2008 20th International Lightning Detection Conference
21-23 April • Tucson, Arizona, USA
2nd International Lightning Meteorology Conference
24-25 April • Tucson, Arizona, USA

ANNUAL RATES OF LIGHTNING FATALITIES BY COUNTRY

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1. INTRODUCTION

This study builds on an earlier study on the worldwide casualty toll from lightning (Holle and López 2003). The annual number of lightning deaths has been compiled in the US since 1900, and in several other developed countries for extensive but varying periods. However, there has been little systematic collection of information on lightning deaths in many regions of the world. Holle and López (2003) made an assessment of the worldwide impact of lightning, and concluded that 24,000 deaths and 240,000 injuries occur per year.

The underlying basis for this study is that a rate of less than 0.3 deaths per million people applies to more developed countries with substantial housing and a decreasing amount of labor-intensive agricultural labor. Other regions were assumed to have an annual lightning fatality rate of 6 deaths per million per year, and this rate was considered applicable to a large portion of the world's population. These assumptions were made in the presence of a small amount of fatality rate data. The present paper will synthesize data that are available in publications when possible. The best data source is for entire countries for long periods. There are also more variable-quality data from regions within countries for short periods that have been extrapolated to a national rate for some countries, since fatality data are often not available for a country for long periods.

Only fatalities are considered in this paper. All prior relevant publications have included fatality data, but most have not included injuries. Annual fatality rates were matched with populations for the same years. Casualties in this study are defined as the sum of fatalities and injuries.

Fatality and injury data are underreported in the best datasets, but death totals are more accurate than injuries (López et al. 1993). Although exact death totals continue to be somewhat inconsistent where data are well documented (Richey et al. 2007), the extent of underreporting in other countries is unknown and may be very large.

The ratio of injuries to deaths appears to be 10 to 1 based on an intensive search of Colorado medical records (Cherington et al. 1999). The US ratio has increased from two reported injuries per reported death in 1960 to eight injuries per death in recent years as data collection continues to improve in NOAA's *Storm Data* for the US (Curran et al. 2000). The ratio of injuries to deaths can be considered to be a useful indictor of the quality of a lightning casualty dataset.

2. LIGHTNING FATALITY RATES BY COUNTRY OVER MULTIPLE DECADES

2.1. US 20th century trend

The premise for the study is shown by the time series of population-weighted fatality rates from the US since 1900. Figure 1 shows the annual death rate per million people to be highest at 6.3 in 1901 (López and Holle 1998, Table 1). Later in the 20th century, the annual rate reached 0.6 deaths per million people starting in 1970. The rate continued to decrease after 1970 to 0.3 deaths per million per year (Cooper et al. 2007; Lengyel 2004). The effect is a reduction by more than an order of magnitude in the US population-weighted fatality rate during the 20th century.

A major shift from rural to urban areas also occurred during the 20th century in the US, as shown in Figure 1 (López and Holle 1998). This shift is nearly coincident with the reduction in the fatality rate.

In addition to the rural-urban migration, it has been hypothesized that other factors occurred coincidentally (López and Holle 1996). Many of the following factors are also apparent in a comparison of 1890s lightning deaths with those in the 1990s (Holle et al. 2005):

- Large buildings frequently occupied by people became more substantial,
- Meteorological forecasts and warnings greatly improved,
- Awareness of the lightning threat increased through education, planning, and detection,

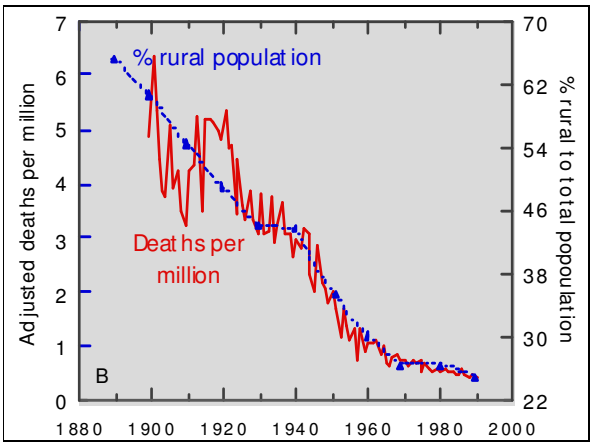

FIGURE 1. Annual time series for the US from 1900 to 1991. Solid line shows lightning deaths per million people, and dashed line shows percent rural population (López and Holle 1998).

- Improved medical care and emergency communications prevented some lightning casualties from resulting in deaths,
- Other socioeconomic and climatic changes may have also contributed to the change.
- To this previously-published list can be added frequent access to protection provided by fully enclosed metal-topped vehicles (Holle 2008).

Large substantial buildings, where people live and work in the latter part of the 20th century in more developed countries, provide significant protection to people inside them. Such buildings surround occupants with the effect of a Faraday cage such that a direct strike to the building is conducted around people inside the structure. People inside such buildings that are grounded according to building codes are usually very safe from lightning during a thunderstorm as long as they are not in direct contact with the conducting paths of electrical, telephone and cable wiring, as well as plumbing.

None of these factors has been quantified further since Holle and López (2003), and all are difficult to isolate. The present study will examine national lightning fatality data over the past two centuries for indications of the effects of these factors.

b. Decadal trends by country

Published studies of national lightning fatality rates are shown in the following series of tables. Decadal trends will be presented by country in alphabetical order after the US data corresponding to Figure 1 are shown. If data are not available for all 10 years in a decade, the partial years' results are applied to the whole decade.

United States: Lightning fatality statistics were not compiled in the US until the 20th century. Collection was started in part due to the efforts of Kretzer toward the end of the 19th century (Kretzer 1895). This lack of data during the 19th century was noted earlier by Anderson (1879) as follows: "…the Chief of the Bureau of Statistics writes that no record of deaths or fires caused by lightning is kept - a somewhat curious admission on the part of such a practical and methodical country."

