Chapter

Mitigating the Hazard of Lightning Injury and Death Across Africa

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Abstract

Lightning injuries, deaths, and the economic consequences of lightning damage to property and infrastructure continue to be a significant public health challenge and economic development issue in many tropical and subtropical areas of the world, especially sub-Saharan Africa. This chapter will discuss the scope of the hazard, known risk factors including common cultural beliefs that inhibit public education, existing data sources, medical effects and long-term disability, lightning formation and detection, injury mechanisms, existing lightning safety programs and their challenges, and the work being done to decrease injuries, death, and property damage from lightning in Africa by the African Centres for Lightning and Electromagnetics Network (ACLENet).

Keywords: ACLENet, lightning, lightning strike, lightning fatalities, lightning injury, lightning safety, lightning occurrence, disaster risk reduction, lightning detection, mechanisms of injury, lightning myths

1. Introduction

This chapter will summarize the hazards of lightning injury, death, and property damage in Africa. Lightning kills and injures not only people but their livestock, still a frequent measure of a family's worth. It threatens economically challenged countries with damage to infrastructure including utilities, mining, aviation, and many other industries, as well as causes losses from downtime, food spoilage, lost work, lost data, and other problems from damaged electronics [1].

2. Methodology

The number of lightning safety researchers is small and well known to each other. A significant portion of the literature since 1990, particularly for Africa, has been written, mentored, or summarized in papers by the first two authors of this chapter. Most of the literature on lightning safety and injury prevention is published in engineering and physics journals and may not be available to medical or public health experts through the usual search engines. An extensive bibliography on safety and demographics of lightning casualty papers, maintained by Mr. Holle, serves as the basis for this chapter [2].

3. History and limitations of lightning injury studies

Unlike many infectious diseases and other causes of injury, lightning injury is not reportable to any government agencies or databases worldwide. A number of other data sources and collection techniques have been used with varying degrees of completeness [3, 4].

For example, the general public in the United States might expect that everyone injured by lightning would seek immediate medical care so that hospital diagnoses or admission information would be a good source for the number of lightning injuries and deaths. However, a sizeable number of survivors do not seek care until a few days after the injury when symptoms do not resolve [5]. Those cases do not make it into any databank. Additionally, not all patients seen in emergency departments require admission, and emergency physicians may use symptom-based complaints such as pain, weakness, or mental status changes rather than "lightning injury." Even coroner's reports may not list "lightning injury" [5, 6].

Prior to the internet, U.S. death and injury statistics were collected as news reports provided by contracted clipping services for Storm Data, a monthly publication of the National Centers for Environmental Information [7]. **Figure 1** shows the death rate per million population collected for more than a century in the United States. During the clipping service era, studies showed that between 30 and 70% of deaths were unreported and injuries much more so [8–11]. Data on property damage, while included in Storm Data, are even less well documented than injuries, particularly because insurance companies are loath to share their claims information [12–15].

Of those injured by lightning, 90% survive, although many have permanent disabilities [6, 16]. The derivative 10:1 injury/death ratio has long been used for projecting total injuries in developed countries.

With the development of the internet, online news reports, and online searches have made up-to-the-minute collection of deaths in the U.S. routine with deaths caused by lightning well documented in the United States and studied in many developed countries [17–20].

Even with the internet as a source, there have been few studies in developing countries, and press coverage is marginal [21, 22] (**Figure 2**). As communication

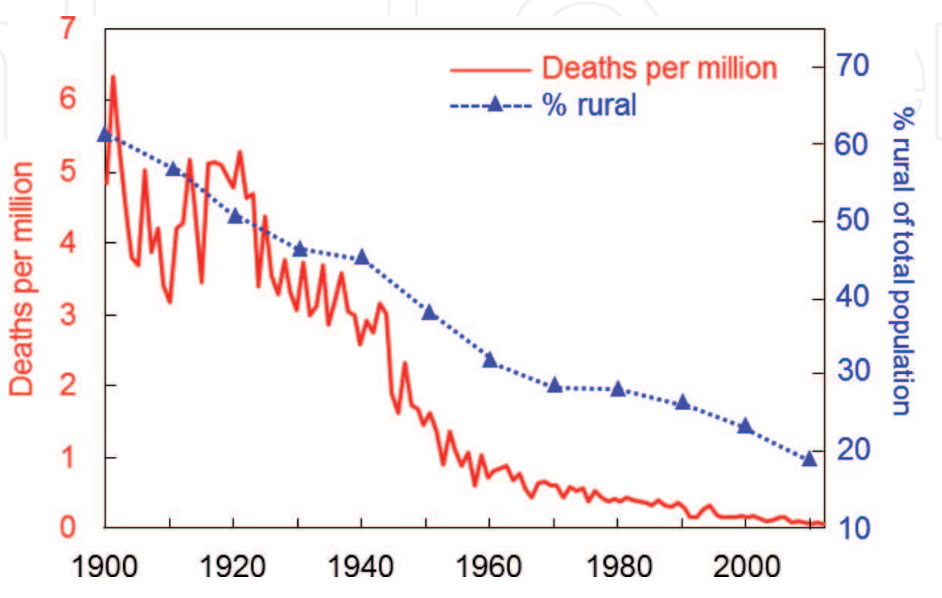

Figure 1.
Solid red line: U.S. lightning deaths per million people from 1900 to 2013 [20]. Dashed blue line: Percent rural population. (©Ronald L. Holle).

