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Lightning Fatalities in Colombia from 2000 to 2009

Norberto Navarrete-Aldana, MD
Emergency Physician
Burn Intensive Care Unit
Simón Bolívar Hospital, Bogota, Colombia
nnavarrete.md@gmail.com

Mary Ann Cooper, MD
Professor Emerita
University of Illinois at Chicago,
Chicago, Illinois, U.S.A.
macooper@uic.edu

Ronald L. Holle
Holle Meteorology & Photography,
Oro Valley, Arizona, U.S.A.
rholle@earthlink.ne

Abstract— **National lightning fatality information has been gathered and published for several decades over Australia, Canada, Japan, the United States, and Western Europe, but few such studies have taken place and been published in the formal literature during the last decade in other areas. National lightning fatality data are difficult to collect in many countries, especially in tropical regions, despite a high frequency of lightning. To partially fill this gap, the current paper provides the first comprehensive national summary of lightning deaths in Colombia. Data from the National Administrative Department of Statistics were gathered for 2000 through 2009 and were classified according to the number of fatalities by year, month, gender, age, and location of the fatality. These data were assigned to geographic departments to determine the fatality rates per type of population. Comparison was also made with the population percentage in rural areas where the outdoor lightning risk may be greater than in cities due to labor intensive agricultural practices, housing that is unsafe from the lightning threat, lack of access to weather forecasts and lightning safety knowledge, and other factors. Data from an international lightning locating system also were used to determine the annual lightning frequency and monthly totals in Colombia. During the ten study years, 757 deaths were identified. The highest mortality rates were in rural areas with a maximum of 7.69 deaths per million per year in the Vaupes Department of eastern Colombia. The death rate for all of Colombia was 1.78 per million per year during the same period.**

Keywords*— *Colombian lightning fatalities, lightning casualties, lightning accident prevention, lightning casualty epidemiology

I. Introduction

Lightning is a common occurrence, especially in tropical and subtropical regions, and causes many deaths and injuries every year. Global estimates range from 6,000 to 24,000 fatalities per year [Cardoso et al. 2011; Gomes et al. 2011; Holle 2008]. At least in developed countries, approximately ten times as many people are injured by lightning as are killed [Cherington et al. 1999]. Unfortunately, many survivors are left with permanent disabling neurological deficits that may make them unable to return to work, leaving families with decreased income and increased demand and stress on caretakers [Cooper 2001].

Colombia is one of the countries in the world with a much higher density of lightning than many other areas. This high frequency is corroborated by currently-available lightning data from satellites such as those shown at http://meso.gsfc.nasa.gov/val/projects/lightning/. Reasons for frequent lightning in Colombia include not only its location near the equator, but also nearby very warm oceanic waters supplying abundant low-level moisture, the movement of the equatorial trough across the region, and large topographic variations in the form of oceanic coastlines and substantial mountain ranges. Such features can produce a large amount of lightning which can be expected to result in a number of lightning-related injuries and deaths. Knowing the epidemiological and geographical characteristics of these events is the first step in initiating prevention and risk mitigation programs specific to Colombia. A similar paper by Cruz et al. [2013] specifically addresses military-related lightning fatalities and injuries across the county.

II. Geography, Climate and Demography of Colombia

The Republic of Colombia in northwestern South America has over 46 million people, the 27th largest national population in the world. Colombia, whose southern tip lies on the equator, has climatic regions that include tropical rainforests, savannas, steppes, deserts and mountainous regions. Two rainy seasons per year occur due primarily to the country's location relative to the equatorial trough, in May through July and during September through October. One of the wettest places on earth has been identified as being located in Colombia (http://www.wunderground.com/blog/weatherhistorian/comment.html?entrynum=135).

Population shifts from rural to urban areas were very frequent during the middle of the twentieth century but have decreased since then. The urban population increased from 31% of the total population in 1938, to 57% in 1951, about 70% in 1990, and currently is about 77%. Thirty cities have a population of 100,000 or more. The nine eastern lowland departments, constituting about 54% of Colombia's area, have less than 3% of the population and a density of less than one person per square kilometer.

