontró que Vichada es el departamento con mayor tasa de mortalidad (7,85), mientras que el Altiplano de Popayán es la subregión natural con mayor cantidad muertes por millón de habitantes por año con 8,62.

Palabras clave: muertes por rayos, rayos, subregión natural, tasa de mortalidad.

Abstract: In many countries, the natural phenomenon of lightning has been studied take into consideration climatic and physiographic conditions. The atmospheric discharges are responsible for the death of more than 6000 people per year around the world. Colombia is located in the intertropical convergence zone and it has a geography characterized by plains and long mountain ranges. These conditions locate Colombia in the region in the region with the highest lightning activity in the world increasing the number of deaths and injuries by this phenomenon, especially in rural zones. This paper presents a study of the total number of deaths and the mortality rate by lightnings for the period from 1997 to 2014. The information about deaths by lightning was taken from the statistics of the National Administrative Department of Statistics (Departamento Administrativo Nacional de Estadísticas – DANE). The results obtained are synthesized for the whole country and are discriminated by departments and natural sub-regions. In this way, the mortality rate obtained for Colombia was 1.51 deaths per million people per year. Likewise, Vichada was the department with the highest mortality rate (7.85), while Popayan plateau was the natural sub-region with the highest number of deaths per million people per year with 8.62.

Keywords: deaths by lightning, lightning, mortality rate, natural sub-regions.

1. Introduction

Lightning is a physical phenomenon characterized by a positive or negative charge transference from cloud to ground, ground to cloud, intra-cloud or cloud to ionosphere [1]. This phenomenon is worldwide observed by geophysicists, meteorologists and engineers due to the damage to structures, equipment and systems. In addition, these electrical discharges cause many deaths and injuries every year [2]. The tropical zone is a zone affected by this phenomenon and Colombia is one of the main countries where more lightnings strike. This is reflected in studies [3], [4], [5], [6], [7], [8] that demonstrate higher values in comparison with other tropical and sub-tropical regions.

In recent years, many investigations [9],[10], [11], [12], [13], [14], [15] about lightning fatalities have been conducted in plenty of countries. According to [14], the fatality rates are lower in developing countries than in lesser-developed countries. Furthermore, the total number of global annual fatalities by lightning ranges from 6000 to 24000 per year. In this context, Doljinsuren and Gomes reported that the fatality rate in Mongolia was 1.54 deaths per million people per year [10], which is higher than those in other countries with a similar keraunic level. In Latin America, the average of human losses due to lightnings is 1.7 per million people per year in comparison with developing countries that have a mortality rate of 0.1 per million people per year [15].

In Colombia, few studies have been carried out for calculating the lightning mortality rate. The most relevant study was presented by Navarrete *et al.* in [16]. In this work, a fatality rate of 1.78 deaths per million people per year during a period of ten years (2000-2009) for all departments of Colombia was registered. On the other hand, in [17] a mortality rate of 2 deaths per million people per year was obtained from 2000 to 2012. For these studies, the database of the National Administrative Department of Statistics (Departamento Administrativo Nacional de Estadísticas - DANE) and reports from national newspapers were taken into account.

With the aim of extending the results obtained by Cruz and Navarrete, this paper presents the number of deaths and the mortality rate by lightning in Colombia for the period from 1997 to 2014. The results obtained are summarized for the whole country and they are differentiated by departments and natural su-bregions. In addition, the relation between population density and ground flash density (GFD) is shown in order to analyze if the mortality rate in the natural su-bregions is influenced by lightning activity.

2. Geography of Colombia

Colombia is the only country in South America with coasts over the Pacific Ocean and the Caribbean Sea. It has a latitudinal location between 17° north and 4° south, with variable topography, three mountain ranges and altitudes up to 5000 masl (see Figure 1). Due to this fact, there

are different climatic conditions (warm, tempered, cold, paramo and snowy or glacial). In addition, Colombia is territorially divided in 32 Departments and 1122 municipalities. The country has a land area of 1.14 million square km with an approximate population of 49 million of inhabitants (data 2017).

