P2.54 LIGHTNING FATALITIES IN TROPICAL AND SUBTROPICAL REGIONS

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ABSTRACT

The number of lightning fatalities has decreased by an order of magnitude in some countries during the last few decades, but not others. In more developed areas, people live and work in grounded buildings, are often near fully-enclosed metal-topped vehicles, and relatively few people work outside in labor-intensive agriculture. In contrast, people in many countries of the world, particularly in tropical and subtropical regions, continue to subsist on labor-intensive agriculture, and spend much of the rest of their time inside unsubstantial buildings that are not safe from lightning.

In the U.S. and other more developed regions, typical lightning death rates are less than 0.6 deaths per million people per year. This rate has applied to the U.S. and other middle-latitude regions for 25 years or more. Nevertheless, it should be pointed out that U.S. lightning fatalities have equaled or exceeded U.S. hurricane fatalities in 18 of the last 20 years.

In lesser-developed countries, the rate may be as high as six deaths per million per year, which is similar to the U.S. rate a century ago during some years. Using this annual rate of six lightning fatalities per million, a worldwide estimate is 24,000 lightning deaths and 240,000 lightning injuries per year.

High lightning fatality rates have been reported in some informal publications and news reports from Africa, Southeast Asia, and India. Such high rates might be expected due to frequent lightning occurrence in rural portions of those areas, and due to inadequate places for safety from lightning. Substantial numbers of deaths are often reported in specific cases from lesser-developed countries. However, there are also some very low reported rates that may be due to data collection inadequacies. The collection of lightning fatality totals over long periods is encouraged on a national basis in order to investigate the validity of these estimates.

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1. INTRODUCTION

The annual number of lightning deaths has been compiled in the U.S. since 1900, and other developed countries for extensive 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 0.6 deaths per million people applies to more developed countries with substantial buildings and dwellings, decreasing labor-intensive agricultural labor, ready availability of fully-enclosed metal-topped vehicles, and additional factors. 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 ideally from entire countries for long periods. But there are more variable-quality data from regions within countries for shorter periods that have been extrapolated to a national rate for some countries.

Only fatalities are considered, since prior publications studied lightning fatalities but usually not injuries. Annual fatality rates were matched with populations for the same years. 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 are 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 is on the order of 10 to 1 based on an intensive search of Colorado medical records (Cherington et al. 1999). The U.S. ratio has increased from two reported injuries per reported death in 1960 to eight in recent years as data collection continues to improve in NOAA's *Storm Data* (Curran et al. 2000).

2. LIGHTNING FATALITY RATES BY COUNTRY OVER MULTIPLE DECADES

Section 2 reviews all known published lightning fatality rate data for periods longer than one decade. Some records date back to the early 19th century. Most information is from more developed countries that were rural agriculturally-dominated regions, but now are more urban with the widespread availability of lightning-safe buildings and vehicles. Fatality rate data for periods shorter than a decade are in section 3.

2.1. U.S. 20th century trend

Since 1900, Figure 1 shows the annual U.S. 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 over an order of magnitude in the U.S. population-weighted fatality rate during the 20th century.

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

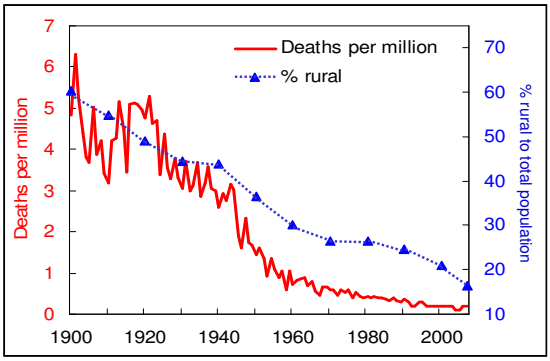

FIGURE 1. Annual time series for the U.S. from 1900 to 2007. Red line shows lightning deaths per million people, and dashed line shows percent rural population (updated from López and Holle 1998).

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,
- 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 nearby access to the protection provided by fully-enclosed metal-topped vehicles (Holle 2007).