III. PREVIOUS LIGHTNING POPULATION DEMOGRAPHIC STUDIES

There has been significant documentation of lightning-caused deaths and injuries in Australia, Canada, Japan, the United States, and Western Europe [Holle 2008]. In those areas, lightning effects on people are decreasing due to a combination of one or more of these factors:

- Widespread availability of large substantial lightning-safe buildings where people live, work, and attend school.
- Widespread availability of lightning-safe fully-enclosed metal-topped vehicles.
- Substantial reduction in the number of people involved in high risk activities such as labor intensive agricultural work.
- Widespread education programs that stress the importance of lightning safety.
- Availability of medical practices that mitigate some of the lightning impacts.

While national lightning fatality data have been compiled in the more developed areas of the world for several decades, data from outside these areas have been relatively scarce [Holle 2008]. In such areas, often with high lightning frequencies, only a few national lightning fatality studies have been published in the last decade or two. These results have appeared more often in conference proceedings, although the studies are now beginning to reach the formal literature, including the present study. The only recent fatality totals published in refereed journals for entire countries outside of Australia, Canada, Japan, the United States, and Western Europe are those from Brazil [Cardoso et al. 2014], China [Zhang et al. 2012], Malawi [Mulder et al. 2012], the Highveld of South Africa [Blumenthal 2005], Swaziland [Dlamini 2008], and Uganda [Ahurra and Gomes 2012].

The present paper attempts to add to this small body of knowledge by addressing lightning fatalities for Colombia. The goal is to add information in a formal publication to the generally deficient documentation of lightning deaths in areas of the world with frequent lightning where there is significant exposure of the population to the lightning hazard. Only after this type of data is collected can government policies for protection of at-risk populations be affected, and lightning safety education for these populations be designed and implemented.

IV. DATA AND METHODS

In Colombia, all accidental deaths are evaluated by officials of the National Institute of Legal Medicine and Forensic Sciences who complete death certificates after conducting autopsies. In more dispersed rural areas, this function may be performed by physicians serving their mandatory social service.

Official vital statistics were collected from death certificates by the National Administrative Department of Statistics (Departamento Administrativo Nacional de Estadistica – DANE). Because an analysis of deaths from lightning has not been done before, we requested development of a customized search for deaths using ICD-10 codes for lightning deaths (X330 to X339 and T750). Data included the year and month of injury, gender and age of victims, and locations of fatalities. It was not necessary to obtain ethical approval because national statistics are freely available for use by the academic community in Colombia. Data were processed using the statistical software package STATA, version 11.

A limitation of our study is that changes occurred in the variables and categories between years of the study. These changes took place after the generation of death certificates in electronic form became operational in 2008, and new information categories were added such as social security, education and marital status. Because these data were not coded for deaths before 2008, they were not included in the present study.

V. RESULTS

A. *Age and gender of lightning fatalities*

A total of 757 lightning-related deaths were identified by the death certificates in the DANE vital statistics between 1 January 2000 and 31 December 2009. The fatalities ranged in age from three days to 81 years (mean of 32 +/- SD of 17 years). There is a cluster of many fatalities between 16 and 25, with a median age of 29 years (Fig. 1). Six hundred and eight victims [80.3%] were males and one hundred forty-nine (19.7%) were females, giving a male:female ratio of 4.1:1.

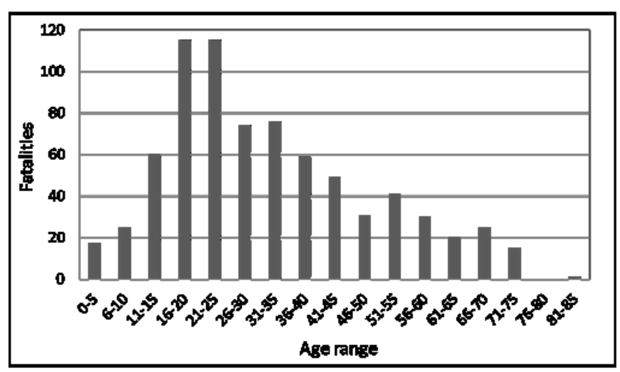

Fig. 1. Age distribution of Colombia lightning fatalities from 2000 to 2009 in five-year increments. There were four patients with indeterminate age during processing of death certificates.

