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ORIGINAL PAPER

Risk of injury and death from lightning in Northern Malawi

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Abstract Rates of lightning mortality in communities on the western shore of Lake Malawi are higher than any other reported rate in the world: 419 strike victims per million people per annum and 84 deaths per million per annum. To document the background to this phenomenon, we conducted comprehensive household interviews with surviving victims and witnesses of every case of lightning strike in seven administrative areas around Nkhata Bay, Malawi. We find that the consequential lightning strikes are significantly more common in the rainy season and during the morning. Among those victims struck by lightning, there is an average ratio of approximately one death to four injuries, which is substantially higher than the commonly accepted ratio of 1:10. Children and adults are at equal risk of being struck. If struck, the probability of death is greater when the victim is outside in the open or outside under cover than indoors under a tin or thatched roof, but is unaffected by different kinds of footwear or whether it is raining. Reported explanations for strikes often center on witchcraft or other forms of social conflict. Our findings extend the study of consequential lightning strikes in the developing world and highlight cultural

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factors associated with this hazard. We end with recommendations for reducing the risk of lightning for rural populations.

Keywords lightning · lightning mortality · Malawi

1 Introduction

Lightning events that directly cause injury or death to humans are estimated to average 0.3 and six fatalities per one million people per annum in developed and developing countries, respectively (Holle and Lopez 2003; Holle 2008), but it is widely recognized that there are localized areas with much higher mortality than this (e.g., 15.5 deaths/million in Swaziland; Dlamini 2009). One reason for local variation in lightning risk is the distribution of lightning strikes; for example, satellite imagery indicates 78% of global lightning flashes occur in the tropics (Christian et al. 2003). A second explanation for inter-population variability is economic modernization (Holle and Lopez 2003). Changing practices in more developed countries since 1900, namely significant shifts of populations to urban areas, the transition away from labor intensive agriculture to more mechanized practices, structural improvements to buildings, and an increase in use and accessibility of metal vehicles that provide protection from lightning are all argued as being responsible for lowered risks of mortality from lightning. Such historical economic trends across western European countries have been associated with declines in fatalities over the last century (Cooper and Abidin Ab Kadir 2010). Nonetheless, the relative roles of lightning flash frequencies and extent of economic development in affecting lightning mortality are not yet known. One key problem is the difficulty in gauging the relative influence of modernization without better data from rural and developing areas of the tropics.

In developed countries, risk of lightning is evaluated using systematic reporting systems (e.g., Zhang et al. 2011), and some assessments additionally estimate social and economic impacts (e.g., Berz et al. 2002; Mills et al. 2010). In developing countries where site-specific data are usually unavailable (Blumenthal 2005; Colombo Declaration 2007), it is common for information on consequential lightning events (CLE)—defined here as lightning-caused injury or death to one or more humans—to be drawn simply from newspaper articles and media reports (e.g., Holle 2008; Dlamini 2009).

Such information is unavailable in many parts of the world, however, as was the case in our study, conducted near Nkhata Bay District, Malawi, so we adopted an anthropological approach to evaluate the risks of lightning to communities and its associated impacts. Specifically, we employed informal meetings with local village leaders, snowball sampling, and household interviews.

Northern Malawi lies near the eastern Congo Basin, which is the global "hot spot" of lightning flash density, and experiences high but not extremely high rates of lightning strikes (Christian et al. 2003). Nonetheless, ethnographic observations in Nkhata Bay suggest that the risk of death by lightning is extreme (Borgerhoff Mulder et al. 2011). Following earlier documentation of extraordinarily high rates of CLE in our study area (Borgerhoff Mulder et al. 2012), this article (1) characterizes factors associated with this risk, (2) investigates social responses, (3) uses this information to provide recommendations for the Government of Malawi, and (4) more generally, draws attention to the presence and risk of lightning hazards in remote areas. We begin by describing the study site in Northern Malawi and our methodology (Sect. 2), next present and interpret our findings (Sect. 3), and conclude with policy recommendations for risk mitigation (Sect. 4).