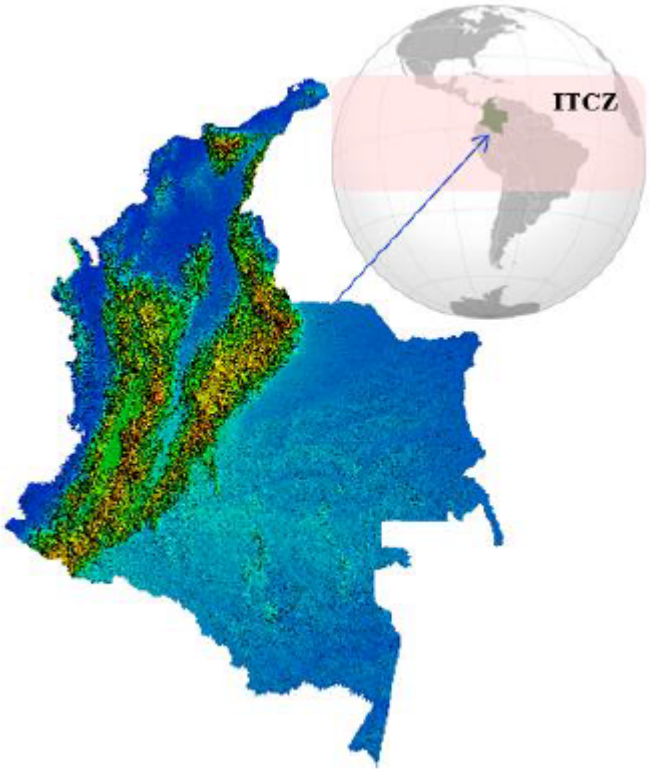

Figure 1
Location and relief of Colombia.

The climate in Colombia is highly influenced by the Intertropical Convergence Zone (ITCZ). The ITCZ is formed when warm and wet winds of the north and south latitudes of the equator clash forming a cloud belt around the tropical region generating thus low pressures and storms. In tropical regions, there are not seasons as in the medium latitudes. During the year, Colombia presents two rainy seasons between May and July and, September and October; the other months are known as a dry season.

According to vegetation, relief, weather, soil classes, among others, Colombia has been divided in 20 sub-regions. These sub-regions were classified using a methodology based on cluster analysis [18]. This process consists of grouping elements or factors (climatic and physiographic) trying to achieve maximum homogeneity in each group and the largest difference between groups.

From the methodology presented in [18] the sub-regions were named as follows: Caribbean Plain, Middle Magdalena Valley, Northeast Mountain, Northwest Mountain, Cundiboyacense Plateau, Central Mountain, Alto Magdalena, Popayan Plateau, South Mountain, Cauca Valley, Pacific, East Plains Piedmont, Catatumbo, Amazon, Pacific

Coastal Plain, Guajira Plain, Orinoquía, Amazonian Piedmont, Baudó Mountains and Sierra Nevada.

3. Methodology

The statistical information of deaths by lightning was obtained from the database of the DANE for the period from 1997 to 2014. DANE is a governmental institution that collects death certificates occurred for different causes in Colombia since 1979. It has data about deaths (accidental or by disease) using the codes provided by the International Classification of Diseases (ICD). In this way, lightning victims are classified with the code X33.

Before obtaining information about X33 cause, the statistics were analyzed bearing in mind variables such as: year, month, department, municipality, gender, type of area (head-municipality, rural and population center), place (home, hospital, work place, public road, etc). This information was used in order to know how many people died in each municipality and to locate them in the Colombia map. Consequently, the mortality rate for each department and natural sub-region was calculate.

4. Results

4.1. Deaths by lightning in Colombia

From the collected information in the period 1997-2014, 1173 deaths by lightning were found. Figure 2 shows the number of fatalities for each year. It can be observed that the years with major events were 2003 and 2005 with 98 and 93 deceased persons. On the contrary, less than 50 people died in 1997 (34), 2010 (44) and 2011 (46).

The annual variation observed in Figure 2 is related with the "El Niño" and “La Niña" phenomena. El Niño is a meteorological phenomenon in which the temperature increases and the rainfall decreases. On the other hand, La Niña is a phenomenon where the temperature decreases and the rain precipitation increases. These phenomena in Colombia are periodically observed. However, in some periods, the rain or dry conditions are extreme.