The decadal list of the lightning fatality rates for the US is shown in Table 1. Data from 1900 through 1991 from the primary source (López and Holle 1998) were supplemented with later data from NOAA's *Storm Data* lists of fatalities. The maximum rate for a 10-year period was 4.8 deaths per million people per year during the first decade of the 20th century, and the maximum single-year death rate exceeded 6.3 per million. The annual fatality rate is now 0.2 per million, or less, in some recent years. Annual fatalities ranged from over 450 in the earlier part of the century to under 50 in some recent years.

TABLE 1. Decadal averages and maximum number of lightning deaths per million people per year in US from 1900 through 2006. Data through 1991 from López and Holle (1998); recent years from Storm Data.

Decade	Decadal fatality rate per year	Maximum annual rate
1900-1909	4.8	6.3
1910-1919	4.5	5.2
1920-1929	4.1	5.3
1930-1939	3.2	3.7
1940-1949	2.4	3.1
1950-1959	1.1	1.6
1960-1969	0.7	0.9
1970-1979	0.5	0.6
1980-1989	0.4	0.4
1990-1999	0.2	0.3
2000-2006	0.2	0.2

Additional US state studies have been published that identify the primary activity or location factors involving local lightning casualties. For this paper, only national US studies are considered.

Australia: Table 2 shows a long Australian record from two sources. One source (Coates et al. 1993) provides the longest known national database. That publication also states that "Prior to 1910 the death totals are underestimated…" Annual fatalities ranged from zero in some years to 17 in 1918.

The annual rates beginning in the 19th century are generally below 3 deaths per million people, although some individual years reach as high as 21 fatalities per million. Starting in the 20th century, rates are lower than in the US for the same decades. There is a broad decline over the long period of record for Australia.

TABLE 2. Same as Table 1 for Australia. Data before the dash are from Coates et al. (1993); after dash from Golde and Lee (1976). M indicates missing data for publication during a decade.

Decade	Decadal fatality rate per year	Maximum annual rate
1824-1829	3.5-M	21.0-M
1830-1839	0.0-M	0.0-M
1840-1849	3.1-M	12.0-M
1850-1859	4.0-M	10.0-M
1860-1869	2.2-M	4.9-M
1870-1879	1.5-M	4.0-M
1880-1889	1.3-M	2.7-M
1890-1899	1.2-M	2.0-M
1900-1909	1.7-M	2.9-M
1910-1919	2.1-M	M-M
1920-1929	1.3-1.3	M-2.1
1930-1939	1.4-1.4	M-2.0
1940-1949	0.5-0.5	M-1.2
1950-1959	0.5-0.5	M-0.9
1960-1969	0.3-0.3 (end 1968)	M-0.5
1970-1979	0.2-M	M-M
1980-1989	0.1-M	M-M

Canada: Table 3 shows decadal data from Canada from two sources that show a similar reduction during the 20th century. The annual fatality rates for corresponding years are less than in the US, which can be expected due to the shorter thunderstorm season at the higher latitude of Canada compared to the US. Annual fatalities ranged from a maximum of 35 in 1929 to a minimum of 1 in several recent years. Rates steadily decline during the 20th century.

TABLE 3. Same as Table 1 for Canada. Data before the dash are from Hornstein (1962); after dash from Mills et al. (2006). M indicates missing data for publication during a decade.

Decade	Decadal fatality rate per year	Maximum annual rate
1921-1929	M-2.2	M-3.6
1930-1939	2.0 (1938-39)-2.2	2.2 (38-39)-2.8
1940-1949	1.5-1.7	2.8-2.7
1950-1959	0.8-0.8	1.2-1.1
1960-1969	0.4-0.4	0.6-0.9
1970-1979	0.4-0.4	0.6-0.7
1980-1989	0.2 (1980-86)-0.2	0.4 (80-86)-0.4
1990-1999	0.2	0.4
2000-2004	0.1	0.3

England and Wales: Table 4 shows the decadal data from England and Wales. There are four publications that record the decadal fatality rates since 1852, with some overlap (Baker 1984; Elsom 2001; Golde and Lee 1976; Lawson 1889). The rates for both decades and individual years beginning in the 19th century are quite low.

The annual lightning death rates per million people are low throughout the period of record, and have decreased in general through the 130-year record. Note that Elsom (1993) includes the same totals from 1852 to 1990 as Elsom (2001) that added some recent years of data.

Many of the publications for England and Wales report death rate or decadal totals, but not the fatalities. Annual fatalities from 1857 to 1880 (Lawson 1889) showed a range from 46 in 1872 to 3 in 1863. During the 20th century from 1975 to 1999, deaths ranged from 11 in 1982 to none in 1985 (Elsom 1993, 2001).

It is difficult to reconcile the statement by Cohen (1990) that "…while in England, it was estimated that the number of persons killed each year by lightning was over one hundred." The original tables in Anderson (1879) list a total of 194 deaths from 1869 to 1877, for a total of more than 100 for the entire period. Lightning deaths for years during this same period ranged from 3 to 46 (Lawson 1889). As a result, the 100 value per year (Cohen 1990) is not in Table 4.

TABLE 4. Same as Table 1 for England and Wales. Data before the first dash are from Baker (1984), followed by those from Elsom (2001), Golde and Lee (1976), and Lawson (1889). M indicates missing data for publication during a decade.

Decade	Decadal fatality rate per year	Maximum annual rate
1852-1860	M- M- M-1.0	M- M- M-M
1861-1870	M- M- M-0.6	M- M- M-M
1871-1880	M- M- M-1.0	M- M- M-M
1880-1889	M-0.6- M- M	M-1.2- M-M
1890-1899	M-0.7- M- M	M-1.5- M-M
1900-1909	M-0.4- M- M	M-0.8- M-M
1910-1919	M-0.4- M- M	M-0.7- M-M
1920-1929	M- M-0.2- M	M- M-0.4-M
1930-1939	M- M-0.3- M	M- M-0.6-M
1940-1949 [1941-50]	0.2- M-0.2- M	M- M-0.4-M
1950-1959 [1951-60]	0.2- M-0.2- M	M- M-0.4-M
1960-1968 [1961-70]	0.1- M-0.1- M	M- M-0.2-M
1971-1980	0.1- M- M -M	M- M- M-M

France: Table 5 shows lightning fatality data from France from two sources. One is from the period of 1835 to 1900 (Flammarion 1904), and the other is from 1968 to 1995 (Gourbière 1998). The fatality rates show a slow decrease over the period of record. Some of the years in the late 19th century had annual rates as high as 4.9 fatalities per million people, which is nearly as high as some individual years as shown in Tables 1 and 2 for Australia and the US. The population of France during those years was two-thirds rural. Rates in the middle 1800s are lower than they were in the US, but in the recent years, they are about the same as for the countries that have been described so far in previous tables.