2 Methods

The study site in Nkhata Bay District (11°36.44′ S, 34°17.62′ E) is located on the western shore of Lake Malawi in Eastern Africa. The administrative boundary of Nkhata Bay District includes a local population of 213,779 residents with a mean density of 52 per km^2, the higher densities being concentrated near the lakeshore (NSO 2008). Mean annual rainfall in regions of Northern Malawi ranges from 763 to 1,143 mm, while Nkhata Bay town receives an average of 1,524 mm; nearly 90% of precipitation occurs during the rainy season from December to March (FAO 2000). Our survey area spans the elevation gradient from the lakeshore at 500 m up to 1,700 m (Ripple Africa, personal communication to TC and MBM, June 2009). Research was first conducted between June and September 2009 in seven traditional authorities (TAs) (Fig. 1). Selection of TAs was based on informal reports of exceptionally high risks of injury or death from lightning.

Non-probabilistic sampling began in 2009 using household surveys to quantify all CLE, regardless of when they occurred. With permission of the District Government, two local

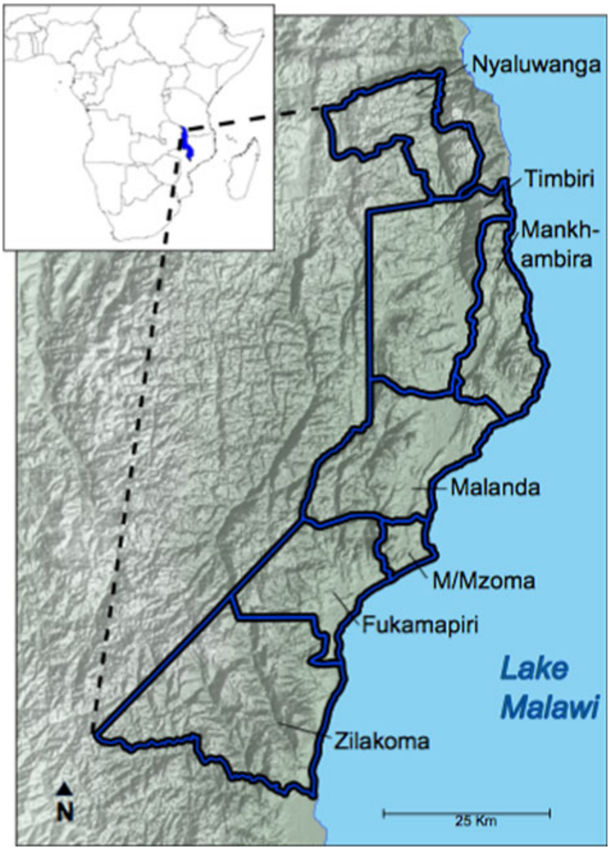

Fig. 1 Study site in Nkhata Bay District, Malawi. Household interviews were conducted to catalog the consequential lightning events in seven traditional authorities (TAs) [TA boundaries correspond to the period of 2008; Mankhambira TA shown here overlaps the urban TA of Mkumbira (not pictured), which comprises Nkhata Bay Town but was not surveyed. During the period of sampling, Fukamalaza TA was administratively combined with Malanda TA] fringing the western shore of Lake Malawi

Table 1 Risk of injury and death from lightning in Nkhata Bay District, Malawi. Data from household interviews give annual means of victims of consequential lightning events (CLE) from October 2007 to September 2010 (col. 2–4), and risk is calculated within the local population (col. 6–8)

Traditional authority (TA)	Mean number victims	Mean number injuries	Mean number deaths	2008 population[a]	Annual prob. being struck ($\times 10^{-6}$)	Annual prob. being injured ($\times 10^{-6}$)	Annual prob. being killed ($\times 10^{-6}$)
Fukamapiri	21	18	3	17,213	1,220	1,026	174
M/Mzoma	7	6	1	9,039	774	627	148
Mankhambira	10	7	3	19,914	502	368	134
Malanda[b]	12	9	2	31,289	373	298	75
Nyaluwanga	2	1	1	7,355	227	136	91
Timbiri	4	3	1	35,987	111	74	37
Zilakoma	<1	<1	0	13,582	25	25	0
7-TA Combined	56	44	11	134,379	419	327	84

Annual probability of becoming a victim (col. 6–8) calculated as number of victims per TA (col. 2–4) divided by TA population (col. 5). Mean victim calculations were rounded (col. 2–4), but greater precision was carried through for calculation of probabilities (col. 6–8)

[a] Data taken from Malawi 2008 Population Census Report (NSO 2008)

