Assessing Lightning Risk in Africa: A Framework Integrating Hazard, Exposure, and Vulnerability via the African Lightning Incident Database

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ABSTRACT: Lightning is a significant yet underreported hazard across Africa, with casualty rates far exceeding those in developed nations. This study analyzes 1290 lightning incident reports from the African Lightning Incident Database (ALID), covering 44 countries between 2018 and 2023, documenting 3047 fatalities and 3703 injuries. We characterize African lightning risk through the hazard–exposure–vulnerability framework. Seasonal casualty patterns closely follow hemispheric thunderstorm activity (hazard). National casualty rates in several central and southern African countries exceed 20 per million annually, which is roughly 20 times higher than developed nations. Only 13% of African incidents involve single victims compared to 90%+ in the United States and United Kingdom, with an average of 5.3 casualties per event reflecting concentrated exposure in group settings. Nearly half (49.6%) of casualties occur indoors in buildings lacking lightning protection, and children account for 57.4% of known casualties, often at unprotected schools (vulnerability). Risk assessment for 15 countries identifies 5 very high risk countries [Democratic Republic of the Congo (DRC), Rwanda, Uganda, Malawi, Guinea] where hazard, exposure, and vulnerability interact to produce extreme casualty risk. Despite reporting limitations, ALID provides foundational evidence for risk characterization and supports targeted interventions including improved building standards for schools and public spaces, region-specific safety education, and expanded early warning systems to reduce Africa's disproportionate lightning impacts.

KEYWORDS: Atmosphere; Social Science; Africa; Lightning; Risk assessment

1. Introduction

While lightning is a global phenomenon, its impacts are disproportionately severe across Africa, where high lightning flash densities combine with extreme socioeconomic vulnerability to produce some of the world's highest fatality rates. Lightning claims more lives per capita in Africa than on any other continent, with casualty rates in some countries exceeding 20 deaths per million people annually, which is more than 20 times higher than those reported in most developed nations (Holle 2016; Holle and Cooper 2018; Zhang et al. 2026). This continuing problem reflects Africa's limited lightning-safe infrastructure, inadequate protection systems, and widespread lack of public awareness that leave millions exposed to a largely preventable hazard. Despite approximately one-third of a billion lightning strokes occurring annually across Africa according to the Global Lightning Dataset (GLD360) network (Vaisala 2026), lightning remains an often overlooked natural hazard on the continent. Previous studies have identified several African countries as having some of the highest population-weighted lightning fatality rates globally (Holle 2016; Holle and Cooper 2018), yet the broader continental picture of lightning-related casualties remains poorly understood (Cooper and Holle 2018). This knowledge gap is driven by underreporting, limited surveillance capacity, and the absence of comprehensive national monitoring systems in many countries. Without reliable and comprehensive data, it remains difficult to accurately assess lightning risk, implement effective mitigation strategies, or develop evidence-based public safety policies across the continent.

In developed nations, weather-related casualty data are often collected through robust and accessible national databases. For example, in the United States, the National Weather Service has systematically recorded lightning-related deaths, injuries, and damages since 1959, alongside other weather phenomena such as hurricanes, floods, and heat waves (https://www.weather.gov/hgx/stormdata). These records are regularly updated and publicly available. Other developed countries also capture the impacts of lightning on people, either independently or, in some cases, as part of broader storm hazard reporting systems, supported by standardized death certificates coded using international classification systems (López et al. 1993; https://www.who.int/standards/classifications/classification-of-diseases).

Many African nations lack such comprehensive systems. Death certificates may not be issued, and centralized agencies rarely record lightning as a distinct cause of death. As a result, lightning casualty data must be assembled from alternative sources such as media reports, military or police records, and informal community reporting. The increasing access of mobile phones and internet across the continent has improved the visibility of lightning incidents. However, reporting remains biased toward events with a large number of fatalities, and nonfatal injuries are frequently underreported or missing altogether.

Additional barriers to data collection include low literacy rates, limited media coverage in rural areas, and Africa's linguistic

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diversity. There are at least 75 languages spoken by over one million people in Africa. News may be reported in local, regional, or national languages, many of which are not indexed by international search engines. While widely available reports are often in Arabic, English, French, or Portuguese, lightning incidents documented in other languages may remain inaccessible. As a result, alternative approaches to data collection are necessary, a topic we will describe in more detail in the methodology section.