Although 18 is the age of majority in Colombia, Colombia defines ‘children’ for medical reasons as those 14 and under. A total of 90 children were found to have suffered lightning deaths (12%) with a mean of 4.8 years of age (SD of +/- 0.1 years). Fifty-nine (66%) were males and thirty-one (34%) were females (male:female ratio of 1.9:1). In women of childbearing age, eight were pregnant when they died (7.3%); 51 (47%) were not pregnant. In about half of the cases (46%), pregnancy status was recorded as unknown.

Most prior studies throughout the world with large samples of lightning casualties have consistently found a male ratio over 70%, both now and in the past and regardless of the economic and developmental level of the country [Cooper et al. 2012; Curran et al. 2000; Holle et al. 2005]. The reason for the dominance of male lightning casualties is not certain but has been attributed to many factors, including the tendency for greater risk taking by males with regard to lightning and other hazards, and greater exposure to outdoor, labor-intense work practices such as agriculture or construction.

B. Inter-annual and monthly variations of lightning fatalities

With respect to the annual totals, more than 50 fatalities were reported every year from 2000 through 2009; the highest incidence occurred in 2003 (Fig. 2). The observed monthly variation in fatalities shows two peaks, one centered in April and another in October (Fig. 3). The highest incidence of deaths occurred in the month of October, 101 cases, while the lowest was in January and February when there were 11 and 15, respectively. This monthly variation is similar to that found by Cruz et al. [2013].

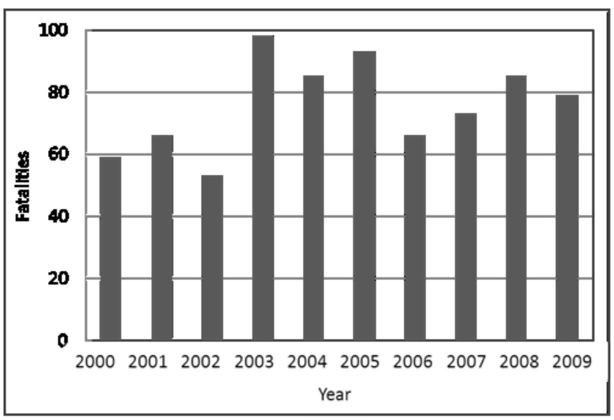

Fig. 2. Annual number of Colombia lightning fatalities from 2000 to 2009.

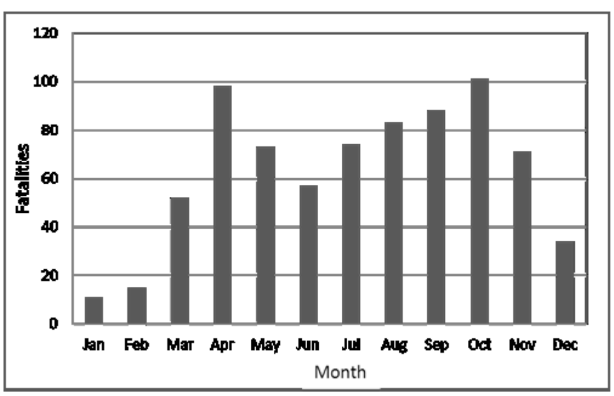

Fig. 3. Monthly distribution of lightning deaths from 2000 to 2009.

TABLE I. FREQUENCY AND PERCENTAGE OF SITES WHERE THE LIGHTNING DEATHS OCCURRED.

Place of death	Number of events	Percent [%]
Home	268	35.4
Workplace	152	20.1
Public road	98	12.9
Hospital/Clinics	35	4.6
Township/village health center	5	0.6
Unknown	24	3.2
Other	175	23.1
Total	**757**	**100.0**

C. Sites of lightning fatalities

With regard to the place where the fatalities occurred, the patient may have died within or outside of a health institution. Those who died outside a hospital were at home, a workplace or on public roads and usually failed to receive any kind of medical attention.

The largest number was at home with 268 of 757 cases (Table I). The next largest category was in the workplace (152). Most deaths occurred before transport to a hospital, since only 40 deaths were reported in health institutions, although it is likely that these places only served as the place where death was officially pronounced, not where it actually occurred. In 592 deaths (78.2%) there was no documentation of medical care being administered.