Large substantial buildings, where people now live and work in more developed countries, provide significant protection to people inside them (Holle 2009). 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 are usually very safe from lightning as long as they 1) can escape house fires initiated by lightning at night, and 2) are not in direct contact with the conducting paths of electrical, telephone and cable wiring, as well as plumbing. Fully-enclosed metal-topped vehicles are also very safe from lightning although the impacts can be large on vehicles.

b. Multi-decadal trends by country

Published studies of national lightning fatality rates are now described. Decadal trends will be presented by country in alphabetical order after U.S. data are shown.

1. United States: From 1900 through 2008 (Figure 1), the maximum annual rate for a 10-year period was 4.8 deaths per million people during the first decade of the 20th century, and the maximum single-year death rate was 6.3 per million. The decadal fatality rate is now 0.2 per million. Annual fatalities ranged from greater than 450 in the earlier part of the 20th century to less than 40 in some recent years. Figure 2 shows that lightning fatalities have equaled or exceeded U.S. hurricane fatalities in 18 of the last 20 years.

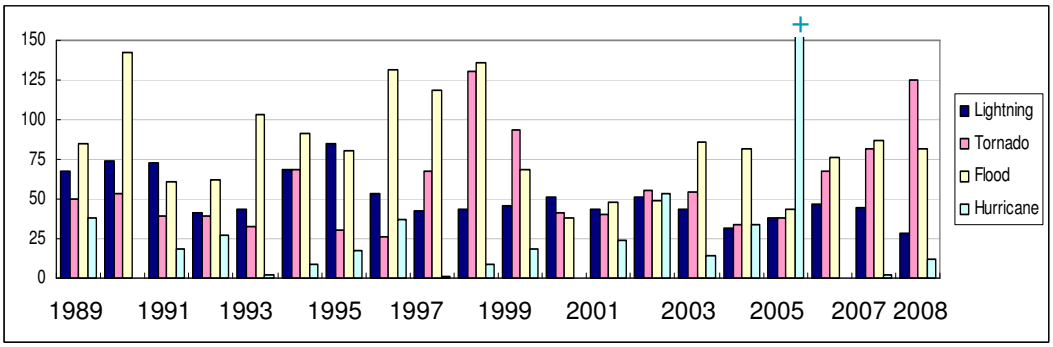

FIGURE 2. U.S. storm-related fatalities from 1989 through 2008 from the NOAA publication Storm Data. *The + sign indicates that hurricane Katrina had 1016 fatalities in 2005.*

2. Australia: A long record from Australia is from Golde and Lee (1976) and Coates et al. (1993). The Coates study provides the longest known single lightning fatality record in the world, and states that "Prior to 1910 the death totals are underestimated…" The same broad decline over the long period of record is found for Australia as in the U.S. Annual fatalities ranged from zero in some years to 17 in 1918. Similar to the U.S., annual rates were much higher in earlier years than now. Starting in the 20th century, rates are lower than in the U.S. for the same decades; expanded results are in Holle (2008).

3. Canada: Hornstein (1962) and Mills et al. (2006) found a similar reduction in Canada as in the U.S. and Australia during the 20th century. The annual fatality rates for corresponding years are less than in the U.S., which can be expected due to the shorter thunderstorm season at the higher latitude of Canada.

4. England and Wales: Four publications record the decadal fatality rates since 1852 (Baker 1984; Elsom 2001; Golde and Lee 1976; Lawson 1889). The lightning fatality rates beginning in the 19th century are quite low, but show the same decrease as the previous countries.

5. France: Flammarion (1904) and Gourbière (1998) also show a slow decrease since the early 19th century. Some 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 for Australia and the U.S. The population of France during those years was two-thirds rural.

6. Japan: Decadal data from Japan are based on annual fatality values kindly provided by Dr. Nobu Kitagawa (personal communication) on behalf of N. Kitagawa, M. Ohashi, and T. Ishikawa. The rates are generally lower than elsewhere, and have decreased in recent years to less than 0.1 per million people per year.

7. Singapore: For this tropical region with a relatively high lightning frequency, Pakiam et al. (1981) compiled decadal data from Singapore since the 1920s. The rates beginning in the early 20th century are almost as high as in the U.S. during the same years. The rates have decreased since then, but not as much as those in the previously-listed countries. The most recent decadal rate for the 1970s in Pakiam et al. (1981) is 1.5 deaths per million per year.

8. Spain: Data for Spain since 1941 indicate a rate in recent years that is quite similar to the U.S. However, the fatality rate was higher (>2.0) in earlier decades of the 20th century, apparently due to a delayed migration from rural to urban settings compared with the U.S. (López and Holle (1996).