[b] Calculations based on the combined consequential lightning event records and population data from Malanda and Fukamalaza TAs due to recent administrative boundary changes

research assistants visited TAs and village leaders to compile records of households affected by strikes; then, interviewers met with the individual(s) identified as best able to report on each case (typically kin of victims, and/or the victims themselves). In cases where the affected household had been abandoned after the strike and the family had left the area, details were taken from neighbors and/or witnesses; where this was impossible, circumstances surrounding the CLE were recorded as missing, but the reported mortality and injury was retained in the database and used for the calculation of overall rates (Table 1). Retrospective data involving details of the CLE, the environmental and social circumstances surrounding it, and its consequences were recorded. Before leaving a household, the interviewee was asked whether he/she knew of further cases of CLE. This process was repeated until all reported cases in the seven TAs had been covered, at which time we judged the sample had reached saturation.

During the first survey in 2009, logistic constraints prevented us in certain areas from conducting follow-ups on all reported CLE. Furthermore, we noted that CLE at lower elevations near the lakeshore occurred at a very high frequency. Accordingly, in September–December 2010, we revisited certain TAs to follow up on missed reports in the first survey and to expand the study area to cover more of the lakeshore area. A final survey was conducted in May–June 2011 to include an additional TA (Zilakoma) and to access areas of another TA (Nyaluwanga) that were previously inaccessible in the wet season.

Surveys identifying 454 lightning victims were analyzed from the three survey periods (June–August 2009, September–December 2010, and May–June 2011). Surveys recorded CLE occurring from 1979 through 2010, but the distribution of CLE was skewed to recent years (Fig. 2a). For analysis, annual periods from October to September were used to coincide with seasonal rain and lightning patterns instead of calendar years. The complete dataset was used whenever possible, but for some estimates, data were restricted to the

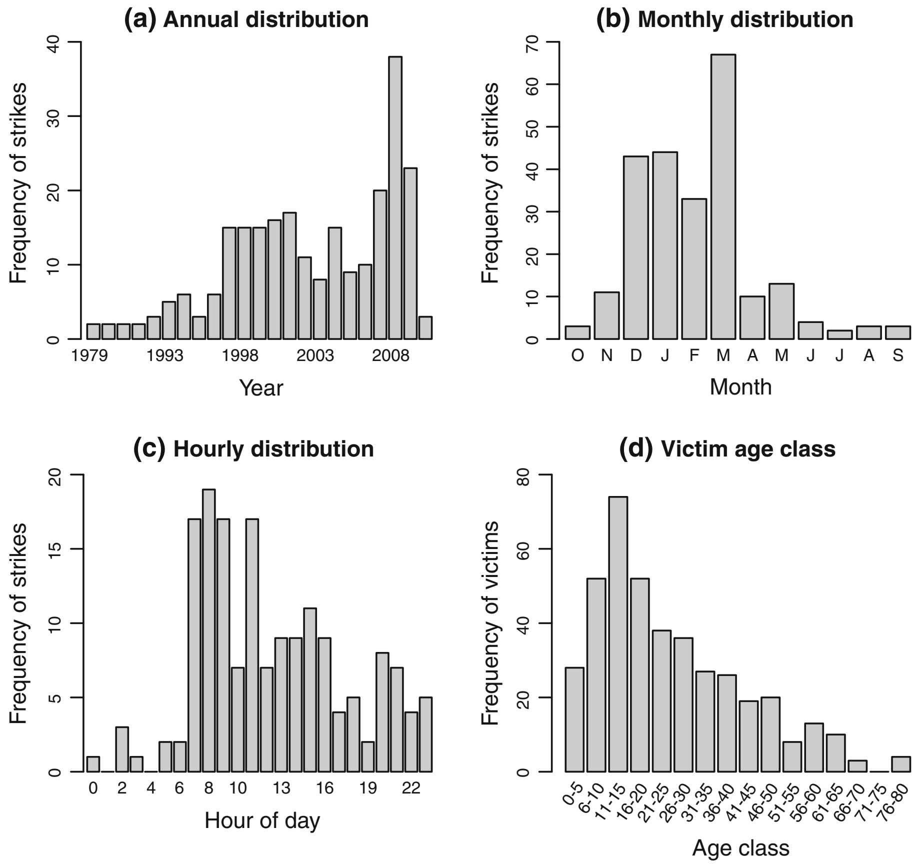

Fig. 2 Descriptive characteristics of consequential lightning events (CLE) causing injury or death reported through household interviews (1979–2010): **a** annual distribution of CLE ($n = 224$) [the distribution is not continuous from 1979 to 2010, no CLE were reported in 1980, 1982, and 1985–1991; data on year and month of strike exist for 224 of the reported 225 CLE]; **b** monthly description of CLE ($n = 224$) [data on year and month of strike exist for 224 of the reported 225 CLE]; **c** hourly description of CLE ($n = 166$); **d** age distribution of victims of CLE ($n = 410$)