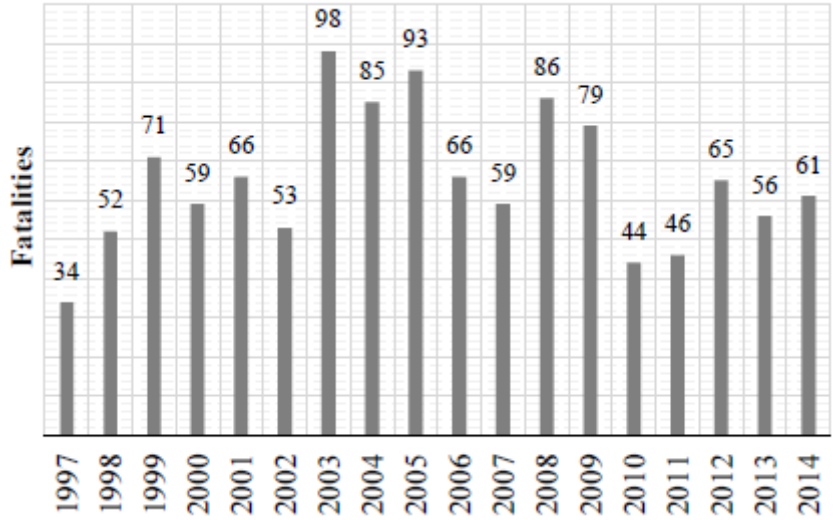

Figure 2 .
Lightning fatalities in Colombia.
Authors.

4.2. Deaths by lightning for departments and natural sub-regions

In accordance with the information found in Colombia, only 8 of 32 departments registered more than 50 deaths. Table 1 shows the fatalities occurred in these departments including the gender of victims. It can be seen that Antioquia is the department with more deaths by lightning with 218 events. In addition, male gender is the most affected by lightning in all Colombia with 959 (82%) cases, while 214 deads (18%) were females.

Table 1 .
Departments with more than 50 lightning fatalities.

Department	Male	Female	Fatalities
Antioquia	181	37	218
Cauca	92	32	124
Santander	64	13	77
Cauca Valley	65	9	74
Bolívar	55	9	64
Magdalena	53	6	59
Boyacá	40	17	57
Córdoba	46	11	57

Authors.

Regarding the distribution of fatalities by natural sub-regions, Figure 3 shows the total number of fatalities by sub-region. It can be observed that the natural sub-region with more registered cases was the Caribbean

plain with 269 (22%) fatalities. In addition, the Northwest and Northeast Mountains reported 185 (16%) and 117 (10%), respectively. For the remaining regions the deaths by lightning were between 97 (8.3%) and 2 (0.2%).

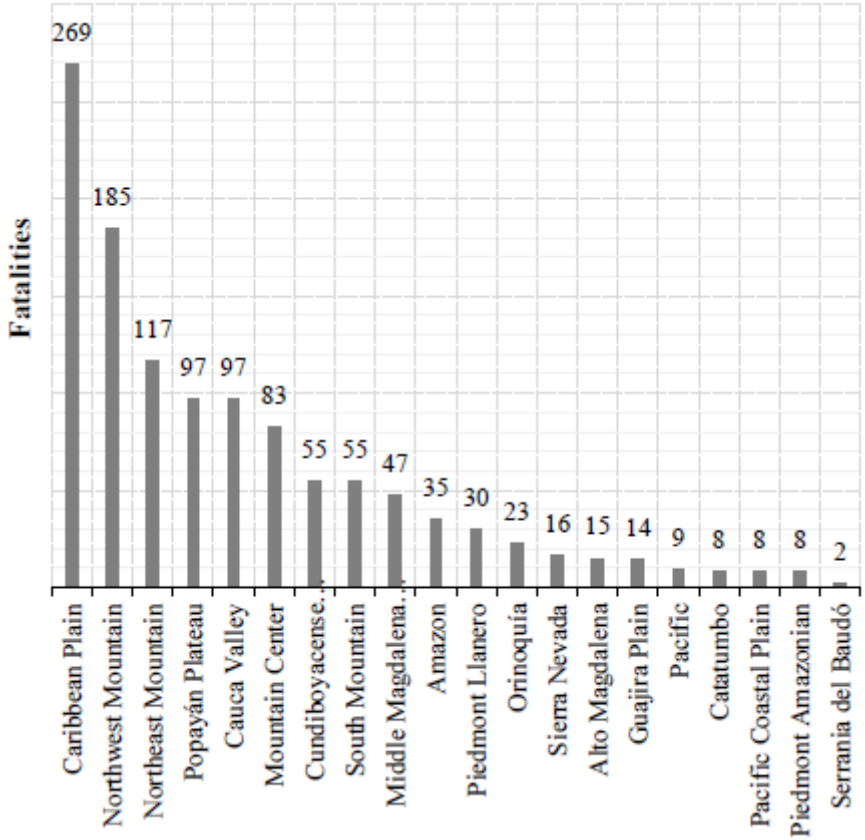

Figure 3 .
Lightning fatalities in the natural sub-regions of Colombia.
Authors.