D. Spatial distributions of lightning fatalities and rates

The number of fatalities by department is shown in Fig. 4 based on Table II. In general, the largest numbers are in the northwest, and the lowest numbers are in the eastern and far western departments. No lightning fatalities were recorded for the archipelago of San Andres during the study years. This dataset is for the entire population of Colombia, and differs from Cruz et al. [2013] where the location of the military units affects the locations of lightning deaths and injuries. Given these findings, the rate of lightning deaths per million people was calculated by department in Fig. 5 based also on Table II. When population is taken into account, the less populated southeastern departments have the highest fatality rates, while the lowest fatality rates are in the west where the population is also sparse. The average of the estimated population of each department was used during the years 2004 and 2005 (the mid-point of the time of the study) as the denominator of the fatality rate. The mortality rate per population in Fig. 5 and Table II varies from zero to 7.69 per million per year among the departments. The annual rate of deaths from lightning in Colombia overall is 1.78 per million per year.

With respect to the urban distribution of deaths, 163 deaths (21.5%) occurred in municipal capital cities, 115 (15.2%) died in towns such as inspections, townships, or villages, and 471

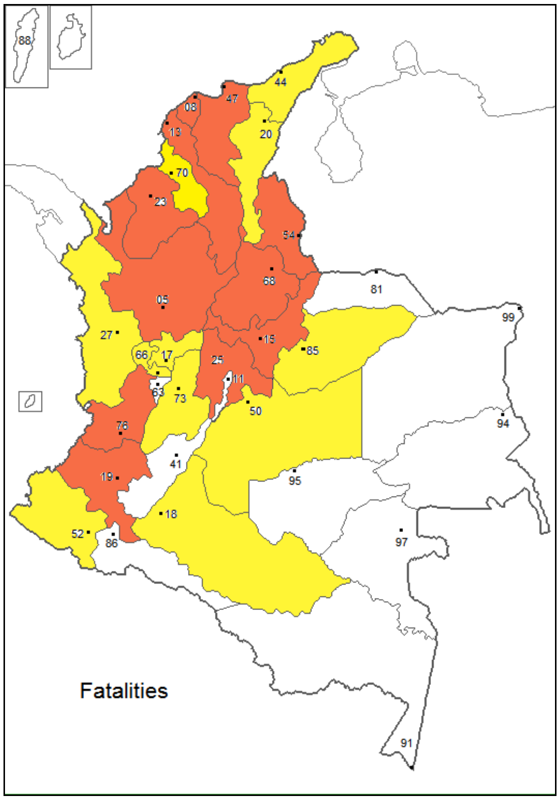

Fig. 4. Map of number of fatalities by department in Colombia from Table II. Top ten departments are orange, 11 to 20 are yellow, and the remaining 11 departments are white.

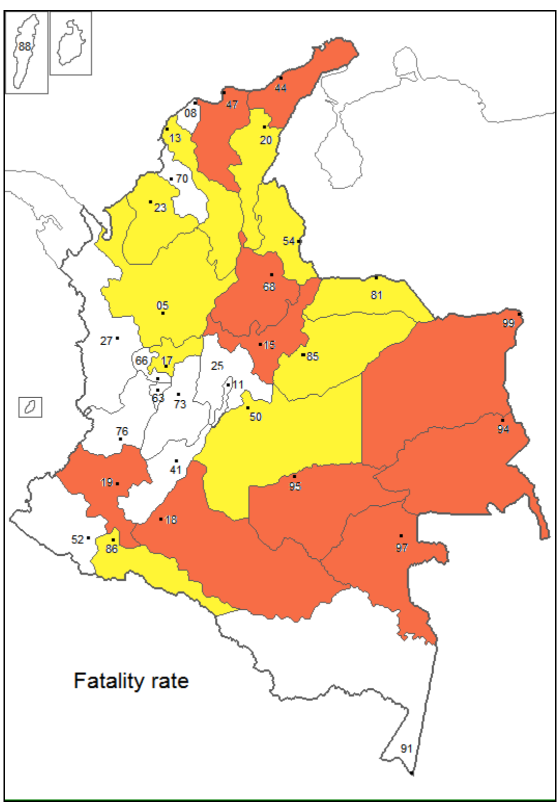

Fig. 5. Same as Fig. 4 for fatality rate.

TABLE II. COLOMBIA DEPARTMENT STATISTICS ARRANGED BY ANNUAL DEATHS PER MILLION BY DEPARTMENT. DASHED LINES INDICATE TOP TEN AND SECOND TEN RANKS OF ANNUAL DEATHS PER MILLION.