DOI: http://dx.doi.org/10.5772/intechopen.90468

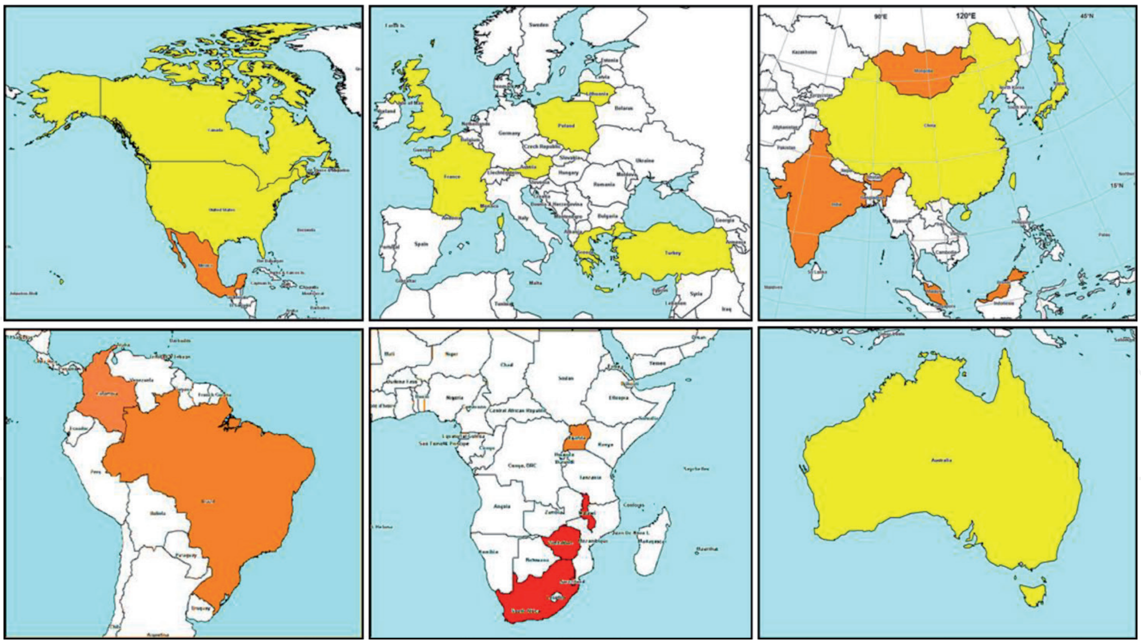

Figure 2.
Lightning fatality rate per million people per year by continent. Red shading indicates rate > 5.0 fatalities per million per year, orange indicates 0.6–5.0, and yellow indicates 0.5 or less. White indicates no national summaries have been published for datasets ending in 1979 or later (updated from [22]). (©Ronald L. Holle).

technology improves and cell phone penetrance grows, it is expected that more incidents will be reported in African media sources. However, for the foreseeable future, single deaths, nonfatal injuries, smaller incidents, and those in distant or hard-to-reach areas are less likely to be reported than those involving multiple people, animals, and children in school [1]. The first source to collect injury data in Africa, the nonprofit African Centres for Lightning and Electromagnetics Network (ACLENet), has been posting news reports across Africa for several years [23].

Different papers have estimated total annual global deaths as 6–24,000 [24–27]. Applying the 10:1 injury/death ratio projects up to 240,000 annual injuries. However, survival and disability rates have not been studied in developing countries, and numbers may be considerably higher for both deaths and injuries.

Lightning researchers have proposed mathematical models and other strategies for estimating lightning injuries and deaths using lightning stroke density data (number of lightning strokes per km^2 per year), population density, socioeconomic measures, and other factors [5, 26–28], but these need refining and validation before they can be used as predictive tools for developing countries. Although lightning may cause fewer deaths worldwide than some other public health threats, the consequences of lightning strike to individuals, families, communities, schools, and economic progress in countries that are already economically challenged should not be underestimated [21, 29–38].

4. Demographics of lightning injury

Lightning was the second largest storm killer in the United States for over a century, exceeded only by floods [5]. Since data collection began in the United States, lightning deaths have roughly paralleled the percentage of the population living in rural areas ([20], **Figure 1**). Although this has been a consistent finding in countries as they become "developed" [24], urbanization is not the only factor governing lightning injury. In Africa, as people move to cities to find work, huge shantytowns often arise on the periphery of cities (**Figure 3**). These dwellings do not meet the

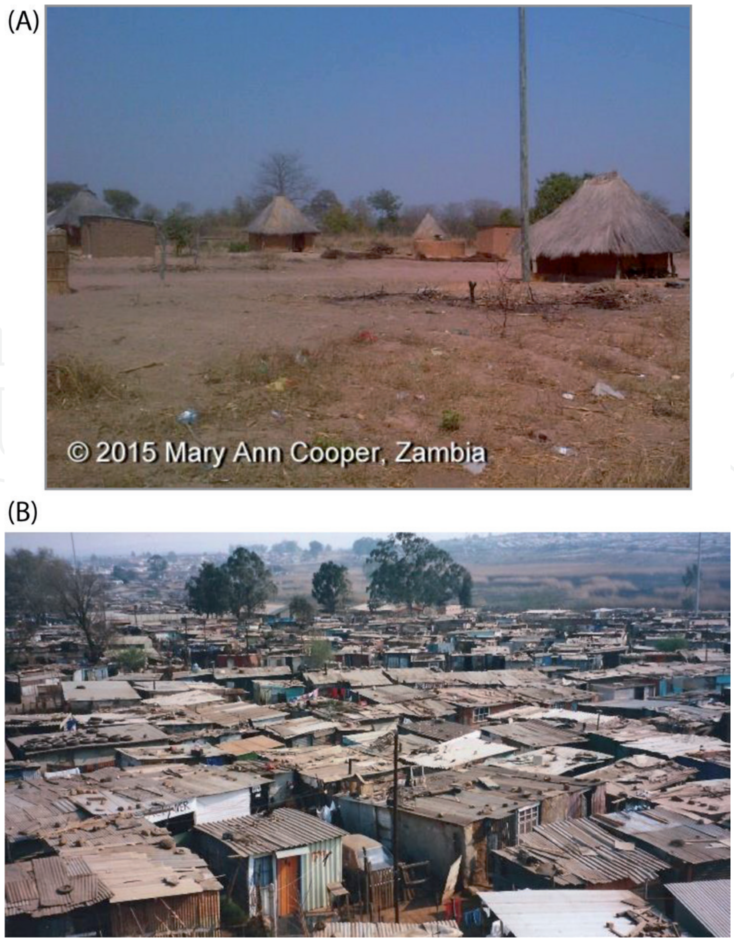

Figure 3.
Typical African dwellings and work areas, particularly in rural areas [1]. (A) Mudbrick with generations-old thatch roofs or sheet metal held down by rocks. In some areas, chicken wire may be cast over the thatch to prevent monkeys and baboons from disrupting the roof. In others, car tires may be placed on the roof because it is thought that their "rubber" will protect the building from lightning. (B) Soweto shantytown. Soweto is a million-plus populated southwest township near Johannesburg, South Africa, and the birthplace of Nelson Mandela. (courtesy Derek Elsom).

definition of "lightning-safe": a substantial, fully enclosed building with plumbing, wiring, and metal structural components running through the walls. Not only do buildings with these features tend to be less likely to collapse in a storm, but the metal and pipes act as a modified "Faraday cage" channeling lightning through the walls and around the inhabitants [5]. Lightning safety advocates avoid using the world "shelter" as almost all "shelters" are not lightning-safe (bus shelters, golf shelters, rain shelters, picnic shelters, etc.) [5].