most recent three years, October 2007 through September 2010. This recent subset was also more comparable, in terms of time, with the demographic statistics from the 2008 Malawi population census used to calculate CLE rates in the population and age-specific risk (NSO 2008). Differing sample sizes were due to incomplete responses to some questions in the questionnaire. Fortuitously, we were able to provide a check of how complete our reports of strikes were after initial sampling. A further 15 cases of lightning victims from 1979 to 2009 were uncovered in the three TAs revisited in 2010, suggesting under-reporting in the initial survey of at least 5% (despite having apparently reached saturation, as defined above).

To ensure cultural acceptability of the study, two lakeside Tongan research assistants (one a health worker, and both known to the study communities) conducted field surveys by visiting the most appropriate interviewee(s) for each CLE in their homes. These assistants introduced the interviewees to the aim of the study and to the nature of the questions before starting. Although the study design allowed for incidents to be recorded without pursuit of further details from affected subjects or witnesses, this never occurred. Consent was verbal because of low levels of literacy and documented through the subjects' agreement to answer a questionnaire on arrival at the household. Risk to subjects was deemed minimal as the data were entirely public, with strike victims and witnesses identified through public knowledge. Both research assistants were very familiar with the etiquette of dealing with sensitive issues in Lakeside Tonga culture: only complete linguistic and cultural fluency can ensure respectful questioning about potentially sensitive issues.

One- and two-way chi-squared tests for counts were used in analyses as appropriate. Because expected counts may be small, *p*-values generated from Monte Carlo simulation are reported throughout. Rounding error causes some reported percentages not to total 100.

3 Results and discussion

3.1 Descriptive results

Our study identified 225 CLE causing 454 injuries and fatalities (Borgerhoff Mulder et al. 2012). The distribution of reports of CLE from 1979 to 2010 shows higher occurrences in more recent years (Fig. 2a). The average annual rate of victims struck by lightning is 10.2 per year from 1979 to 2007 but 56.3 from 2007 to 2010. We suspect that this skewed distribution is due to outmigration of victims and families of victims following CLE, memory erosion, or unrelated deaths of victims and witnesses. The current growth rate of 2.8% in the area (NSO 2008) is unlikely to account for this sudden rise in CLE; even a doubling of population between 1979 and 2007 could not account for the fivefold increase in rate of victims assuming a linear relationship between strike victim and population density. Elevated lightning strikes in recent years driving the increase in victims is possible but unlikely. Furthermore, due to the persistence of subsistence activities in the area, it is unlikely that there have been substantial changes to daily behaviors that might contribute to the increased risk over time.

As reported (Borgerhoff Mulder et al. 2012), the annual rate of villagers being *injured* in a lightning strike in the study area was 327 per million members of the population (Table 1, column 7). However, Table 1 (column 7) shows that this rate varies markedly among TAs, from 25 (Zilakoma) to 1,026 (Fukamapiri) per million. The annual rate of villagers being *killed* by lightning is 84 per million (Table 1, column 8). Again, it varies markedly among TAs, from no deaths reported during the most recent 3 years (Zilakoma) to 174 deaths per year (Fukamapiri).

Monthly CLE are more common during the rainy season (December–March) than would be expected with an even distribution throughout the year, indicating a much higher risk during this period (Fig. 2b) ($X^2 = 235.770$, $p < 0.001$; $n = 224$). Information on the general time of day of these strikes was recorded for 201 of the 225 CLE. Forty-seven percent of CLE occurred from 06:00 to 12:00 h, whereas 31% occurred from 12:00 to 19:00 and 21% between 19:00 and 06:00 h; these frequencies differ significantly from those expected from an even distribution of strikes per hour throughout a 24-h period ($X^2 = 64.931$, $p < 0.001$). Reports stating the exact hour of CLE also indicate elevated occurrence in morning hours (Fig. 2c) ($X^2 = 109.855$, $p < 0.001$; $n = 166$). Such variation is probably related to individuals' daily activities, and our figures suggest that extra caution is needed during morning hours. Results contrast with those of Dlamini (2009) who found lightning fatalities occur almost exclusively between 12:00 and 18:00 h. In addition, data on daily patterns of strikes over southern Africa indicate a peak frequency during afternoon hours (Collier et al. 2006). Further research is necessary to explain these differences in the daily patterns.