The maximum death total in the 19th century was 187 in 1892, and the lowest was 48 in 1843 (Flammarion 1904). Lightning fatalities during specific years during the latter part of the 20th century ranged from a maximum number of 34 deaths in 1969 to a minimum of 5 in 1979 (Gourbière 1998).

Note that the same data from 1835 to 1990 in Flammarion (1904) were grouped in Gourbière (1998) into a single death rate from 1835 to 1863. The data from 1979 to 1994 in Gourbière (1998) were also combined in Gourbière et al. (1997). In addition, the 1900 total from the publication by Flammarion (1904) was quoted again in Gourbière (1999).

TABLE 5. Same as Table 1 for France. Data from Flammarion (1904) and Gourbière (1998). M indicates missing data for publication during a decade.

Decade	Decadal fatality rate per year	Maximum annual rate
1835-1839	2.0-M	3.2-M
1840-1849	2.0-M	3.0-M
1850-1859	2.2-M	3.0-M
1860-1869	3.0-M	3.7-M
1870-1879	3.1-M	4.8-M
1880-1889	3.3-M	4.6-M
1890-1899	3.5-M	4.9-M
1900-1909 [1900]	3.7-M	3.7-M
1910-1919	M-M	M-M
1920-1929	M-M	M-M
1930-1939	M-M	M-M
1940-1949	M-M	M-M
1950-1959	M-M	M-M
1960-1969 [1968-69]	M-0.5	M-0.7
1970-1979	M-0.4	M-0.6
1980-1989	M-0.2	M-0.4
1990-1995	M-0.2	M-0.3

Greece: Table 6 shows decadal fatality rates for Greece (Agoris et al. 2002)). The rates in recent years are somewhat higher than in the other countries mentioned above. Fatalities ranged from 10 in 1999 to one in 1998. The rates show a decrease over the short period of record.

TABLE 6. Same as Table 1 for Greece. Data from Agoris et al. 2002.

Decade	Decadal fatality rate per year	Maximum annual rate
1990-1999	0.5	0.9
2000-2001	0.2	0.4

Japan: Table 7 shows the decadal lightning death rate data for Japan. The annual fatality values were kindly provided by Dr. N. Kitagawa on behalf of N. Kitagawa, M. Ohashi, and T. Ishikawa. The rates are generally lower than elsewhere, and have decreased to a very low rate. Fatalities during the individual years have ranged from 58 in 1963 to 3 in 1993.

TABLE 7. Same as Table 1 for Japan. Data from Kitagawa, Ohashi, and Ishikawa (personal communication).

Decade	Decadal fatality rate per year	Maximum annual rate
1954-1959	0.3	0.5
1960-1969	0.3	0.6
1970-1979	0.2	0.3
1980-1989	0.1	0.1
1990-1997	>0	0.1

Singapore: Table 8 shows decadal data from Singapore (Pakiam et al. 1981). The rates beginning in the early 20th century are almost as high as in the United States during the same years. The rates have decreased, but not as much as those in countries in the previous tables during the more recent years of record. An annual rate of 1.7 deaths per million from 1961 to 1979 was also mentioned in this publication and is consistent with Table 8 (Pakiam et al. 1981). Individual years' fatalities are not included in this publication. However the total was 80 deaths for the 24 years from 1956 to 1979, which averages to 3.3 per year.

TABLE 8. Same as Table 1 for Singapore. Data from Pakiam et al. (1981).

Decade	Decadal fatality rate per year	Maximum annual rate
1922-1929	3.2	6.3
1930-1939	1.2	4.0
1940-1949	1.5	4.6
1950-1959	1.7	4.1
1960-1969	1.8	3.7
1970-1979	1.5	3.5

Spain: Table 9 for Spain since 1941 indicates a rate in recent years that is quite similar to the US. The fatality rate was higher in earlier decades of the 20th century, apparently due to a delayed migration from rural to urban settings compared to the US (López and Holle 1998). Since the urban shift, the rate appears to have reduced to about the same lower level as in the US. The annual number of lightning deaths ranged from 43 in 1954 to 9 in 1991. The 1991 data were obtained from a Spanish government publication summarizing natural disasters in that year, and published in Cooper et al. (2007).

TABLE 9. Same as Table 1 for Spain. Data from Cooper et al. (2007).

Decade	Decadal fatality rate per year	Maximum annual rate
1941-1949	2.0	4.8
1950-1959	2.6	4.7
1960-1969	1.5	3.0
1991	0.2	0.2

Sweden: Table 10 for Sweden has earlier information than any other dataset. Deaths for individual years from 1816 to 1877 were reported in Anderson (1879). The annual number of lightning deaths ranged from 36 in 1834 to 2 in 1840 and 1843. The annual fatality rates per million are relatively high through these early years, and range from 2.6 to 5.2 by decade. Individual years had annual rates as high as 12.5 per million. There is not much of a trend through the period; population was mainly rural during the 19th century.

TABLE 10. Same as Table 1 for Sweden. Data from Anderson (1879).