Another "lightning-safe" area to choose in a thunderstorm is nearly any fully enclosed metal vehicle such as a school bus, automobile, truck, and most mechanized farming equipment. Open carts, including boda bodas, golf carts, and others are not lightning-safe [20, 21].

To illustrate the difference substantial, lightning-safe construction makes, **Figure 4** compares the relative frequency of locations of U.S. deaths from lightning from the 1890s, before indoor plumbing and wiring was common, with the most recent decade for which data was available [40]. In the 1890s, over half of the U.S. population lived in rural areas where few buildings had indoor plumbing, electrical wiring, or what would nowadays be considered reasonably lightning-safe construction. **Figure 4** shows that the largest percentage of deaths in the 1890s occurred indoors because when lightning hit them, they were likely to collapse on the inhabitants and any surviving inhabitant was likely to have lightning injuries.

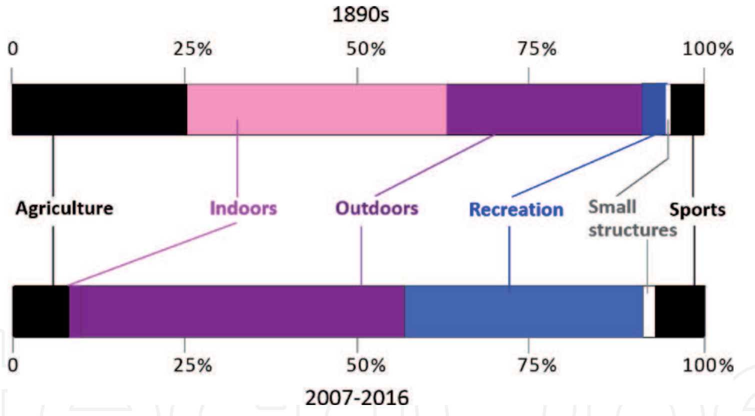

Figure 4.
Comparison of the percentage of locations where U.S. lightning fatalities occurred in the 1890s versus the 2007–2016 decade (updated from [40]). (©Ronald L. Holle).

As housing construction became more substantial and more likely to be lightning-safe, the share of indoor lightning deaths decreased to nearly zero and has certainly been less than one per year for the past two decades in the United States. Similarly, as farming in the United States became mechanized, fewer people were "exposed" to lightning. Nowadays, the vast majority of people killed by lightning in the Unites States and other developed countries are pursuing recreational and other outdoor nonwork activities such as organized sports, gardening, fishing, boating, or running and are almost always within a few feet of safety [1].

Figure 4 shows the second most common location of U.S. deaths in the 1890s was for labor-intensive outdoor activities with farming coming a close third. **Figure 4** is useful because the U.S. 1800's data gives a reasonable approximation of where to expect lightning deaths to occur in developing countries including sub-Saharan Africa where over 90% of buildings are not lightning-safe.

The fatality rate from lightning in the United States is now more than two orders of magnitude lower than a century ago ([1, 20, 39], **Figure 1**). Over the last decade, lightning deaths in the United States have averaged 27 per year or less than 1 in 12,000,000 population [40]. The fatality rate per capita has become very low in developed countries during the last century due to widespread availability of "lightning-safe" structures and metal-topped, fully enclosed vehicles, extensive public education by broadcast meteorologists and in-print and electronic media, mechanized agriculture, weather apps, good forecasting that incorporates lightning warnings, and other factors, including the fact that there is simply less lightning in most developed countries, which tend to be in temperate climates, compared to tropical and subtropical areas of the world [1, 5, 39].

Table 1 shows many differences in known demographics of lightning injuries between developed and developing countries. In developed countries, it is well known that the injury to death ratio is about 9:1, so that 90% survive [6, 16, 41]. The injury/death ratio in Africa and developing countries is unknown but is expected to be lower since fewer lightning-safe locations are available, resulting in a higher proportion of deaths. More people die per lightning event in the developing world than in the United States and other developed countries, particularly in agricultural and school events [47, 48]. Injuries, in general, are less well documented as some victims may not seek medical care immediately and most countries do not require reporting of these medical visits nor of lightning-related diagnoses [5, 6].

Whereas the male-to-female fatality rate in developed countries is consistently about 3:1 [2], many developing countries have a large portion of their population involved in labor-intensive agriculture during the daytime when thunderstorms

Measure	Developing countries	Developed countries
Deaths/million	Unknown	Well documented (0.01–0.5/million)
Number of deaths per event	Multiple deaths	Single deaths
Injury/death ratio	Unknown, expected to be lower due to lack of "lightning-safe" areas	10:1
Male/female deaths	Tends to be more equal	3:1
Age range	Equal risk for everyone	Males age 15–30

Table 1.
Demographics of lightning injury (©MACooper).

are most common. No lightning-safe locations are typically available to these people, and deaths and injuries are often nearly equally distributed between males and females [5, 41–44]. A recent study of labor-intensive agriculture in India and Bangladesh shows that 47% of the fatalities and injuries were females as they worked during the daytime hours when thunderstorms are most frequent [40, 44]. In addition, dwellings occupied outside of working hours often are not lightning-safe due to their construction of mud brick with thatch or sheet metal roofing (**Figure 3**).