Furthermore, the map with the same events previously mentioned is shown in Figure 4. In this map, each point highlighted in red color represents an event. These points were located using the coordinates (latitude and longitude) of the municipality where the event happened.

4.3. Lightning Mortality Rate

In this section, the lightning mortality rate in Colombia is presented. This parameter is also analyzed in accordance with the departments and the natural regions. For this work, the mortality rate is defined as the total number of deaths during a particular period of time among a particular type or group of people. In addition, the unit of measurement for the mortality rate used here is per million population per year. Using these definitions, the lightning mortality rate was calculated using the total number of fatalities by lightning and the population in each zone (country, department or natural sub-region).

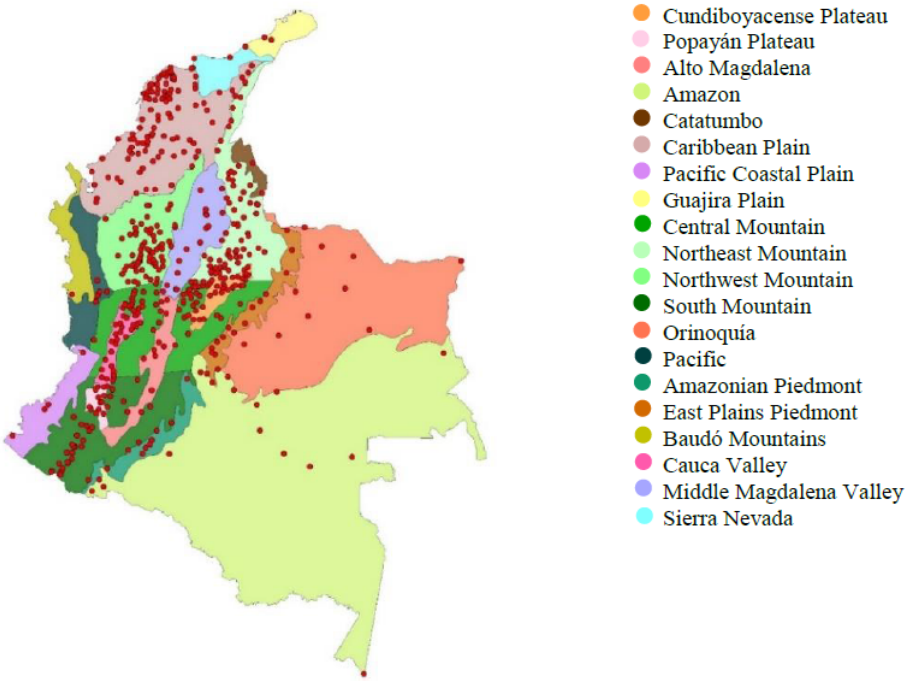

Figure 4 .
Deaths by lightning and natural sub-regions in Colombia.
Authors.

To estimate the population, the methodology presented in Navarrete *et al*. was used [16]. In this way, the population of years 2005 and 2006 (the midpoint of the time of the study) was averaged and included as the denominator of the fatality rate. Table 2 presents the lightning mortality rate for Colombia and each department. For the total population of Colombia, a mortality rate of 1.51 deaths per million people per year was found. The results show that Vichada is the department with the highest mortality rate (7.85 deaths per million people per year), while the lower mortality rate was found in Bogotá with 0.1 deaths per million people per year.

A special case is San Andrés where no deaths by lightning were reported during 18 years. When analyzing Analyzing the population, it was observed that the less populated departments located at the south of the country present the highest mortality rate, while the lowest fatality rates are concentrated in the southwest. These low rates are related to the departments with the largest population (more than one million people).

Analyzing Table 2, it can be observed that 63% of the departments present a lightning mortality rate higher than the value calculated for Colombia. These values are the result of the relation between the number of events and the population of the department. From these departments with high mortality rate, 38% have a population of less than one million people and less than 30 fatalities were registered, while the remaining 25% of the departments reported more than 45 cases with a population greater than one million people. The mortality rate for these departments varies between a minimum value of 1.72 and a maximum value of 7.85 deaths per million people per year.