CLE for which weather was recorded ($n = 108$) occurred more frequently during rain (81%) than when it was not raining (19%). In terms of location ($n = 218$), CLE occurred most frequently outside in the open (42%), while strikes were also observed hitting non-metal-roofed houses (22%), metal-roofed houses (19%), and other features outside such as trees (17%). This does not indicate a difference in risk associated with specific weather conditions or locations, only the frequency of locations where CLE were reported.

3.2 Factors affecting individual risk of mortality in a lightning strike

Children between the age of 11 and 15 years were most commonly struck by lightning (Fig. 2d), followed by those 6–10 and 16–20 years, most likely reflecting the age structure of Malawi. When comparing age structure of victims recorded from 2007 to 2010 with Malawi census figures (NSO 2008), the proportion of strike victims <18 years of age (52%) did not differ from the proportion of the population in the study area (53%) ($X^2 = 0.021$, $p = 0.933$).

Of the 450 victims of CLE between 1979 and 2010 for which outcomes were reported, 61% resulted in unconsciousness only, 8% in unconsciousness with other injuries, 3% in no loss of consciousness but other injuries, 2% in no ill effects, and 26% in death. This mortality rate is substantially higher than the 10% rate calculated for developed countries (Cherington et al. 1999; Cooper 2001) and, critically, used in estimations for developing countries (Holle and Lopez 2003). Note, our figures refer to the immediate outcome of the CLE and not results of differential treatment, either at the scene of the accident or at the local medical facility.

We next discuss circumstances surrounding injury and death from lightning. First, strike victims were either barefoot (56%), wearing rubber sandals (30%) or shoes (14%) when struck ($n = 264$); this footwear pattern is likely to be similar for non-victims, but we have no observational data to assess relative risk. If struck, the probability of death was similar regardless of footwear type (mortality rate: 26% barefoot, 20% sandals, 22% shoes; $X^2 = 1.215$, $p = 0.533$; $n = 63$), which supports the accepted idea that footwear offers no protection from lightning (National Weather Service 1994; Cooper et al. 2007). Second, 79% of victims were struck in the rain and 21% when it was not raining ($n = 212$), but the probability of death was similar regardless of the presence of rain (mortality rate: 27% while raining, 21% while not raining; $X^2 = 0.586$, $p = 0.558$; $n = 54$). Third, victims were most often injured or killed outside in the open (33%), followed by under thatched roofs (28%), tin roofs (24%), and outside under cover (15%) ($n = 435$). When considering deaths alone in these locations ($n = 115$), mortality rates were higher among victims struck outside, with those struck in the open experiencing the greatest risk of death (34%); mortality rates among strike victims in the other reported locations—outside under cover (28%), or indoors under thatched (24%) or tin (18%)-roofed structures—demonstrated that risk of death differed by location with the greatest risk of death occurring outside in open or outside under cover ($X^2 = 8.361$, $p = 0.034$). Furthermore, a greater *total number* of deaths occurred outside in the open (43%) than in the other reported locations, which agrees with findings from Swaziland where police reports identified the highest number of fatalities occurring outside (Dlamini 2009).

Finally, we observed no instances of lightning victims who initially survived the strike and received emergency treatment but then later died of injuries sustained from the lightning event. The long-term outcome for victims was recorded for 317 survivors. Of these, 85% made a full recovery, while permanent symptoms included hearing damage (8%), headaches (3%), other lasting pain (3%), and psychological damage (2%). These effects were reported through interviews and provide only a qualitative assessment of lasting impacts although they are consistent with those tracked in clinical cases in the United States of America (Cooper and Andrews 1995).