While lightning deaths in developed countries rarely involve more than one person, and injuries to groups are few, deaths in developing countries often involve more than one person, sometimes with more than ten deaths per event [35]. Sometimes this is because people, particularly students, are packed together in classrooms and churches or walking with several others [1]. This leads some experts to hypothesize that ground current, responsible for at least 50% of deaths in developed countries, may play an even larger role in these situations [20, 50].

Multiple studies done by Holle [2] have shown that the majority of those killed die during the afternoon hours when thunderstorms are more likely to occur. In more developed countries, the dominant profile of lightning casualties is the young male. Risk-taking in recreation, workplaces, and organized sports tends to be dominated by males between about 15 and 30 years old. In lesser developed countries, the distribution by ages is much more dispersed. The lack of lightning-safe dwellings, schools and workplaces means that all ages and both genders are equally vulnerable at all times [27, 34, 41, 44].

5. Risk factors for lightning injury

The factors that increase the risk of lightning injury are well known ([1], **Table 2**). Like infectious diseases, lightning injuries are related to exposure. Exposure is related to the amount of lightning that occurs in a given area over time (**Table 2**, dark orange), common socioeconomic factors (mid-orange), and cultural beliefs (light orange and **Tables 2**, **3**) about lightning that affect behavior.

The frequency of lightning in a given area is measured as strokes/km^2/year (stroke density), which can vary substantially depending on season, topography, and other factors but, in total, is reasonably unchanging from year to year [38]. Most lightning occurs in cloud (IC) than cloud-to-ground (CG), but *all* lightning is dangerous because any stroke can change direction and start toward the ground where people are located. Worldwide lightning data over decades has shown no change that can be attributed to climate change, despite speculations to the contrary [46].

Lightning stroke density is higher in tropical and subtropical areas of the world, precisely where people are less likely to have substantial, developed housing and

Factors that increase risk	Factors that decrease risk
High lightning stroke density	Low lightning stroke density
Large rural population	Mostly urban population
Increasing population	Stable or decreasing populations
Labor-intensive, outdoor work such as farming, fishing, and animal husbandry	Mechanized farming and stricter laws governing work conditions
Inadequate building construction. No lightning protection mandated for public and frequently inhabited buildings; lack of technical knowledge about lightning protection; use of lightning protection materials that are not compliant with international lightning protection codes	High-quality building construction involving wiring, plumbing, and metal components in the walls and roof combine to act as a 'Faraday cage' to safely divert lightning energy around inhabitants. Code-compliant lightning protection mandated for public buildings and those frequently inhabited by large numbers of people
Lack of lightning-safe areas for easy evacuation; lack of proven actions that individuals can take to decrease risk	Easy availability of lightning-safe buildings and fully enclosed metal vehicles within easy reach. Widespread personal knowledge of lightning injury avoidance behavior
No or little lightning detection data or nonavailability to the public	High-quality lightning detection data incorporated into weather forecasts
Lack of reliable and timely weather forecasts or forecasts that are only available to specific sectors of the economy, primarily aviation	Weather forecasting systems with high-quality forecasts and weather apps available to the public on a free and real-time basis
Delayed or nonexistent access to high-quality medical care	Easy access to high-quality medical care
Low literacy rate; multiple languages	High literacy rate
Little or no valid public education on lightning safety; strongly held beliefs that injuries are inevitable, regardless of personal behavior, and that lightning is called down by witches and other cultural beliefs	An active media; news reports of injuries; enthusiastic public education with wide access to lightning safety information; knowledge of how lightning is formed and where it is statistically more likely to hit

Table 2.
Risk factors for lightning injury and death. Modified from Cooper and Tushemereirwe [1] ©MACooper.

where work is more often outdoors [46]. The Democratic Republic of the Congo and Lake Maracaibo in Venezuela are hotspots for the highest stroke density in the world [46]. **Figure 5** shows stroke density map of Africa.

Despite studies showing stable negative population growth in most developed countries, the population of Africa continues to increase, putting more people at risk.

The vast majority of factors determining risk of lightning injury are socioeconomic and, therefore, could be modified given adequate resources, education, and infrastructure improvement. During the day, people are at higher risk of lightning injury when they are involved in labor-intensive outdoor work such as animal husbandry and farming, when they do not have access to "lightning-safe" buildings for habitation and work, and when they are exposed as they walk to the market, work near their homes or on fishing boats, or attend school and church either outdoors or in non-lightning-safe buildings [1, 35–37]. At night, as people sleep in lightning-unsafe dwellings, entire families are at risk. It is difficult for people who have not worked extensively in Africa to understand life there, but the fact is that nearly everyone in sub-Saharan Africa is at risk 24/7/365 regardless of the activities they are pursuing [10, 16–26, 29–37, 47, 50–53].

A small sample of common beliefs about lightning in Africa
Lightning is punishment from a god for wrongdoing.
Thunder is a warning that the god who controls lightning is walking on the earth.
Muti (folk medicine in Africa) can ward off lightning damage to a house.
Wearing red attracts lightning.
Mirrors should be covered during thunderstorms because they can attract or reflect lightning to kill someone nearby.
Individuals can call lightning down to harm others; witches can be hired to call down lightning on an enemy.
It is necessary to hire a sangoma to assure good weather for your wedding or other important event. If the weather is bad, it is because someone who wishes you harm hired a stronger sangoma.
A person who has been injured by lightning requires purification by traditional healers before it is safe to touch them (delaying resuscitation and first aid efforts) or before the person can be prepared for burial.

Table 3.
Common cultural beliefs about lightning. (©MACooper).