The mortality rate for the natural sub-regions was also calculated. The results of this analysis are shown in Table 3. Similarly, in the natural sub-regions the mortality rate depends on the total number of deaths and the population for each region. From the 20 sub-regions, 13 exceed the mortality rate calculated for Colombia (1.5) with values between 1.60 and 8.62 deaths per million people per year.

Accordingly, Popayan plateau is the sub-region with the highest fatality rate with 8.62, while Cundiboyacense plateau exhibits the lowest mortality rate with 0.34.

Comparing the results for the Northwest Mountain (2.56) and the South Mountain region (1.37), it can be observed that the mortality rate is different although their populations are similar (more than 2.2 million people). Thereby, it is verified that mortality rate is strongly influenced by the number of events. For the regions mentioned above, 117 events and 55 events were found, respectively. The same analysis was made for the Middle Magdalena Valley and the Pacific Coastal Plain that have a similar population and yet present a great difference in the mortality rate.

Table 2.
Lightning mortality rate deaths per million people per year by department.

Department	Deaths	Average Population	Deaths/ million-year
Vichada	8	56608	7.85
Guainía	4	35538	6.25
Cauca	124	1273507	5.41
Guaviare	9	96343	5.19
Vaupés	3	39510	4.22
Arauca	14	233690	3.33
Magdalena	59	1154980	2.84
Boyacá	57	1256755	2.52
Caquetá	17	423133	2.23
Santander	77	1963063	2.18
Córdoba	57	1478826	2.14
Antioquia	218	5720140	2.12
Meta	30	791933	2.10
Norte de Santander	45	1249124	2.00
Cesar	31	909662	1.89
Bolívar	64	1888756	1.88
Casanare	10	298324	1.86
La Guajira	23	695151	1.84
Putumayo	10	311629	1.78
Caldas	30	969619	1.72
Sucre	21	775779	1.50
Chocó	12	456185	1.46
Cundinamarca	48	2299559	1.16
Risaralda	17	900233	1.05
Valle del Cauca	74	4183349	0.98
Atlántico	37	2180898	0.94
Tolima	23	1367462	0.93
Nariño	26	1551282	0.93
Amazonas	1	68170	0.81
Quindío	7	536018	0.73
Huila	4	1018572	0.22
Bogotá D.C.	13	6892666	0.10
San Andrés y Providencia	0	70815	0.00
Total	**1173**	**43147274**	**1.51**

Authors.

Table 3.
Lightning mortality rate deaths per million people per year by natural sub-region.

Natural Sub-region	Deaths	Average Population	Deaths/ million-year
Popayán Plateau	97	625337	8.62
Orinoquía	23	279684	4.57
Middle Magdalena Valley	47	747728	3.49
Amazon	35	590956	3.29
Northeast Mountain	117	2535324	2.56
Amazonian Piedmont	8	188549	2.36
Northwest Mountain	185	5070344	2.03
Sierra Nevada	16	440807	2.02
Caribbean Plain	269	8281868	1.80
East Plains Piedmont	30	974097	1.71
Central Mountain	83	2813590	1.64
Pacific	9	309428	1.62
Guajira Plain	14	909662	1.59
South Mountain	55	2229395	1.37
Cauca Valley	97	5100791	1.06
Baudó Mountains	2	129652	0.86
Pacific Coastal Plain	8	763958	0.58
Catatumbo	8	800302	0.56
Alto Magdalena	15	1589055	0.52
Cundiboyacense Plateau	55	9118123	0.34
Total	**1173**	**43076460**	**1.51**

Authors.

4.4. Relation between population density, GFD and mortality rate

Deaths by lightning are a consequence of the strong thunderstorms that occur in great part of the Colombian territory. A study published in 1990 by Universidad Nacional and The Colombian Weather Service show the first keraunic level map (thunderstorm days) for the country. This map presents more than 140 thunderstorm days per year for some regions of the country [19]. consequently, this section shows the influence of lightning activity in the mortality rate obtained for each sub-region.