Decade	Decadal fatality rate per year	Maximum annual rate
1816-1819	5.2	12.5
1820-1829	2.9	5.8
1830-1839	3.6	12.1
1840-1849	2.8	6.3
1850-1859	3.4	6.9
1860-1869	2.6	6.4
1870-1877	3.0	6.1

3. LIGHTNING FATALITY RATES BY COUNTRY DURING SINGLE TIME PERIODS

Table 11 shows single-period national fatality rates. Most of them provide detail for no more than one decade; longer periods were reviewed in section 2. Various datasets are included, both as published in journals and conference papers, as well as those from web sites.

a. Zimbabwe

Of particular note for estimating the tropical African fatality rate is the Zimbabwe value of 14.2 or `21.4 deaths per million (Table 11). Chitauro (1990) quotes 150 deaths in one year, while in the same publication, Van Olst (1990) quotes 100 deaths in a year. The differing estimates indicate the difficulty in acquiring accurate data on lightning deaths in many countries. In 1976, the rural population of Zimbabwe was 80%, which is higher than in the US in the early 20th century (Figure 1), when the death rate was as high as 6.3 deaths per million. While the Zimbabwe fatality rate is high, it is not entirely inconsistent with the early rural US rate.

b. China

The lightning death rate in China can affect the worldwide rate since the country is so populous. However, there are no complete records in China, so partial national datasets are considered in Table 11:

- Ming et al. (2007) reported an average of 420 deaths and 412 injuries in China from 1997 to 2005. Note that the ratio of injuries per death of 1.0 is likely to indicate an underreporting of injuries, based on recent intensive US studies of medical records that show around 10 injuries per death (Cherington et al. 1995; Curran et al. 2000). The lower number of injuries than expected may also indicate an underreporting of fatalities in the same data collection. Using these data, the national annual rate is 0.3 fatalities per year.
- A 2006 news report stated that 82 deaths had occurred in June that year (Table 11). Assuming that June represents 20% of the annual total, the annual amount is 410 deaths for the country, a value that is quite consistent with Ming et al. (2007), since the same database may have been referenced. The result is the same annual rate of 0.3 deaths per million.
- A 2005 news report stated that "About 3000 to 4000 Chinese are killed or injured by lightning each year…" Assuming that one injury occurred for each death, as found by Ming et al. (2007), a total of 1750 deaths per year is obtained, which corresponds to a higher national annual rate of 1.3 fatalities per million in China. Additional reports from 2007 stated that 499 to 659 people were killed in August through early September of that year. All fatalities were described as villagers, and 79% were identified as working in fields.
- A 2007 news report stated that 141 people died from lightning in July 2007. Assuming that July represents 25% of the annual total, the annual total of 564 deaths for the country leads to an annual rate of 0.4 deaths per million.

c. Europe

Four 19th century national reports are included in Table 11 from one publication (Anderson 1879). All of the following death rates are high, and were collected when these countries were mainly rural:

- Bavaria reported 1355 deaths from 1843 to 1873, an average of 44 deaths per year. This total corresponds to an annual rate of 8.7 deaths per million people.
- European Russia reported 2161 deaths from 1870 to 1874, an average of 432 deaths per year. This total corresponds to an annual rate of 6.2 lightning deaths per million people.
- Prussia reported 1004 deaths from 1869 to 1877, an average of 112 deaths per year. This total corresponds to an annual rate of 4.3 deaths per million people.
- Switzerland reported 33 deaths in 1876 and 1877, corresponding to an annual rate of 6.0 deaths per million people.

In Europe during the 20th and 21st centuries, several countries have had single values provided in various sources, as follows:

- Austria: Deaths were noted in Golde and Lee (1976) from a 10-year summary previously published in German for Austria in 1971. The annual rate is 0.6 per million for 1960-1970, while Pakiam et al. (1981) includes an annual fatality rate of 1.3 per million for a shorter period from 1964 to1968.
- Hungary: Deaths were noted in Golde and Lee (1976) from a 10-year summary previously published in German for Hungary in 1962. The annual death rate is 0.5 per million from 1950 to 1960.
- The German Federal Republic is quoted to have an annual fatality rate of 0.8 per million from 1952 to 1960 (Pakiam et al. 1981).

- Ireland had a rate of 0.1 deaths per million people per year from 1954 to 1973 (Baker 1984).
- Lithuania has an annual death rate of 0.5 based on recent data (Galvonaite, 2004). This report stated that one to three casualties occur per year. Assuming an average of two casualties per year, and that one-fourth of reported casualties are deaths, an annual average of 0.5 deaths was concluded, which corresponds to an annual fatality rate of 0.1 per million.

d. Additional countries

Other single-period national data that provide lightning fatality rates in Table 11 are as follows:

- Bangladesh (0.9) and Sri Lanka (2.4) annual fatality rates are higher than in the more developed countries (Gomes et al. 2006). However, they appear to be lower than expected in terms of the number of deaths reported in anecdotal news reports (Holle and López 2003).
- India had 473 lightning deaths from 1982 through 1989 (Nizamuddin 1992). The number of fatalities ranged from 117 in 1983 to 28 in 1987. The resulting annual fatality rate of 0.1 deaths per million people seems very low in view of several factors. First, at least two thirds of the population of India lived in rural areas during this period. Second, the author of the study commented that "…the majority of the lightning deaths occurred in the countryside". Finally, a report for a portion of one year in the state of Orissa (Table 12) found an annual rate of 2.5 deaths per million. Since India is so populous, a better determination of its rate has a major effect on the lightning death rate worldwide.
- Malaysia has an estimated 100 to 150 lightning deaths per year, according to a lightning researcher in the country (personal communication). Using 125 per year, an annual rate of 3.4 deaths per million people is obtained.
- Nepal: "Lightning killed 40 villagers in the southeastern Nepal" according to Agence France-Presse on 17 December 2004. A conservative extrapolation to a total of 100 for the entire country for the whole year results in an annual rate of 2.7 deaths per million people.
- South Africa is reported in an online article dated 26 May 2006 by Creamer Media Engineering News as having an annual rate during four recent years of 8.8 deaths per million people in rural regions, and 1.5 in urban areas. No actual numbers for fatalities were provided in the online article, only the rates. The value of 1.5 has also been quoted from 1963 to 1969 (Pakiam et al. 1981). Note in Table 12 that the Highveld region of South Africa was identified as having an annual rate of 6.3 lightning fatalities per million people.
- Vietnam casualties were in a 2003 report by Associated Press that "In Vietnam, dozens of people are killed or injured by lightning each year during the rainy season, which starts in May." While somewhat informative, the definition of dozens is unclear. Using a total of 100 deaths results in an annual death rate of 1.2 per million people. This value is much lower than found for Bac Lieu province (Table 12).