9. Sweden: Data for Sweden extend back to 1816, earlier than any other dataset (Anderson 1879). The annual fatality rates per million were relatively high through the 19th century, ranging from 2.6 to 5.2 per decade. Individual years had annual rates as high as 12.5 per million. This is an important indication of the lightning rate in a mainly rural country before the introduction of lightning-safe buildings and vehicles. Also note that the lightning frequency in Sweden is very much lower than in tropical and subtropical areas.

In summary, lightning fatality rates have decreased substantially since the 19th century in the countries described above. They are mainly more developed countries that have transitioned from rural agriculturally-dominated regions to having urban populations with widespread availability of lightning-safe buildings and vehicles.

3. LIGHTNING FATALITY RATES BY COUNTRY FOR LESS THAN A DECADE

Additional lightning fatality rates are available for shorter periods up to a decade. Longer periods were reviewed in section 2.

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. Chitauro (1990) quotes 150 deaths in one year, while Van Olst (1990) quotes 100 deaths in a year in the same publication. 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 U.S. in the early 20th century, when the death rate was as high as 6.3 deaths per million. While the Zimbabwe fatality rate is high, it is consistent with the early U.S. rate.

b. China

The lightning death rate in China can affect the worldwide value since the country is so populous. Since there are not yet any complete published records for China, two partial datasets are considered:

- A 2005 news report stated that "About 3000 to 4000 Chinese are killed or injured by lightning each year…" The assumption can be made that three injuries occurred for each death, since deaths are often reported more often than injuries. Assuming 3500 deaths per year and this injury ratio, a rate of 0.7 fatalities per million per year in China is obtained. The extent of underreporting is unknown, so these approximations make 0.7 very tentative.
- A 2006 news report stated that 82 deaths had occurred in June that year. Assuming that June represents 20% of the annual total, the annual amount is 410 deaths for the country, resulting in a rate of 0.3.

c. Europe

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

- Bavaria from 1843 to 1873 had an annual rate of 8.7 deaths per million people.
- European Russia from 1870 to 1874 had an annual rate of 6.2.
- Prussia from 1869 to 1877 had an annual rate of 4.3.
- Switzerland in 1876 and 1877 had an annual rate of 6.0.

In Europe during the 20th and 21st centuries, several countries had the following fatality rates:

- Austria from 1960-1970 had an annual rate of 0.6 (Golde and Lee 1976), and 1.3 from 1964 to1968 (Pakiam et al. 1981).
- Hungary from 1950 to 1960 had an annual rate of 0.5 (Golde and Lee 1976).
- The German Federal Republic from 1952 to 1960 had a rate of 0.8 (Pakiam et al. 1981).
- Ireland from 1954 to 1973 had a rate of 0.1 (Baker 1984).

d. Tropical and subtropical countries

Single-period national data in tropical and subtropical countries that provide lightning fatality rates 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.
- India had 473 lightning deaths from 1982 through 1989 (Nizamuddin 1992). The resulting annual fatality rate of 0.1 seems very low. 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 found an annual rate of 2.5.
- 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 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.
- 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 in rural regions, and 1.5 in urban areas. The value of 1.5 was also quoted from 1963 to 1969 (Pakiam et al. 1981). Note that the Highveld region of South Africa was identified as having an annual rate of 6.3.
- Vietnam casualties were in a 2003 report by Associated Press that "…dozens of people are killed or injured by lightning each year during the rainy season, which starts in May." Using a total of 100 deaths, the result is an annual death rate of 1.2. This value is much lower than 8.8 found for Bac Lieu province (section 4).