Code	Department	Died	Average population	Annual deaths /million/ year	% rural population
97	Vaupés	3	39,033	7.69	64.7
19	Cauca	71	1,263,858	5.62	62.0
99	Vichada	3	55,188	5.44	62.4
95	Guaviare	5	94,866	5.27	47.9
18	Caquetá	14	418,052	3.35	45.0
15	Boyacá	41	1,253,671	3.27	48.5
47	Magdalena	37	1,145,230	3.23	31.3
94	Guainía	1	34,922	2.86	69.4
44	La Guajira	19	667,684	2.85	46.1
68	Santander	55	1,952,806	2.82	27.2
23	Córdoba	41	1,457,229	2.81	49.7
85	Casanare	8	292,197	2.74	32.0
20	Cesar	24	897,334	2.67	29.4
81	Arauca	6	231,074	2.60	39.5
05	Antioquia	142	5,643,511	2.52	23.9
13	Bolívar	45	1,870,660	2.41	25.5
17	Caldas	22	967,591	2.27	30.7
54	Norte de Santander	25	1,238,465	2.02	23.8
50	Meta	15	774,750	1.94	27.1
86	Putumayo	6	308,638	1.94	56.3
27	Chocó	8	451,965	1.77	52.1
70	Sucre	13	768,273	1.69	36.0
25	Cundinamarca	37	2,260,293	1.64	36.0
91	Amazonas	1	67,277	1.49	62.1
52	Nariño	19	1,531,949	1.24	53.9
66	Risaralda	11	894,525	1.23	23.1
08	Atlántico	25	2,151,045	1.16	5.0
76	Valle del Cauca	38	4,139,615	0.92	13.7
73	Tolima	12	1,362,424	0.88	34.4
63	Quindio	2	532,965	0.38	13.5
41	Huila	2	1,004,140	0.20	40.6
11	Bogotá, D.C.	6	6,787,079	0.09	0.2
88	Arch. de San Andrés	0	70,237	0.00	28.5
00	National total	757	42,628,541	1.78	25.6

(62.2%)] in dispersed rural areas. Location information was available on all but eight certificates (1.1%). In Colombia, a "municipality" is the basic territorial entity of the political-administrative division of a state with at least 14,000 inhabitants, has a municipal seat which usually bears the same name of the municipality and serves as its capital. Populations smaller than municipalities called "populated centers" have at least 20 contiguous houses, neighbors, or attached to each other in the rural area of a municipality.

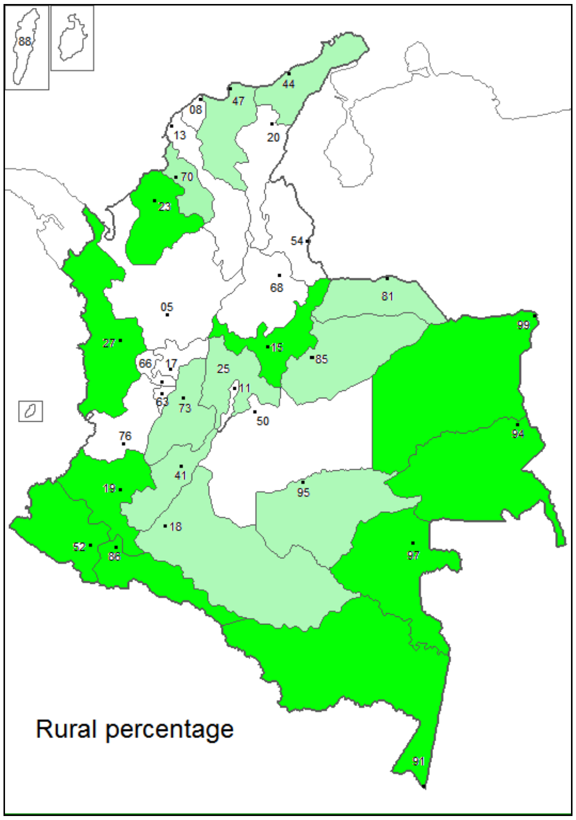

Fig. 6. Same as Fig. 4 for rural population percentage.

The rural population percentage was calculated and shown in Fig. 6 (based on Table II). In general, the departments with the highest fatality rates (Fig. 5) are often the most rural departments where daily exposure may be maximal and safe housing and shelter is limited.