4. REGIONAL LIGHTNING FATALITY RATES

In addition to rates for entire countries, some samples have been published that pertain to large regions within a country (Table 12).

a. China

The estimates for provinces in China are as follows (Table 12):

- Ming et al. (2007) list the fatality rates for 31 regions in China from 1997 to 2005. As mentioned in section 3b, Ming et al. (2007) found one casualty per death for the entire country. Two assumptions were used to interpret the regional results in Ming et al. (2007). The factor of two was used, then an additional correction factor of 10 appears to be appropriate to apply to regional casualty rates per million in Table 1. With these two assumptions, the lowest annual rates are 0.1 deaths per million in nine of the 31 regions. Rates exceed 1.0 in three regions, and are as high as 1.9 in the Hainan region.
- Guangdong province is reported to have had 74 deaths per year from 2000 to 2004 (Zhihui et al. (39). The resulting annual death rate is 0.9 per million people. This same rate was obtained from a Reuters news report of 14 July 2006, where 82 people were identified as killed by lightning in June 2006. Assuming that June provides 20% of the deaths for the year, the result is an annual fatality rate of 0.9 per million in the province. Ming et al. (2007) show a similar value of 0.8 for Guangdong, using the above assumptions.
- Guizhou province was reported on a Chinese website to have had 22 deaths in 2004 by 9 July. The total of 44 deaths extrapolated to the entire year results in an annual rate of 1.2 deaths per million. Ming et al. (2007) show 0.9 for Guizhou, using the above assumptions.
- Hainan province was reported on a Chinese website to have had 36 deaths through June 2001; a total of 80 was estimated for the year. The resulting death rate of 10.6 per million is very high, and may be partly explained by the statistic that the province is currently 80% rural. Ming et al. (2007) show and annual rate of 1.9 per million for Hainan, the highest rate for any region, using the above assumptions.

TABLE 11. Annual lightning deaths per million people for single periods by country, and references. Deaths in parentheses are estimated from partial datasets.

Country	Year(s)	Fatalities	Death rate	References
Austria	10	48	0.6	Golde and Lee (1976)
	5	Not stated	1.3	Pakiam et al. (1981)
Bangladesh	2005	133	0.9	Gomes et al. (2006)
Bavaria	1843-1873	1355	8.7	Anderson (1879)
China	1997-2005	3776	0.3	Ming et al. (2007)
	2004	(875)	0.7	Xinhua News Agency website (2005)
	2006	(410)	0.3	Reuters (2006)
	2007	(564)	0.4	BBC News (2007)
European Russia	1870-1874	2161	6.2	Anderson (1879)
German Federal Republic	1952-1960	Not stated	0.8	Pakiam et al. (1981)
Hungary	10	6	0.5	Golde and Lee (1976)
India	8	473	0.1	Nizamuddin (1992)
Ireland	20	7	0.1	Baker (1984)
Lithuania	Recent	0.5	0.1	Galvonaite (2004)
Malaysia	Recent	100-150	3.4	Personal communication
Nepal	2004	(100)	2.7	Agence France-Presse (2004)
Prussia	1869-1877	1004	4.3	Anderson (1879)
South Africa	1963-1969	Not stated	1.5	Pakiam et al. (1981)
	4	Not stated	8.8 rural 1.5 urban	Creamer Media Engineering News (2006)
Sri Lanka	2003	49	2.4	Bandara (2004), Gomes et al. (2006)
Switzerland	1876-1877	33	6.0	Anderson (1879)
Vietnam	Recent	Dozens	1.2	AP news (2003)
Zimbabwe	Recent	150	21.3	Chitauro (1990)
		100	14.2	Van Olst (1990)

- Yunnan province was reported on a Chinese website to have had 25 deaths through June 2007. Extrapolating to the entire year, an annual rate of 1.4 deaths per million is found. Ming et al. (2007) show 1.0 for Yunnan, using the above assumptions.
- In contrast, the Hong Kong Observatory reported 6 deaths in 15 recent years, for an annual fatality rate of less than 0.1 per million people. Since Hong Kong is highly urban, such a low rate is consistent with the assumption that lightning death rates are less in such regions.

b. Other Countries

Sample rates have been published for large regions within some countries (Table 12):

- Brazil: The Sao Paul metropolitan area was identified as having 20 strikes to people during January and February 2001 (Amorim et al. (2005). Assuming that 5 of these 20 are deaths, and the annual total is 15 deaths, the resulting annual death rate is 0.8 per million.
- India: The northeast province of Orissa was quoted in the *Times of India* on 5 June 2006 as having 45 lightning deaths in the prior three months. A value of 90 was assumed for the year in this rural region, which results in an annual death rate of 2.5 per million. This rate is higher than the value of 0.1 deaths per million per year that was shown in Table 11 for the entire country of India.
- South Africa: The predominantly urban Highveld region has a rather high annual rate of 6.3 lightning deaths per million (Blumenthal 2003, 2005). This value is consistent with the online quote described in Table 11 as being 8.8 in rural areas and 1.5 in urban regions.
- Spain: The province of Navarra from 1950 to 1999 had an annual fatality rate of 0.9 per million (Aguado et al. 2000). This 50-year rate is consistent with the national rate for Spain that decreased from 2.6 deaths per million people in the 1950s to 0.2 in 1991 (Table 9).
- Vietnam: The southern coastal province of Bac Lieu was quoted as having 7 deaths per year, for an average annual death rate of 8.8 per million. The report from Associated Press quoted the director of the provincial flood and storm control bureau on a web site dated 24 May 2005. This rate may reflect both labor-intensive agriculture and structures unprotected from lightning. Note a lower national rate of 0.9 reported for Viet Nam (Table 11).
- Yemen: The Saada governorate of Yemen was reported on 30 August 2005 in the *Yemen Observer* to have had 13 lightning deaths in the previous week. An extrapolated value of 50 deaths in one year results in an extraordinarily high rate of 71.4 deaths per million people. It is unknown if the 13 deaths are anomalous or if the extrapolation is incorrect.