Figure 5
Lightning Location System (LLS) in Colombia.
Keraunos

According to lightning activity, one of the most important parameters is ground flash density (GFD). This parameter is the measurement of the number of lightning strikes to ground in an area of a square kilometer per year. To calculate this parameter in each natural sub-region the data provided by Lightning Location System (LLS) installed in Colombia was used. The LLS is based on LINET Technology [20] and was implemented

in the year 2011. Currently, the system is composed by 19 sensors as shown in Figure 5. During the last six years more than 100 million strokes have been detected.

In this work, the GFD for 13 of the 20 sub-regions was calculated. These regions were analyzed due to high lightning activity. The events were presented mainly in mountains ranges and their vicinity. Additionally, the population density is other factor that was taken into account in this analysis and it is also associate with the GFD. The population density was calculated with the total population and the area of the examined zone (country or sub-region). As a result, it was possible to obtain the number of people who inhabit in a square kilometer was obtained. Applying this definition, the population density for Colombia was 37 people per square kilometer.

Figure 6 shows the values of GFD for each natural sub-region. These data are similar to those obtained previously in [13]. In addition, the average population density during 18 years (1997-2014) was included. It can be seen that GFD varies between 15.9 flashes/km^2-year and 1.7 flashes/km^2-year. The highest values of GFD were found in the Middle Magdalena Valley region and the Northwest Mountain region with 15.9 and 10.1 flashes/km^2-year, respectively. However, for these natural sub-regions the population density is lower than 100 people/km^2 and the mortality rate is below to 3.5 deaths/million-year as shown in Figure 7.

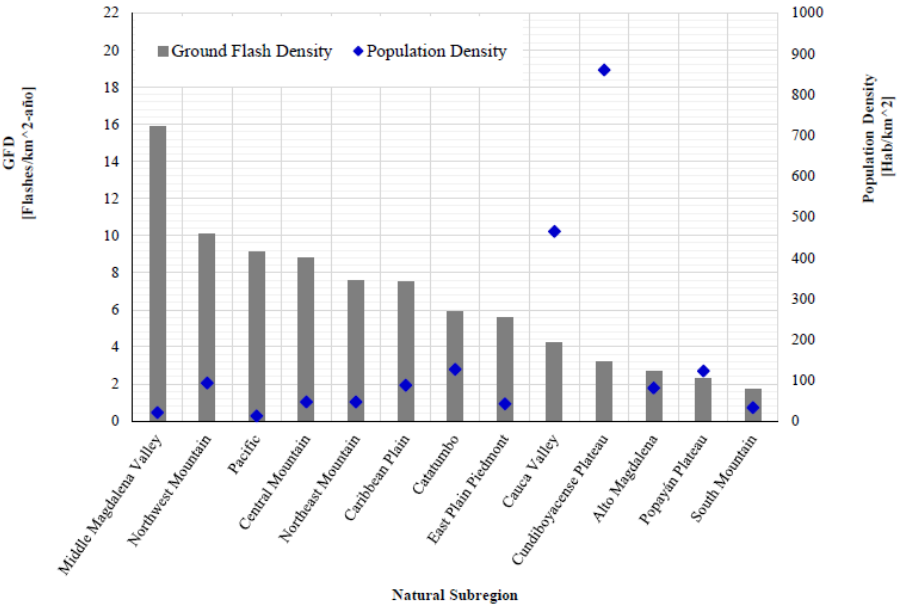

Figure 6.
Ground flash density vs population density in 13 natural sub-regions.
Authors.

The values of GFD and mortality rate are showed in Figure 7, these parameters are correlated in 10 sub-regions while in the sub-regions of Catatumbo, Popayan Plateau and South Mountain mortality rate are higher.

In addition, the sub-regions Cundiboyacense Plateau and Cauca Valley have lower values of mortality rate and GFD but have a higher population density with 865 and 465, respectively. These results were obtained because the population is highest than 5.1 million people.