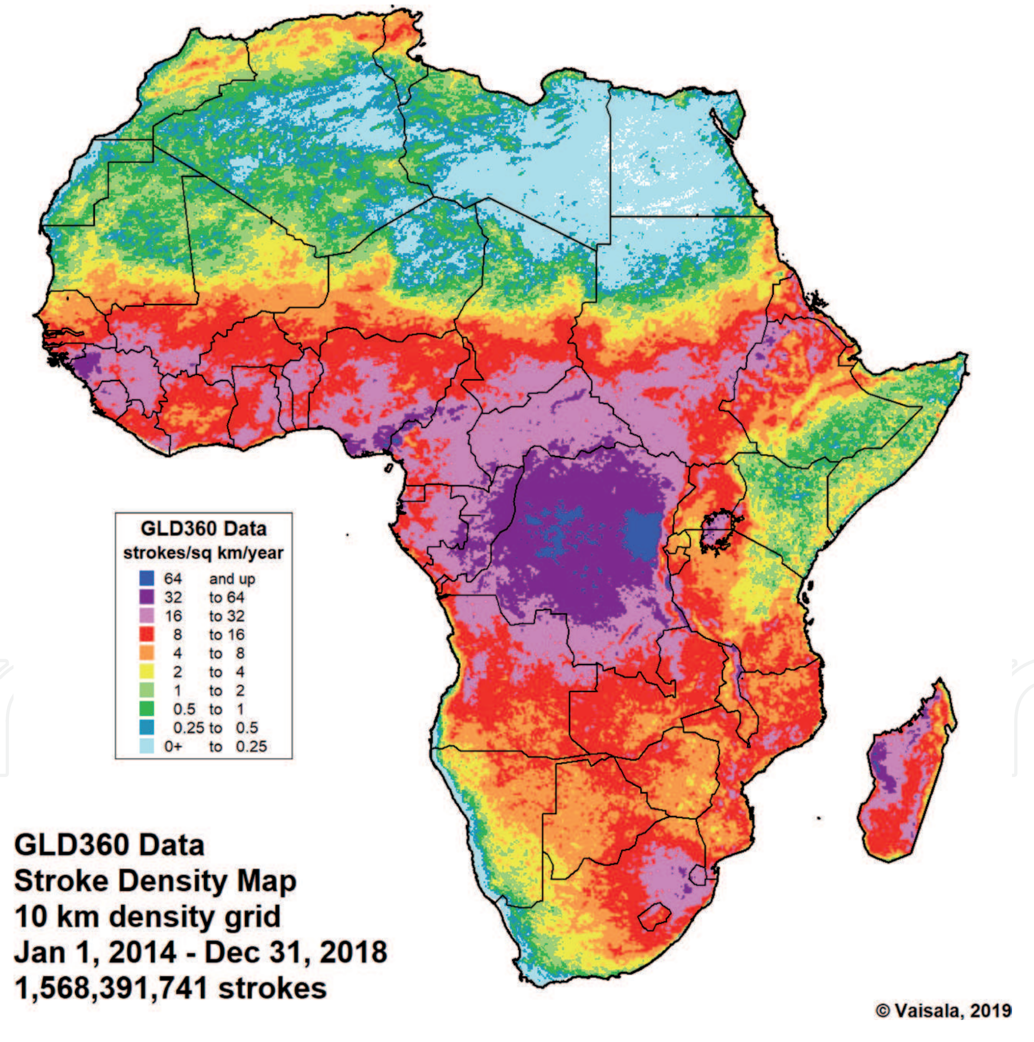

Figure 5.
Lightning stroke density per square km per year from the global lightning dataset GLD360 network from 2014 through 2018. The density map depicts 1,568,391,741 strokes. Scale is at lower left; grid size is 10 by 10 km [46].

Most developing countries do not have or may not enforce building codes that require lightning protection (LP) for public buildings such as schools, churches, hospitals, and other frequently inhabited buildings. Proper LP is delineated in internationally recognized codes [54, 55]. The design and installation of LP is a very specialized field and beyond discussion in this chapter [50]. In practice, it is seldom part of the curricula for engineers or architects and is nearly always "learned on the job" although more countries are instituting LP training and certification. Because of this complexity, it is nearly impossible for the average local official, school principal, or administrator to judge between code-compliant plans and those offered by fast-talking charlatans or by well-meaning but untrained LP purveyors. Further discussion of the unvalidated claims of those using early streamer emitters (ESE) and other fraudulent practices is beyond this text, although an overview can be accessed at [50]. Unfortunately, the infiltration of purveyors of ESE and other unproven philosophies of lightning protection has resulted in multiple countries adopting lightning protection codes that are not compliant with the international IEC standards, notably France, Spain, Turkey, and many others. All wishing to have LP installed should inquire what code will be used before accepting a contract or design [50, 54, 55].

A factor that makes lightning injuries strikingly different in the developing world is the combination of keraunoparalysis (KP) (kerauno—lightning) and building construction using dry thatch [5, 49, 56–58]. Lightning injury often causes a temporary paralysis that lasts for at least several minutes to hours. This is particularly a problem for families working or sleeping inside their mudbrick home roofed with tinder-dry, generations-old thatch. KP can prevent even the most fit young person from escaping a home as the burning thatch starts to fall ([5, 49, 56], **Figure 6**). These are the injuries that result in the media writing "burned beyond recognition" or "charred," terms that are never seen in the United States or other developed countries [21, 49].

Governmentally, many developing countries have little or no access to lightning detection data sources. Most meteorological authorities, while mandated to serve a country's airports to assure international flights, commerce, and tourism, have limited resources and no mandated obligation to warn citizens of droughts, floods, lightning, or other weather hazards [39, 50, 59, 60]. There are no weather apps in most of these countries, and those that exist may access poor data sources or incorporate time lags of 20–30 minutes, making their displays useless for lightning safety and injury prevention. Near-real-time warnings (delayed by less than 30 seconds) are available on a subscription basis from several vendors but are largely unaffordable or unknown to industry, government meteorological authorities, and the public in Africa [39, 50]. ACLENet is piloting this type of warning system at a few schools in Uganda.

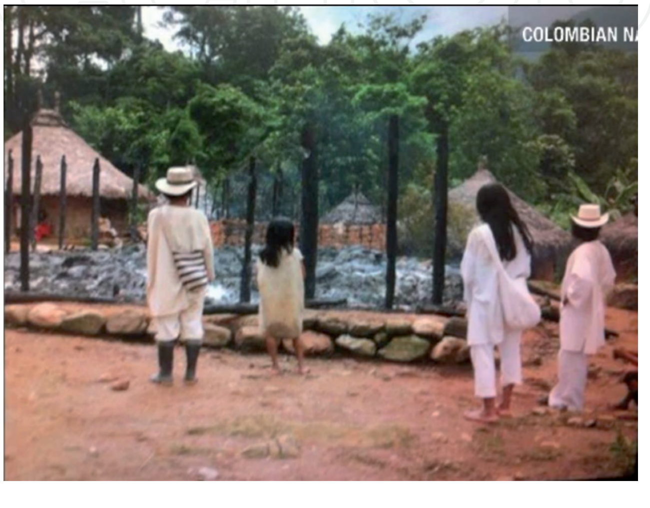

Figure 6.
Eleven tribal leaders were killed when the thatch building where they were meeting caught fire from a lightning strike. (used with tribal permission).