TABLE 12. Annual lightning deaths and deaths per million people for regions of countries, and references. Deaths in parentheses are estimated from partial datasets.

Country	Year(s)	Fatalities	Death rate	References
Brazil				
Sao Paulo	2001	(15)	0.8	Amorim et al. (2005)
China				
31 regions	1997-2005	10 to 701	0.1-1.9	Ming et al. (2007)
Guangdong	2000-2004	370	0.9	Zhihui et al. (2006)
Guizhou	2004	(44)	1.2	Xinhuanet.com website (2004)
Hainan	2001	(80)	10.6	Xinhua News Agency website (2001)
Hong Kong	15	50	0.04	Hong Kong Observatory website (2005)
Yunnan	2007	(60)	1.4	China Economic Net website (2007)
India	2006	(90)	2.5	*Times of India* website (2006)
Orissa				
South Africa	1997-2000	38	6.3	Blumenthal (2003, 2005)
Highveld				
Spain	1950-1999	16	0.6	Aguado et al. (2000)
Navarra				
Viet Nam	Recent	7	8.8	Director, provincial floods and storms control bureau
Bac Lieu				
Yemen	2005	(50)	71.4	*Yemen Observer* website (2005)
Saada				

5. COMBINED RESULTS BY CENTURY

a. 19th century

Table 13 and Figure 2 combine the 19th century fatality rates. Data were available during the 19th century for eight countries in Europe and Australia, as described in sections 2 and 3.

While there is a wide range, the median decadal value in these countries in the 19th century was in the range of 3 deaths per million people per year. Rates over 4 deaths per million per year for a decade in a country were not unusual. Note that most countries in Table 13 were in Europe, which has less lightning than many tropical regions of the world. Rates were higher in some regions during quite a few decades. Rates were usually lower in England and Wales.

In general, the 19th-century populations in these countries lived in rural areas and had agricultural occupations. In addition, homes and workplaces had little to no protection provided by wiring and plumbing that serve to provide safe places for people inside them when lightning struck buildings.

TABLE 13. Lightning deaths per million people per year for eight countries by decade during 19th century.

Decade	Australia	Bavaria	England and Wales	European Russia	France	Prussia	Sweden	Switzer-land
1810-1819	M	M	M	M	M	M	5.2	M
1820-1829	3.5	M	M	M	M	M	2.9	M
1830-1839	0.0	M	M	M	2.0	M	3.6	M
1840-1849	3.1	8.7	M	M	2.0	M	2.8	M
1859-1859	4.0	8.7	1.0	M	2.2	M	3.4	M
1860-1869	2.2	8.7	0.6	M	3.0	4.3	2.6	6.0
1870-1879	1.5	8.7	1.0	6.2	3.1	4.3	3.0	M
1880-1889	1.3	M	M	M	3.3	M	M	M
1890-1899	1.2	M	M	M	3.5	M	M	M

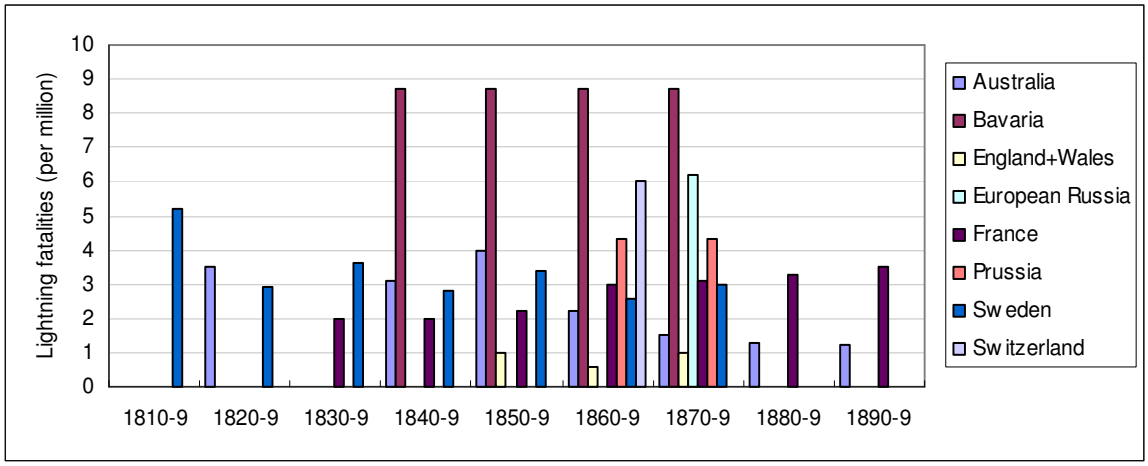

FIGURE 2. Lightning deaths per million people per year for eight countries in Europe by decade during 19th century, taken from Table 13.

b. 20th century

Fatality rates are combined for the 20th century in Tables 14 and 15, and Figures 3 and 4. Data were available in this century for eight countries in Europe and eight more in the rest of the world, based on data in sections 2 and 3.

Table 14 and Figure 3 summarize decadal rates during the 20th century for eight countries in Europe. Most rates are quite low, especially in the latter half of the century. While there is a wide range, the median annual rate in Europe is in the range of 0.3 deaths per million. This value represents a ten-fold reduction since the typical range of 3 fatalities per million per year during the 19th century in Europe (Table 13). The rates for Spain in Table 14 and Figure 3 include the regional annual rate of 0.6 fatalities per million for Navarra, Spain (1950-1999) from Table 12 averaged with national data for Spain in Table 9.

Table 15 and Figure 4 summarize decadal rates from eight countries outside Europe during the 20th century. During the first half of the 20th century in the more developed countries of Australia, Canada, Japan, Singapore, and the US, the typical annual rate was around 2 deaths per million. During the last half of the 20th century, the developed countries have had a median annual value of around 0.4 deaths per million. This value is similar to the rate of 0.3 late in the 20th century in European countries. However, recent rates in South Africa and Zimbabwe are quite high, and may be representative of lesser developed regions of the world. The regional annual rate of 6.3 deaths per million people in Table 12 for the Highveld of South Africa (1997-2000) was included in Table 15.