VI. Lightning Data

Although lightning data are not available for Colombia during the 2000-2009 study period, the major features of the distribution of lightning over a large country tend to have relatively minor variability from year to year. Fig. 7 shows a map of lightning frequency in Colombia during 2012 detected by the network providing stroke information to the Global Lightning Dataset GLD360 owned and operated by Vaisala Inc. [Pohjola and Mäkelä 2013; Said and Nag 2012]. This map shows a large range of lightning occurrence from very high lightning frequencies in the northwest to much lower frequencies in the central and southeast areas of the country.

With regard to time of year, Fig. 8 shows the monthly variation of lightning through the year for the entire country based on 2012 lightning data. As noted previously, two rainy seasons occur per year in Colombia due partly to the country's location relative to the equatorial trough with maxima in lightning occurring from May through July and during September through October. The two lightning maxima are somewhat different than the month-to-month variation in lightning fatalities in Fig. 3.

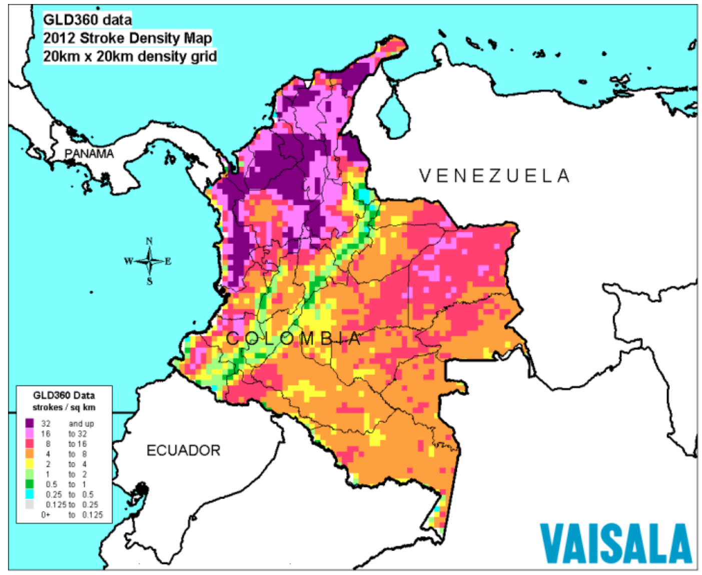

Fig. 7. Map of lightning over Colombia during 2012 in 20 by 20 km bins color coded according to scale on lower left. A total of 14,939,495 mostly cloud-to-ground lightning strokes are summarized in this Fig..

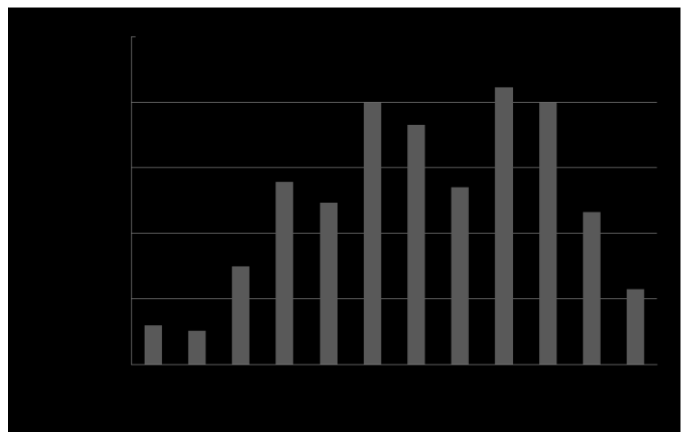

Fig. 8. Monthly variation of lightning strokes over Colombia from Vaisala's Global Lightning Dataset GLD360 during 2012.

VII. Discussion

Since all deaths in Colombia are apparently recorded in the DANE database, it is fortuitously and surprisingly much more complete and comprehensive regarding lightning deaths than data in most countries, even the most 'developed' ones. One limitation of our study is its retrospective character. In this study, the quality of the database can be a source of bias, because it depends on people that are not part of the research, and hence, the database can be incomplete or biased. Issues may arise, for example, in the case of an inexperienced young doctor in a rural area, where the body does not evidence external injuries, and may decide that the cause is unknown or a cardiac cause. However, the process of generating death certificates is standardized for all medical staff in the country, so this is the best database available because all deaths are recorded in the DANE.