Many of the most lightning injury-prone countries have inadequate or hard-to-reach medical care and other supports such as trained personnel, ambulance services, first aid providers, and other first responders [50]. Besides the high exposure and risk of lightning strike, victims also have less chance of survival during the acute phase or access to specialized services such as cognitive therapy and chronic pain management for those who survive [5, 16, 56].

All of the socioeconomic factors listed in **Table 2** could be addressed and improved, but the cost and time to do so would be enormous and prohibitive for most African countries which may already be economically challenged. Public education, however, does not need to cost nearly as much as revising buildings and medical infrastructure [18, 61, 62], and it is probably the easiest and fastest way to make a difference [18, 61–63]. ACLENet has worked with other agencies in Uganda to begin public education through television broadcasts and newspaper inserts which teachers often hang as classroom posters and use for lesson plans [64].

The third major set of contributors to risk are the long-held cultural beliefs about lightning (**Table 2** light orange), a small sample of which are listed in **Table 3**. These beliefs have been taught for generations and are nearly impossible to counter except by persistent public education or by community elders who have been trained [65–67]. In some countries, if a family member has been injured by lightning, communities may shun the family, believing the family to be cursed and forcing them to leave their communities, property, and friends to start over [30]. In the Democratic Republic of the Congo, a head teacher and two teachers at a private school were imprisoned after being accused of "calling down lightning" to kill students at the public school in order to induce parents to enroll their children in their private school [66]. Widows or other women with no family to protect them may be stoned as witches if someone in their village is killed by lightning [65]. Other common myths can be found in the monthly ACLENet newsletters [66].

6. Mechanisms of lightning injury

Medically, lightning injury could be investigated from a number of different approaches including cellular physiology or electrical field effects, flashover versus internal flow of energy, and others [5, 50]. However, considering the five common electrical mechanisms of injury is the most useful for prevention and lightning safety education [5, 45]. To complicate further, these can be combined, and blunt or concussive trauma/barotrauma may be overlaid on any of the five [5, 45, 68]. **Figure 7** shows the relative distribution of these mechanisms in developed countries. The distribution is not known in developing countries, but it is suspected that ground current plays an even larger role.

Ground current (also called earth potential rise and step voltage): The mechanism that kills the most people is ground current, where lightning strikes the surface of the earth and spreads to nearby people. It can affect a large number of people either inside or outside an unprotected building. Children crowded together in unprotected school buildings are at particular risk [47].

Side flash/splash: This occurs when trees, poles, towers, and many other objects that are not necessarily tall are struck and a portion of the lightning jumps to a nearby person.

Upward streamer (leader): As a thundercloud moves above the earth, opposite charges are induced on the surface of the earth and in objects on the ground under the cloud whether they are a tree, a home, a person, or a blade of grass. Upward streamers, not usually visible from these objects, will reach up and attempt to

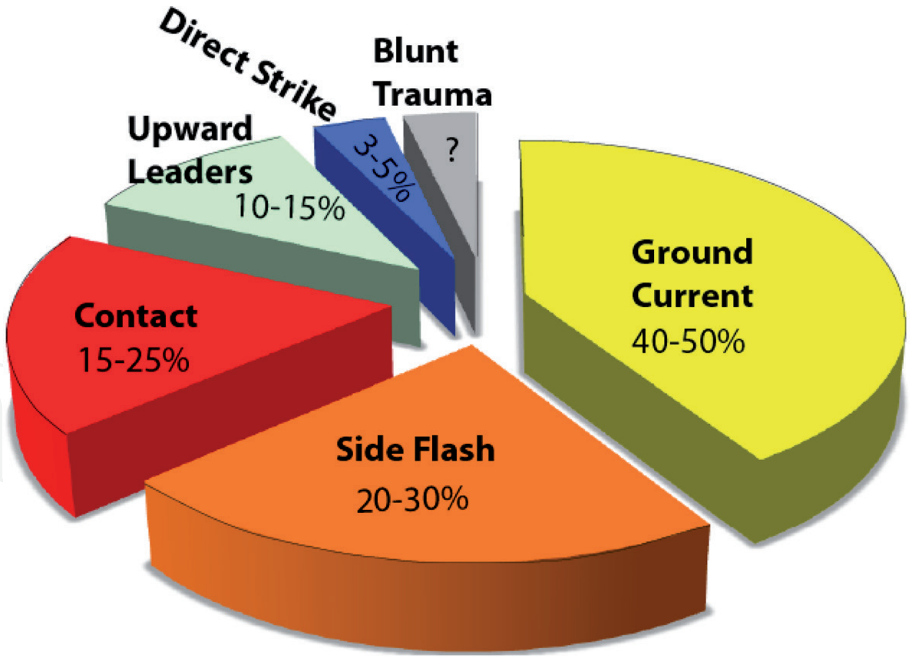

Figure 7.
This chart shows the frequencies of the primary lightning fatality mechanisms [45]. (©MACooper/RLHolle).

Figure 8.
Cows killed by lightning as they gathered by an ungrounded wire fence. This is a common occurrence and can be from contact injury as lightning energy is conducted from a distance or from ground current. Sideflash from the fence is less likely. (©MACooper).

connect with the downward-moving lightning channel. The upward leader is strong enough to cause injury even if the lightning channel is not completed [69–72].

Contact: This occurs when the person is in contact with conducting paths such as plumbing, corded telephones or appliances, headsets, or wiring, either outdoors or inside structures. Contact injury may also occur as animals gather next to long metal wire fences [**Figure 8**].