TABLE 14. Lightning deaths per million people per year for eight countries in Europe, and regions of European countries by decade during 20th century.

Decade	Austria	England and Wales	France	German Federal Republic	Ireland	Greece	Hungary	Spain
1900-1909	M	0.4	3.7	M	M	M	M	M
1910-1919	M	0.4	M	M	M	M	M	M
1920-1929	M	0.2	M	M	M	M	M	M
1930-1939	M	0.3	M	M	M	M	M	M
1940-1949	M	0.2	M	M	M	M	M	2.0
1950-1959	M	0.2	M	0.8	0.1	M	0.5	1.6
1960-1969	1.0	0.1	0.5	M	0.1	M	M	1.1
1970-1979	M	0.1	0.4	M	0.1	M	M	0.6
1980-1989	M	M	0.2	M	M	M	M	0.6
1990-1999	M	M	M	M	M	0.5	M	0.2

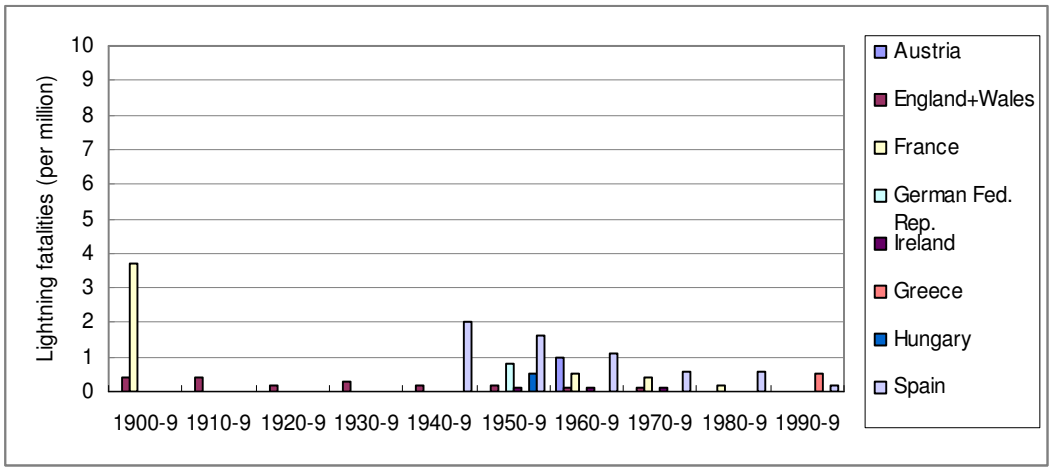

FIGURE 3. Lightning deaths per million people per year for eight countries in Europe by decade during 20th century, taken from Table 14.

TABLE 15. Lightning deaths per million people per year for eight countries outside Europe by decade during 20th century.

Decade	Australia	Canada	India	Japan	Singapore	South Africa	United States	Zimbabwe
1900-1909	1.7	M	M	M	M	M	4.8	M
1910-1919	2.1	M	M	M	M	M	4.5	M
1920-1929	1.3	2.2	M	M	3.2	M	4.1	M
1930-1939	1.4	2.1	M	M	1.2	M	3.2	M
1940-1949	0.5	1.6	M	M	1.5	M	2.4	M
1950-1959	0.5	0.8	M	0.3	1.7	M	1.1	M
1960-1969	0.2	0.4	M	0.3	1.8	1.5	0.7	M
1970-1979	0.2	0.4	M	0.2	1.5	M	0.5	M
1980-1989	0.1	0.2	0.1	0.1	M	M	0.4	17.8
1990-1999	M	0.2	M	>0	M	6.3	0.2	M

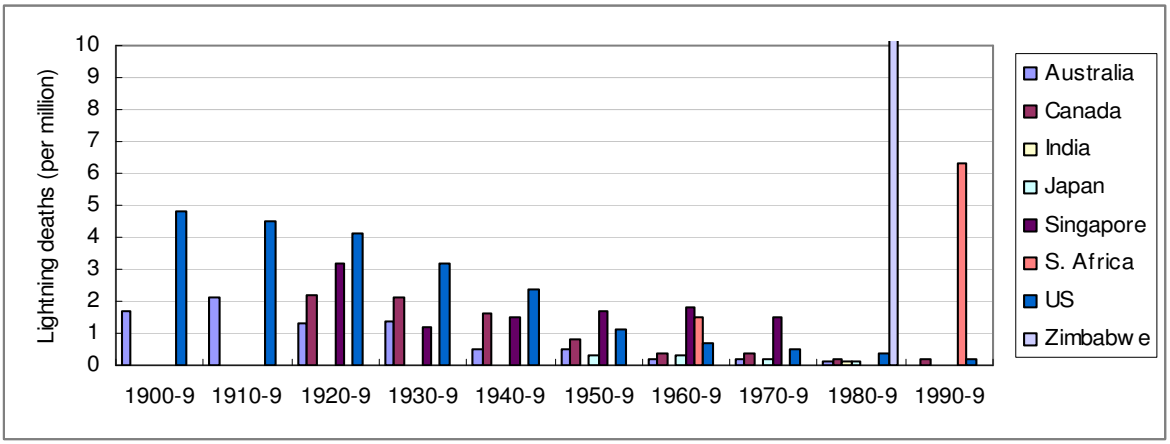

FIGURE 4. Lightning deaths per million people per year for eight countries outside Europe by decade during 20th century, taken from Table 15. Note that 1990s Zimbabwe value is 17.8.

c. 21st century

Table 16 combines results for 15 countries in several previous tables into one 21st-century list beginning in 2000. National data are provided first, when available, followed by regional results from Table 12. The same rates are repeated in both columns of Table 16 when only one year of data, or one number for several years was provided by several sources.

There is wide variation among the most recent data. Some countries and regions have annual rates as low as 0.1 to 0.2 fatalities per million people, or lower. Many of these lower rates are in Europe and North America and other more developed countries, and their rates have been decreasing for over a century.