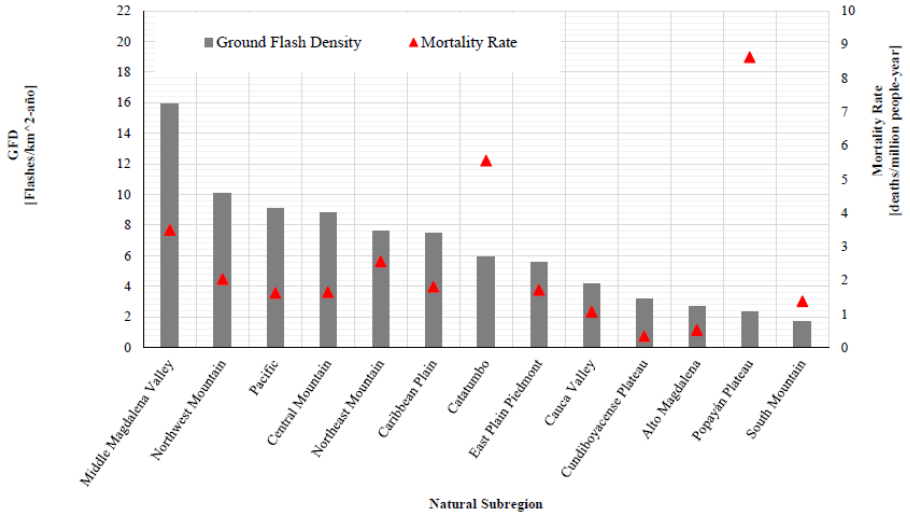

Figure 7.
Ground flash density vs Mortality rate in 13 natural sub-regions.
Authors.

The population density and mortality rate are correlated in the Figure 8. Taking into account the behavior of the three parameters in the sub-region of Middle Magdalena Valley, a high value of GFD of 15.9 is observed along with both a low population density of 21 and a high mortality rate of 3.49. These results indicate that people who live in this zone are more exposed to be struck by an atmospheric discharge.

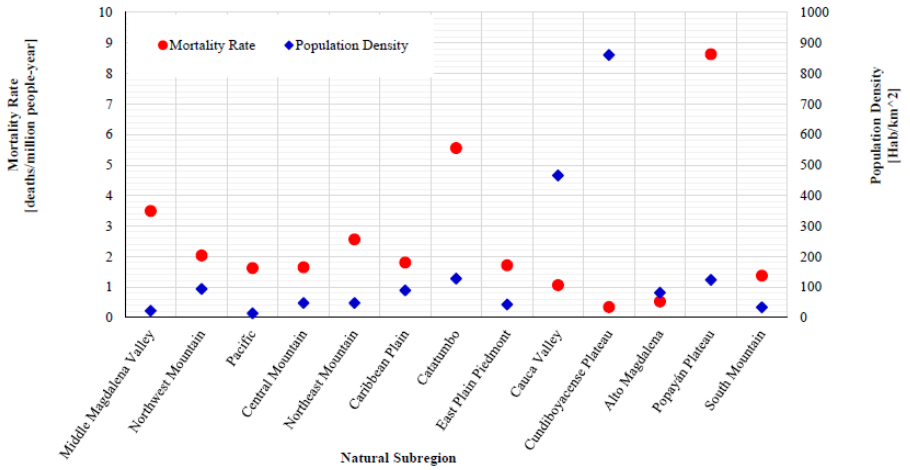

Figure 8.
Mortality rate vs Population Density in 13 natural sub-regions.
Authors.

5. Conclusions

This work discusses the importance of studying the lightning phenomenon in Colombia since it is one of the latin american countries with more victims by lightning.

Annually, an average of 65 people dies in Colombia representing a mortality of more than 1.1 deaths per million people per year.

Based on the information provided by DANE about lightning fatalities since 1997 to 2014, 1173 cases were registered where the highest number of cases occurred in 2003 and 2005 with 98 and 93 victims by lightning, respectively. Besides, just in 25 % of the departments more than 100 dead people was reported; 82 % were males and 18 % were females.

A Colombia map with the natural sub-regions was elaborated aiming to show the regions most susceptible to lightning and where more people died. The regions with more fatalities were the Caribbean Plain, Northwest Mountain and Northeast Mountain with 269, 185 and 117 cases, respectively.

Departments with the highest mortality rate were Vichada, Guainía, Cauca and Guaviare with more than 5 deaths per million people over the year. The natural sub-regions the highest mortality rate were Popayán Plateau, Orinoquía, Middle Magdalena Valley and Amazon with 8.62, 4.57, 3.49 and 3.29 deaths per million population per year.

The population density and DDT are not correlated but mortality rate if directly interrelated with DDT. In this way, when the population density is low, the risk that a person dies by an atmospheric discharge will be high. In future works is suggested to calculate the GFD for the sub-regions remaining and update values in the sub-regions that were determined in this work.

References

[1] Instituto Colombiano de Normas Técnicas-ICONTEC, NTC 4552-1: *Protección contra descargas eléctricas atmosféricas (Rayos) - Parte 1: Principios Generales*. 2008, pp. 1–78.