Direct strike: Contrary to public belief, direct strike is the least common mechanism causing only perhaps 3–5% of deaths [5, 39, 45, 73]. A direct injury occurs when the lightning stroke attaches directly to the victim and is most likely to occur in the open. While it is intuitive that a direct strike might be the most likely to cause fatalities, this has not been shown in any studies.

Blunt trauma (concussive/explosive trauma, barotrauma): Blunt trauma has long been suggested as a mechanism of lightning injury [5]. As lightning passes through the air, rapid heating and expansion of the air occurs so that those nearby may experience a concussive force as if they were near an explosion. Blumenthal investigated barotrauma in his dissertation and likened it to being near a 5 kg of TNT blast [68]. Barotrauma is independent of the other electrical mechanisms of injury but may potentially overlay any of them [5, 39, 68]. People may also be thrown by opisthotonic contractions and experience musculoskeletal injuries as would be expected [5, 67].

7. Lightning injury

As noted in Section 3, in developed countries, nearly 90% of those injured by lightning survive but are often left with disabling sequelae [5, 10, 11, 16, 45, 56]. The percentage of survivors in developing countries may be considerably smaller where people are exposed 24/7/365, may be affected by keraunoparalysis in unsafe structures that catch on fire, and cannot access high-quality medical and rehabilitative care.

A large range of injuries has been reported including damage to the ears, eyes, skin, heart, and brain. For a more complete and referenced discussion, see Cooper et al. in Auerbach [5]. The proximate cause of death is cardiac arrest and anoxic brain injury at the time of the strike, even if a partially successful resuscitation delays the legal pronouncement for a few days [5, 11, 74]. Later, deaths may be due to suicide as survivors become despondent when they cannot find help for their brain injury and other sequelae, may not be able to return to work and lose their homes, or lose the support of their friends and family due to personality changes and other stressors [75, 76]. Others may self-medicate with alcohol, drugs, or herbs for their post-injury chronic pain and frustration [76].

People tend to take their experience with common household electricity and scale it up, predicting that lightning must cause horrible burns [5, 67]. They may even have heard of the destructive injuries caused by high-voltage injuries. However, in developed countries, lightning burns tend to be superficial and insignificant compared to the neurologic injuries that are suffered. Less than ½ of lightning survivors surveyed by the Lightning Strike and Electric Shock Survivors, International (LSESSI) support group several years ago had damage of any kind to their skin [16, 74–76]. Given the majority of injuries are not direct strikes or direct injuries but from mechanisms where the strength of the strike has been mitigated by dissipation across longer distances or other factors (ground current, contact injury, upward streamer), this is a reasonable finding. However, the lack of burns will often result in physician skepticism and legal disputes with worker insurance denial [5, 58, 75, 76].

Long term, lightning survivors may suffer temporary or permanent neurological sequelae including chronic pain syndromes and cognitive damage similar to those reported in the now widely recognized post-concussive syndrome with attention deficit, memory problems, learning difficulty, frontal lobe damage causing irritability and personality changes, and loss of multitasking and executive function, all resulting in inability to return to their previous level of employment [5, 16, 75, 76]. Blunt injury from being thrown may also cause musculoskeletal pain [5, 68]. As with other brain injured people, frustration, impatience, instant rage, and other personality changes may drive away family members, further compromising the survivor's recovery [5, 16, 75, 76].

Disability may significantly affect a family's socioeconomic status if the survivor is unable to return to work or needs chronic care [5, 16, 39, 51, 58, 75, 76]. A further setback to the victim's family, particularly in developing countries such as those in Africa, is a common belief that a family affected by lightning injury is "cursed" or was punished for bad behavior such as beating their wives or children. The community may shun the entire family so that they have little choice but to leave their community, home, and employment to start over in a new community where their tragedy is unknown [5, 30, 39].

Currently there is no way to reverse or decrease the damage cascade that is set in motion when the injury first occurs. The Lightning Strike and Electric Shock Survivors, International is a support group that has helped hundreds of survivors and their families to find help and knowledge about their injuries [16, 50, 75, 76]. Treatment is standard for pain syndromes, anoxic brain injury, eighth nerve tinnitus and balance problems, and cognitive disability. Unfortunately, this type of care is expensive and seldom available in developing countries. In the developed world, some survivors may return to work, but it may be in a different field or with lesser responsibility and income.

As in most injuries and illnesses, prevention is far better than caring for those injured by lightning. In developed countries, lightning injury prevention through public education is simple and cost-effective [17, 18, 61, 63, 77]. However decreasing lightning injuries in developing countries is a much more complex task than in countries where lightning-safe structures and vehicles are common and almost universally close at hand.

8. African Centres for lightning and electromagnetics network, Inc.

The African Centres for Lightning and Electromagnetics Network (https://ACLENet.org) is a pan-African network of national centers dedicated to reducing deaths, injuries, and property damage from lightning across Africa [1]. It was formed with multiple goals in mind (**Table 4**). Among its many activities, ACLENet is attempting to establish an injury and damage database by collecting news reports for each of the countries in Africa and working with citizen reporters to document injuries and deaths as well as property damage [23].

The majority of lightning deaths can be avoided if there are "lightning-safe" areas to evacuate to, if good weather forecasts and warning systems are available to the public, and if individuals have been educated in actions they can take to avoid injury [1, 17, 18]. Almost none of these are available to the vast majority of sub-Saharan Africans, particularly in rural areas, leaving entire families at risk 24/7/365 whether they are working in their fields, walking to the market, cooking near their homes, worshipping, or in school [1]. Children in school tend to be at particular risk because typical classes have about 50 children packed into classrooms that are not protected and are not lightning-safe [1, 47].

In June 2011, 18 children were killed by one lightning strike with another 38 children injured and transported to the hospital from Runyanya Primary School in Kiryandongo, Uganda [78]. Prior to this incident, the head teacher related that

ACLENet's multifaceted goals
To assess the impact of lightning on each nation's citizens and economy
To educate teachers, parents, pupils, and the public on lightning safety and injury prevention
To work with governments to assure that code-compliant lightning protection systems are designed for new schools and other important buildings
To work with universities to train Africa's own lightning experts for the future
To improve engineering training and professional qualifications in lightning protection
To advise on code-compliant lightning protection of utilities and other economically important industries
To improve the availability of accurate and timely lightning data, weather forecasting, and warnings

Table 4.
Modified from Cooper et al. [1] (©MACooper).

the school had 600 pupils attending. After the incident, parents were afraid to send their children, and children were afraid to attend school where they had seen their friends die. The enrollment fell to under 400. Children cannot learn if they are anxious about being killed every time dark clouds roll across the sky. After lightning protection was installed at the school by ACLENet, the head teacher related that enrollment climbed to over 1100 [79].