However some low rates are also included for more rural agricultural areas such as Bangladesh and China, which appear to represent incomplete data collection. At present, high rates of lightning deaths are found from very limited data in Africa and some portions of Asia. Lightning frequencies are also high in these regions, and the population is often rural, oriented toward agriculture, and living or working in structures that often are not safe from lightning. The lack of current reliable data for these populous regions is a significant gap for this study.

TABLE 16. Annual lightning deaths per million people during the first decade of the 21st century. National rates are followed by regional rates when available.

Country	Decadal fatality rate	Maximum annual rate
Bangladesh	0.9	0.9
Brazil (Sao Paulo)	0.8	0.8
Canada	0.1	0.3
China	0.5	0.7
Guangdong	0.9	0.9
Guizhou	1.2	1.2
Hainan	10.6	10.6
Hong Kong	0.04	0.04
Greece	0.2	0.4
India (Orissa)	2.5	2.5
Lithuania	0.1	0.1
Malaysia	3.4	3.4
Nepal	2.7	2.7
South Africa	8.8 rural	8.8 rural
	1.5 urban	1.5 urban
Sri Lanka	2.4	2.4
Vietnam	1.2	1.2
Bac Lieu	8.8	8.8
United States	0.2	0.2
Yemen (Saada)	71.4	71.4
Zimbabwe	14.2	14.2

6. DISCUSSION

At this point, it is appropriate to include the table in Holle and López (2003) that listed the assumptions relating to the estimate of 24,000 worldwide annual lightning deaths. The Holle and López (2003) table is repeated here as Table 17 (numbers have been added to the factors). As mentioned in the introduction, the annual rate of 6 deaths per million was assumed to apply to four billion people, which gives an annual worldwide result of 24,000 fatalities.

The present study attempted to address factor number 2 in Table 17, that of the 6 per million rate per year. Unfortunately, the results from sections 1 to 5 of the present study do not provide a definitive answer that can accept or reject this rate. Quite a few more developed regions support a lower rate, while others show 6.0 to be a candidate to consider. The lightning fatality rate information continues to be missing for the most heavily-populated areas of the world with high lightning frequencies in Africa, Southeast Asia, and the Indian subcontinent.

Substantial numbers of deaths are often reported in anecdotes from lesser-developed countries such as in Holle and López (2003) and other sources. Nearly all recent multiple-casualty events in those areas occur during labor-intensive agriculture, or when people seek safety inside homes, schools, and other buildings and small structures that provided inadequate or no protection from lightning. These incidents are consistent with factors 3, 4, 8, and 9 in Table 17.

TABLE 17. Factors that can change the estimate of 24,000 worldwide lightning fatalities per year, except to add numbers to the factors (Holle and López 2003, Table 3).

Factor	Change	Impact on number of deaths
1. Area of high lightning frequency	Too small Too large	Increase Decrease
2. Fatality rate of 6 deaths per million people	Too low Too high	Increase Decrease
3. Rural-agricultural setting of people in high lightning areas compared to US and western Europe in 1900	More rural Less rural	Increase Decrease
4. Buildings occupied by people in high lightning areas compared to US and western Europe in 1900	Less substantial More substantial	Increase Decrease
5. Fatalities in areas outside Table 1 regions	Add areas	Increase
6. Organized recreational sports compared to US and western Europe in 1900	More	Increase
7. Meteorological forecasts and warnings	Improved	Decrease
8. Awareness of the lightning threat through education, planning and detection	Enhanced	Decrease
9. Medical care and emergency communications	Enhanced	Decrease
10. Other socioeconomic changes	Unknown	Unknown

7. CONCLUSIONS

The lightning fatality rate in Australia, Canada, Europe, Japan, and the US has dropped by an order of magnitude, or more, from the 1800s to the present. Death rates were typically 3 per year per million people in the 1800s in these more developed countries, while it is now on the order of 0.3 deaths per million per year. This order-of-magnitude reduction coincides with a major population shift from rural to urban areas and away from labor-intensive agriculture, as well as the occupancy of substantial buildings, better forecasts and awareness of weather and lightning, improved medical care and emergency communications, the widespread availability of fully enclosed metal-topped vehicles, and other unknown factors. Since most of these middle-latitude regions do not have especially high lightning frequencies, a higher rate could be considered to apply to other areas.

The suggestion was made in Holle and López (2003) that an annual rate of 6 deaths per million was appropriate for rural agriculturally-dominated areas with little protection inside unsubstantial buildings that may be common in those regions. The recent data for lesser developed countries are incomplete in time

and space. Some high rates have been reported in Africa, Asia, and India where such rates might be expected due to frequent lightning occurrence. However, there are also some very low rates that show indications of being due to data collection inadequacies. One of the more reliable indicators of data quality is the ratio of injuries to deaths, which is on the order of 10 to 1 when lightning casualties are very well documented.

An original question of the present paper was to examine whether it was possible to attribute an annual rate of 6 lightning-caused deaths per million people to a large population of the world. While a lower lightning death rate of 0.3 can be applied to more developed regions, the higher rate is less clear. While no single rate for lesser developed countries is evident in the available data, an annual rate of 6 deaths per million people in Africa and Asia continues to be a number to consider as a starting point. The other issue is to how many people this rate should be applied. As shown for China and South Africa (Table 16), there are high rates in mainly rural regions, while the rate is very low in urban areas.

For the lack of better information, the estimate of 6 deaths per million per year continues to be a candidate for the appropriate rate that can be modified in the future with better information. If this rate applies to 4 billion people (Holle and López 2003), the resulting worldwide estimate continues to be 24,000 deaths and 240,000 injuries worldwide from lightning every year. The collection of lightning fatality totals over long periods is encouraged on a national basis in order to investigate the validity of these estimates.

Acknowledgments

The author appreciates the national fatality data contributed from personal notes by researchers around the world. The author is responsible for any misrepresentations or omissions that may have occurred in published or unpublished data. Some results are from collaborative studies with Dr. R.E. López of the National Severe Storms Laboratory; this study may not have taken place without his initiative.

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