4. REGIONAL LIGHTNING FATALITY RATES

Lightning fatality rates for entire countries across multiple decades were shown in section 2, and for countries during less than a decade were in section 3. There are also some samples that are available for large regions within a country.

a. China

- Guangdong from 2000 to 2004 (Zhihui et al. 2006) had an annual fatality rate of 0.9 per million people. This is the same rate as can be obtained from a Reuters news report of 14 July 2006.
- Guizhou province data were reported on a Chinese website on 9 July 2004. When extrapolated to the entire year, the result is an annual rate of 1.2.
- Hainan province data were reported on a Chinese website through June 2001. The result is a very high rate of 10.6 per million. and could be partly explained by the statistic that the province is currently 80% rural.
- The Hong Kong Observatory, in contrast, reported an annual rate of less than 0.1 for this area. Since Hong Kong is a highly urban area, such a low rate is consistent with the assumption that lightning death rates are less in such regions.

b. Other Countries

In other countries, some samples have been published that pertain to large regions within a country. The assumptions made with limited data after extrapolation are described in Holle (2007). The following are the results of these more limited samples:

- Brazil: The Sao Paul metropolitan area was identified to have an annual death rate of 0.8 (Amorim and Morales 2005).
- India: The northeast province of Orissa was quoted in the *Times of India* on 5 June 2006 can be extrapolated to have a rate of 2.5. This rate is higher than the 0.1 that was shown in the previous section for all 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 section 3 as 8.8 in rural areas and 1.5 in urban regions.
- Vietnam: The southern coastal province of Bac Lieu was quoted in the Associated Press on 24 May 2005 as having an average annual death rate of 8.8. This high rate may reflect the combination of labor-intensive agriculture and structures unprotected from lightning in this province. Note that a lower national annual rate of 0.9 deaths per million was reported for all of Viet Nam in section 3.
- 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.

5. COMBINED RESULTS BY CENTURY

a. 19th century

Figure 3 combines the available 19th century fatality rates in Europe and Australia. Details are in sections 2 and 3 and Holle (2008).

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 were in Europe, which has less lightning than many tropical regions of the world.

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. These features make the 19th-century data important to consider for tropical and subtropical regions.

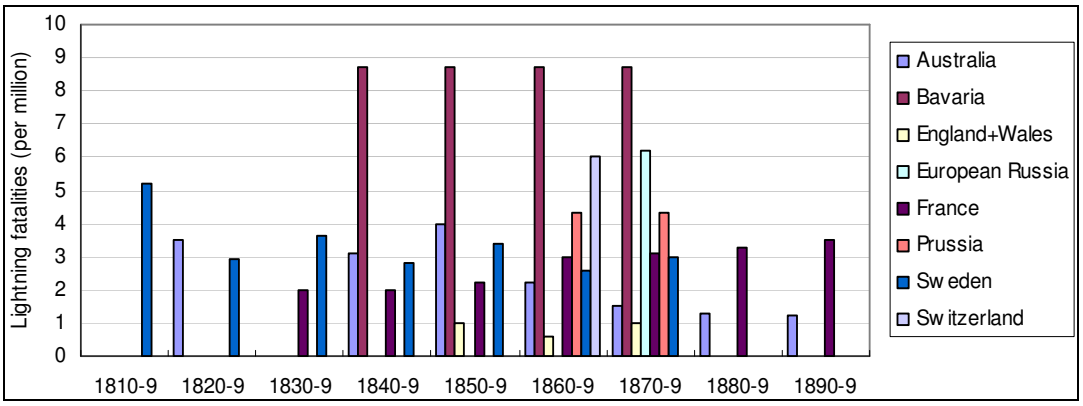

FIGURE 3. Lightning deaths per million people per year for eight countries in Australia and Europe by decade during 19th century.

b. 20th century

Fatality rates are combined for the 20th century in Figures 4 and 5. 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 and Holle (2008).

Figure 4 summarizes 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 and Australia (Figure 3).

Figure 5 summarizes 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 U.S., the typical annual rate for full decades 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 tropical and subtropical regions of the world.