3.3 Rates of lightning-caused injury and death in a comparative context

The most comprehensive data available on lightning-caused fatality and injury come from Holle and Lopez (2003) and Holle (2008) drawing on figures from the *International Conference on Lightning and Static Electricity* (ICOLSE). Those authors estimated the annual lightning-caused mortality rate to be 6 per million for people living in less-developed regions of the world (and 0.3 per million for people of the developed world). Comparing Northern Malawi's rate of fatalities from lightning to that of Holle's for the developing world, Nkhata Bay exhibits a rate 14 times higher. The Swaziland study indicated a fatality rate of 15.5 persons per million based on police records and newspaper articles (Dlamini 2009), but fatalities recorded through household interviews in our study in Nkhata Bay District average 5.4 times higher than this, with rates from some specific areas (Fukamapiri TA) attaining 11.2 times that of Swaziland. While we acknowledge that localized variation may be masked at the national level, these local Malawian rates are nevertheless noteworthy.

In order to compare Northern Malawi's rates of lightning-caused injury to the rest of the world, we apply a 10:1 injuries-to-death ratio as first proposed by Cherington et al. (1999) and later used to produce the ICOLSE estimates of fatalities and injuries for developing areas (240,000 and 24,000, respectively) (Holle and Lopez 2003). These figures lead to an estimated average rate of being struck in the developing world of 66 per million against which we compare our measured rate of 419 per million in Nkhata Bay (Table 1, column 6), a difference of more than 6 times. Comparisons are coarse because data on rates of injury are poor in many areas (as discussed above), but, these factors notwithstanding, Nkhata Bay demonstrates a particularly high rate of occurrence of CLE affecting humans.

3.4 Direct and interpretive responses to lightning events

Data on immediate responses from bystanders exist for 443 of 454 victims of CLE. These data indicate that victims, family of victims, or bystanders view CLE as serious. Eighty-six percent of surviving individuals were immediately transported for medical care to health centers accessible in Nkhata Bay, where they were typically treated with intravenous drip, oral pain medication and prescribed rest. Of survivors, 2% were taken to traditional healers and 12% received no care. Even the majority of fatalities (78%) were transported to either police or health facilities.

In addition, however, traditional coping mechanisms were frequently called upon to make sense of the threat of lightning. For example, among the victims struck between 2007 and 2010 ($n = 146$), witchcraft was invoked as a cause of the injury or death in 44% of the cases. In addition, where reasons were given for strike-caused *fatalities* ($n = 29$), witchcraft was named as the underlying cause in 83% of the reports. Explanations most commonly referred to disputes over land but also to intra-family and neighborhood conflict. Interviewees also reported some CLE as outcomes of misdirected witchcraft targeted at others, and some CLE resulted in disputes among those involved over the legitimacy of the accusations. However, the sensitivity of these questions prevented quantitative descriptions. In a case study of witchcraft in South Africa, CLE were commonly associated with witchcraft accusations (Meel 2009).

4 Conclusions

Lightning is a serious threat to the inhabitants of the TAs on the western shore of Lake Malawi. Our data suggest that the risk of death or injury from lightning is substantially higher than the global average published by ICOLSE, which is based on existing published reports. We do not believe that Malawi is necessarily unique in this respect but rather we suspect that there is a serious lack of systematic data on this phenomenon from which to make meaningful worldwide estimates of variability. Household interviews and snowball sampling, as used in this study, can improve estimates of CLE or death derived from death certificates, hospital discharge data, and newspaper articles. The methodology can also investigate circumstances surrounding CLE.

Reduction in lightning risk in more developed areas of the world came about through gradual progression of changing labor practices and building construction (Cooper and Abidin Ab Kadir 2010). Where risk of lightning represents a substantial threat, as is evident in Northern Malawi, then direct intervention may be required. Recommendations currently exist for reducing risk of CLE, which are applicable in developing areas (e.g., The Colombo Declaration 2007; Zimmermann et al. 2002). These include the use of lightning conductors where appropriate, building improved shelters, and education about lightning risks. Recommended behavioral changes include avoiding open areas and bodies of water and seeking shelter in building structures. If well grounded, any metal conductor extended upwards from a building will reduce risk of injury to occupants, but such materials can be difficult to acquire. Scrap metal (as an alternative to copper or aluminum) or even rope soaked in salt water solution and run up above a roof can divert a lightning strike if well grounded (P. J. Richerson, personal communication). Safety education among rural populations may be the most feasible way forward in rural areas of the developing word, however, and should be a priority of local and national governments.

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