Perhaps more alarming than deaths is the fact that lightning is survivable but can leave survivors with permanent disabilities that make adults unable to return to work to support themselves and their families and children less able to learn in school to become contributing, productive citizens [5, 16, 56, 75, 76]. As with any significant disability, the family suffers at least as much as the survivor does, and the economic impact to the family can be great.

In addition to deaths and disabling injuries to people, lightning often destroys livestock, the main source of income and wealth for many families in developing countries (**Figure 9**) [39]. Sometimes these incidents are reported by the media, but there is little reliable data on total livestock deaths or on damage to infrastructure such as utilities, mining, agriculture, and other industries. Additionally, the hundreds of languages in Africa confound good data gathering.

The effects of lightning damage to property has not only direct effects on the structure but also indirect economic effects including food spoilage from lack of refrigeration after electrical failure, electrical parts and repairs unaffordable or not available for days, hospitals without power, and expensive, nearly irreplaceable electronics damaged along with their databases and records [1, 39, 80]. It is estimated that aggregate economic losses to unprotected installations, both due to damage and downtime, will grow exponentially as a result of the explosive growth in usage of electronics, the extension of national power grids into rural areas, and mushrooming communication towers across Africa [35, 81–83]. Lightning damage to infrastructure occurs in countries that can ill afford more economic threats due to already struggling with issues such as drought, HIV, underemployment, or civil strife.

In developed countries, lightning damage is almost always covered by insurance. However, in Africa, studies indicate lack of penetration of insurance across the African continent. Conservative estimates put the extent of insurance coverage at as little as 3.5% of the potential African market [84]. For public health threats like lightning, lack of insurance can be devastating. In Africa, emergency response and medical care to victims without health insurance is limited or nonexistent. Businesses without insurance coverage may be forced to close.

Two stories illustrate the outcome lack of insurance coverage for lightning events can cause:

Figure 9.
Cattle killed by lightning in South Africa. (photo courtesy Ian Jandrell).

1. Reported on October 17, 2019, 11 head of cattle belonging to 1 farmer were killed by lightning at Mboza in northeastern KwaZulu-Natal, leaving the farmer unable to provide for his family as cattle farming was his only means of subsistence [85].

2. When a community radio station in northern Uganda was hit by lightning destroying a major part of their infrastructure and equipment, lack of insurance forced it to close down [86].

The African Centres for Lighting and Electromagnetics Network (ACLENet - https://ACLENet.org) is a nonprofit organization dedicated to decreasing deaths, injuries, and property damage from lightning across Africa. It seeks to change the toll of lightning across Africa (**Table 4**) by addressing lightning from many aspects:

1. Establishing a database of news reports of injuries and property damage and encouraging individuals and the media to report them so that the impact of lightning on each nation's citizens and economy can be assessed [23].

2. Educating the public on how lightning occurs, mechanisms of injury, and what individuals can do to protect themselves and their families [64, 87]. Due to extensive public education with involvement of the media, U.S. lightning deaths have decreased from over 100/year to less than 30/year for the past decade [17, 18, 63]. Fortunately, all the National Oceanographic and Atmospheric Administration (NOAA) lightning safety materials, curricula for schools, games, animations, posters, and public service announcements are free to download and use from the website [41]. Further, the authors of most of these materials are willing to work with African lightning safety advocates to "Africanize" the settings, languages, and idioms (personal communications).

3. Protecting schools with code-compliant designs ([54], **Figure 10**). If children and teachers feel secure from lightning injury, they are more likely to attend school and continue their studies despite thunderstorms. One of the schools

Figure 10.
Installation of lightning protection system at a typical classroom building at Runyanya school, Uganda. Details: (A) air terminal; (B) down conductor; and (C) ground terminal or "earthing ring." (©ACLENet).

protected by ACLENet has written detailing that the surrounding community now feels safe to use the school as a meeting place since it was protected [88]. Effective lightning safety education and behavior change for communities begins with children in so many ways!

4. Decreasing the cost of LP by using local materials to avoid expensive imports and developing “templates” for schools and other common buildings that can be used across Africa.

5. Fostering graduate education to train Africa’s own experts. The University of Zambia is accepting the first class in lightning science and electrical engineering, a program developed under the mentorship of one of ACLENet’s founders, Chandima Gomes, to start January 2020.

6. Working with governments to assure implementation of internationally recognized lightning protection codes consistent with IEC 62305-1,2,3,4 [54].

7. Working with utilities, mining, aviation, and other industries to provide lightning protection for infrastructure as well as lightning safety education for their staff.

8. Advocating improved training and professional qualifications for LP designers, engineers, and installers.

9. Conclusions

Lightning is a significant cause of weather-related death and injury across Africa [1, 5, 39]. While it is a largely preventable death in developed countries where “lightning-safe” areas are usually readily available and within a few feet of those threatened [1, 17, 18, 61, 77], the majority of sub-Saharan Africans are at risk 24/7/365 due to living in dwellings that are not lightning-safe. Further risk factors include engaging in largely outdoor, labor-intensive work such as farming and shepherding [40]. Worshippers often meeting outdoors and children walking to or attending school, roadside shopkeepers, those walking to the market, working in mines, or other outdoor activities are also all at risk [1, 47]. Poor or nonexistent lightning detection systems, little or no incorporation of lightning data into forecasting, no warnings to the public and those at risk, cultural beliefs, and many other factors keep injuries, deaths, and property damage from lightning a substantial threat to entire families, schools, villages, and populations [1].

ACLENet was founded to address many aspects of lightning safety, public education, and injury prevention and to work with governments and other agencies with similar goals [89].

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