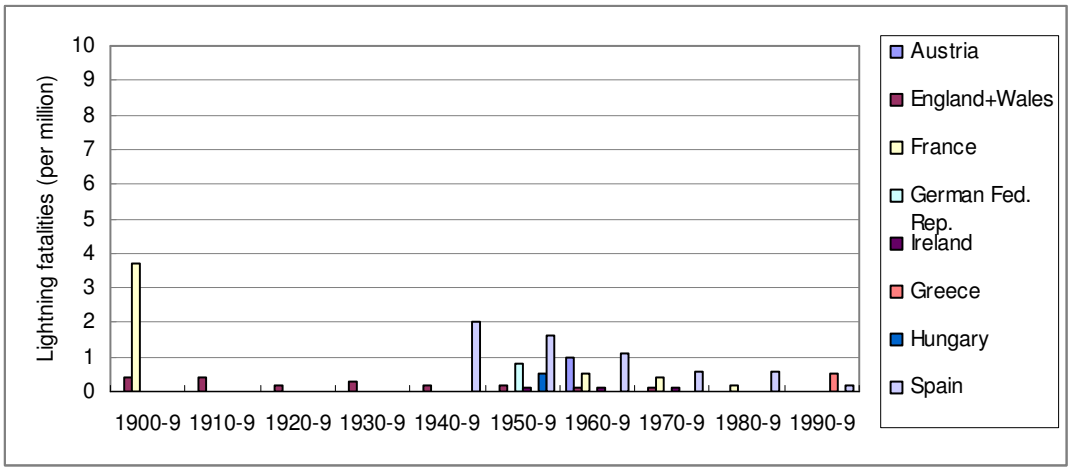

FIGURE 4. Lightning deaths per million people per year for eight countries in Europe by decade during 20th century.

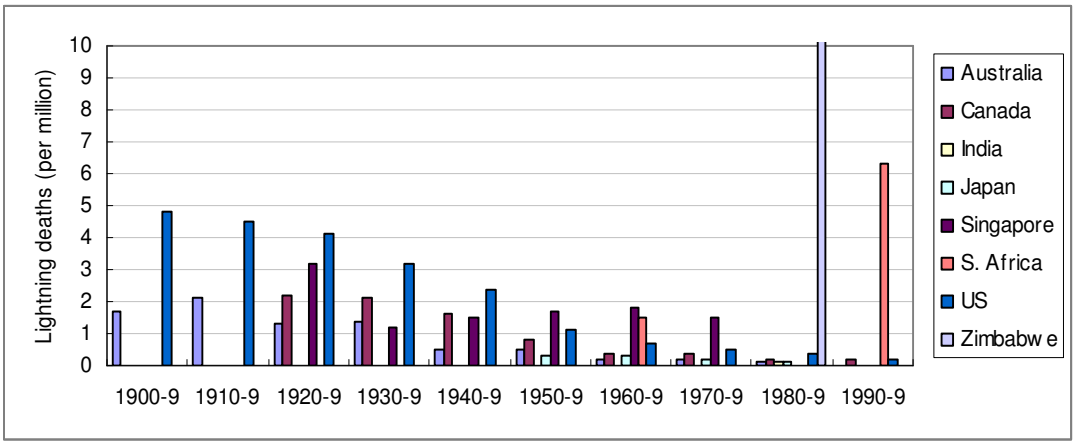

FIGURE 5. Lightning deaths per million people per year for eight countries outside Europe by decade during 20th century. Note that 1990s Zimbabwe value is 17.8.

c. 21st century

Table 1 combines results for 15 countries into one 21st-century list beginning in 2000. National data are provided first, when available, followed by regional results. 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, where 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 1. Annual lightning deaths per million people during the first decade of the 21st century. National rates are followed by regional rates when available.

Country Province	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 1.5 urban	8.8 rural 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

Table 3 in Holle and López (2003) is included here that listed assumptions relating to the estimate of 24,000 worldwide annual lightning deaths. 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 2 in Table 2, that of the 6 per million rate per year. Unfortunately, the results from the present study do not provide a definitive answer that can accept or reject this rate. Most developed regions support a lower rate, while others show the rate of 6 per million per year to be a candidate. 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 Holle and López (2003). 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 (Holle 2009). These incidents are consistent with factors 3, 4, 8, and 9 in Table 2.

TABLE 2. 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 no. of deaths
1. Area of high lightning frequency	Too small	Increase
	Too large	Decrease
2. Fatality rate of 6 deaths per million people	Too low	Increase
	Too high	Decrease
3. Rural-agricultural setting of people in high lightning areas compared to U.S. and western Europe in 1900	More rural	Increase
	Less rural	Decrease
4. Buildings occupied by people in high lightning areas compared to U.S. and western Europe in 1900	Less substantial	Increase
	More substantial	Decrease
5. Fatalities in areas outside Table 1 regions	Add areas	Increase
6. Organized recreational sports compared to U.S. 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 U.S. 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, 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 with better information in the future. 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 reliable, objective, and uniform lightning fatality totals over long periods is encouraged on a national basis in order to investigate the validity of these estimates.

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