[2] H. Torres-Sánchez, El rayo: Mitos, leyendas, ciencia y tecnología, 2da Ed. Bogotá D.C., 2002.

[3] H. Torres-Sánchez, G. Bernal, R. López, and A. Joya, "Estudio y caracterización de Descargas Eléctricas Atmosféricas en Colombia." 1990.

[4] L. Barreto and H. Torres-Sánchez, "The lightning parameters and its spatial and temporal dependence. CIGRE." 1996.

[5] H. Torres-Sánchez, "Variation of lightning parameter magnitudes within space and time," *Int. Conf. Light*. Prot. ICLP 1998, 1998.

[6] H. E. Rojas, A. S. Cruz, and C. A. Cortés, "Characteristics of Lightning-generated Electric Fields Measured in the Bogotá Savanna, Colombia," Rev. UIS Ing., vol. 16, no. 2, pp. 243–251, 2017. DOI: https://doi.org/10.18273/revuin.v16n2-2017022

[7] E. Soto, E. Perez, and D. Del Rio, "Obtención del índice de tasa de fallas de líneas de distribución ante impactos indirectos de rayo en zona tropical,"

Rev. UIS Ing., vol. 17, no. 1, pp. 217–222, 2018. DOI: https://doi.org/10.18273/revuin.v17n1-2018021

[8] C. Younes, "Evaluación de parámetros del rayo con mediciones terrestres y satelitales para Colombia," Universidad Nacional de Colombia - Sede Bogotá, 2002.

[9] K. P. Naccarato, T. Atmospheric, and E. Group, "Lightning warning and analysis of lightning threats risks for human life protection in Brazil.," in *International Conference on Lightning Protection (ICLP 2012)*, 2012, pp. 1–10.

[10] M. Doljinsuren and C. Gomes, "Lightning related human casualties in Mongolia," in *International Conference on Lightning Protection (ICLP 2016)*, 2016, pp. 1–4.

[11] M. Hajikhani, M. Z. A. Ab-Kadir, M. Izadi, C. Gomes, and J. Jasni, "Lightning fatalities and injuries in Malaysia from 2008 to 2015," in *International Conference on Lightning Protection (ICLP 2016)*, 2016, pp. 1–6.

[12] R. L. Holle and M. A. Cooper, "Lightning-caused Deaths and Injuries at Schools," in *International Conference on Lightning Protection* (ICLP 2016), 2016, pp. 1–5.

[13] R. L. Holle, "Lightning-caused Deaths and Injuries Related to Agriculture," in *International Conference on Lightning Protection* (ICLP 2016), 2016, pp. 1–6.

[14] R. L. Holle, "The Number of Documented Global Lightning Fatalities," in *International Conference on Lightning Protection* (ICLP 2016), 2016, pp. 1–4.

[15] L. G. Barrucho, "¿Cuáles son los países latinoamericanos donde hay más muertes por rayos?," *BBC Mundo*, Apr-2014.

[16] N. Navarrete-Aldana, M. A. Cooper, and R. L. Holle, "Lightning fatalities in Colombia from 2000 to 2009," in *International Conference on Lightning Protection* (ICLP 2014), 2014, pp. 40–46.

[17] C. A. Cruz Mosquera, "Evaluación del Riesgo por Rayos Incluyendo un Sistema de Alarma de Tormentas (SAT) en Colombia," Universidad Nacional de Colombia, 2015.

[18] Keraunos S.A.S, "Identificación y Análisis de los Niveles de Calidad del Servicio Alcanzables en las Redes de Distribución de Energía Eléctrica del SIN," Bogotá D.C., 2013.

[19] H. Torres, G. Bernal, R. López, andg A. Joya, "Estudio caracterización D.E.A. en Colombia," 1990.

[20] H.-D. Betz, K. Schmidt, P. Oettinger, and M. Wirz, "Lightning detection with 3-D discrimination of intracloud and cloud-to-ground discharges," *Geophys. Res. Lett.*, vol. 31, no. 11, Jun. 2004.

Additional information

Cómo citar este artículo: A. S. Cruz, H. Torres, H. D. Aranguren, J. C. Inampués, "Lightning mortality rate in Colombia for the period 1997 - 2014," Rev. UIS Ing., vol. 17, no. 2, pp. 65-74, 2018.