At first, some of these comparisons of fatalities and lightning appear to be inconsistent. However, closer inspection of the data shows underlying features that are common to studies in other countries. With regard to the location of lightning fatalities, the dominance in the northwest part of Colombia in Fig. 4 matches quite well with the detected lightning frequency in Fig. 7. However, the fatality rate does not match the lightning frequency.

López and Holle [1998] pointed out a strong relationship between a decreasing lightning fatality rate and decreasing percentage of rural population in the United States. The rural population in the United States decreased from over 60% in 1900 to 25% by the end of the century. This change corresponds with a decrease in the lightning fatality rate from over five US deaths per million in some years early in the 20th century to under 0.5 per million in recent years. Similar decreases have been observed in more developed countries as urbanization occurred [Holle 2008].

The urban migration in the United Sates and other developed countries has also coincided with other factors mentioned in Section 2, notably more lightning-safe buildings and vehicles, less labor-intensive agriculture, as well as better education and medical practices with regard to lightning. As a result, it follows that it is not especially surprising that the spatial distribution of the fatality rate in Fig. 5 is reasonably similar to the rural percentage distribution in Fig. 6. As mentioned earlier in section 5D, Colombia data show a larger ratio of the deaths occurring in dispersed rural areas (62.2%), which relates well with more rural activities away from lightning safe buildings and vehicles, as well as little pre-hospital assistance and lack of adequate resuscitative measures in the local community.

The largest number of lightning deaths in Colombia tends to occur in the more urban regions simply because the population is concentrated in urban areas. In other countries, the urban population tends to be involved in activities around the home, in recreation, and in workplace activities, based on studies of a similar population in the United States [Holle 2008].

However, although the rural population is sparse, it has the highest fatality rates perhaps because the rural population tends to be involved in high exposure, labor-intensive agriculture at the time of the lightning fatality occurrence with little chance of individuals reaching adequate safe shelter. In addition, rural housing tends to be made up of structures that do not provide adequate lightning safety so that little safe shelter is available even in the best of times or when relaxing and sleeping. An estimate in the late 1990s indicated that more than 85% of all housing units in Colombia were detached houses, ranches, and huts. Three-fourths of all dwellings were made of bricks, adobe, mud or stone; nearly 15% had external walls of wattle or daub; 7% were wood; and 3% were mostly cane (http://www.nationsencyclopedia.com/Americas/Colombia-HOUSING.html#ixzz2OaOnXeY6).

It will be difficult to target specific lightning safety education to the population until it is known where the most common sites of death occur such as in fields or on roads, inside inadequate buildings such as homes, under trees, etc, data that were not coded on death certificates. More research needs to be done on this in order to support public education design and dissemination as well as to decide measures that might provide safe shelters in the communities most affected.

VIII. Conclusions

This study adds to a short list of only a few national summaries of lightning fatalities published in the refereed literature during the last decade from outside Australia, Canada, Japan, the United States, and Western Europe.

Analysis was made of 757 lightning fatalities in Colombia from 2000 through 2009 based on death certificates. Many of them were young males. Fatalities tended to occur most often in March through May, and August through October. The most common locations were at home and in the workplace, although many places of death were unknown or uncoded. The number of fatalities was more frequent in the more populous departments, while the death rate per million was greater in less populated and rural areas. The largest number of fatalities also coincided with a higher frequency of lightning measured by a detection network.

While the Colombian DANE system provides admirably complete data in many respects, more information of location and activity in which victims are engaged may help design appropriate public education. In urban settings, lightning injury prevention education may be lifesaving. Because there tend to be more lightning-safe buildings and vehicles in the urban situations, ‘safe’ places can be emphasized in those areas. In rural areas, several other factors come into play. Risk there is increased due to labor intensive agricultural practices as well as because there are fewer lightning-safe locations and vehicles. In addition, people may travel long unprotected distances by foot between home and work, market, or school.

A two pronged approach involves education that stresses seeking safety and what safe places are, as well as implementation of safe shelters for work and all other activities of the family including homes, schools, churches and other places that may not be well protected against lightning. As in other developing countries and those with high poverty areas, new lightning injury prevention solutions because of inadequate housing and the types of increased risk may need to be developed. In all areas, educational activities need to target young males since they are consistently the most likely group to be killed in all studies done to date.

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