To help address this gap, the African Centres for Lightning Education Network (ACLENet, formerly the African Centres for Lightning and Electromagnetics Network) was founded to promote lightning safety through research, education, and advocacy. A key initiative is the African Lightning Incident Database (ALID; Holle and Cooper 2018), the first known effort to systematically compile lightning casualty data across Africa, primarily using media reports and other public sources. Multilingual volunteers play a crucial role in monitoring local coverage by translating local language reports. With ALID, a more complete, multinational dataset is now available (Cooper 2025), enabling the first continentwide analysis of lightning-related fatalities and injuries. This study examines spatial and temporal trends, identifies vulnerable populations, and explores the circumstances surrounding lightning incidents in Africa.

Previous studies on lightning casualties in Africa have primarily focused on individual countries or subnational regions, often using small datasets drawn from police reports, media coverage, or hospital records. For example, research in Uganda has shown the vulnerability of schoolchildren during thunderstorms, particularly in buildings lacking lightning protection systems (Holle and Cooper 2016; Tushemereirwe et al. 2021). Other country-level analyses have emerged from Malawi (Kalindekafe et al. 2018), Swaziland (now Eswatini; Dlamini 2009), and South Africa (Blumenthal 2005; Jandrell et al. 2009; Gijben 2012), but these efforts have generally been limited in scope and not comparable across regions due to inconsistent data sources and reporting standards.

With the creation of ALID, this study provides the first comprehensive, cross-national analysis of lightning casualties in Africa using systematically compiled data. We characterize African lightning risk through the hazard–exposure–vulnerability framework, integrating climatological observations (hazard), documented casualty patterns and demographics (exposure), and infrastructure deficiencies (vulnerability). We examine spatial and temporal patterns, assess risk for countries with sufficient data, and explore the circumstances surrounding lightning incidents. The findings provide an empirical foundation for evidence-based risk reduction interventions and public health policy. The remainder of this paper is structured as follows: Section 2 outlines the methodology, data collection, and risk assessment framework; section 3 presents key findings including integrated risk assessment; and section 4 discusses implications for lightning risk reduction, policy, and future research.

2. Data and methodology

a. Data collection through ACLENet

Since January 2018, ACLENet has systematically collected and published lightning injury and fatality reports from across Africa. These reports are listed in the monthly newsletter "The African Flash" and are archived by country and year on the ACLENet website for public access (https://aclenet.org/programs/research/country-news/). Most reports come from hourly Google Alerts on the term "lightning," monitored in English since 2018 by one of the authors (RLH). Since 2024, ACLENet staff have collected news reports weekly in several languages. Volunteers later joined to monitor alerts in Portuguese (since November 2018) and French (since March 2021), translating and submitting reports as needed. Additionally, any observer may submit an incident through ACLENet's website or via email. A growing network of "citizen reporters" across multiple countries contributes reports, including some translated from local-language radio or newspaper stories that may never appear online.

Prior to 2015, many African countries did not regularly publish news reports online. Some older reports were only available in print. RLH maintains a personal hard copy archive, which identified an additional 361 lightning events, primarily from 2005 to 2015, in South Africa and neighboring English-speaking countries. For these cases, only the country, number of fatalities and injuries, and month of occurrence were extracted. All of these reports have been added to ALID on ACLENet's website.

b. Data content and standardization

The level of detail in each report varies considerably depending on the source. Most reports include the year, date, and sometimes the estimated time of the event, along with the number of fatalities and injuries, the gender and age of those affected, and a brief narrative describing the circumstances. Some reports provide additional contextual information, while others contain only minimal details. To preserve long-term accessibility, each report is reformatted into a standardized, downloadable Word file and posted on the ACLENet website. These files include the original title, publication date and time, source link, report text, and, when available, the name of the submitting citizen reporter. In many cases, the listed date corresponds to the publication date of the news article rather than the actual date of the lightning incident. Figure 1 presents an example report from Kenya, showing the title, date, original link, and a brief event description.

The number of reports has grown steadily each year as more volunteers have joined the data collection effort. Although most current reports originate from online media sources, not all of these preserve their content indefinitely, so that posting online on the ACLENet website assures access. Duplicate reports from multiple media outlets are sometimes retained when they include substantially different information. Some sources summarize lightning activity over several days, weeks, or months, potentially introducing both overlapping and unique data. In multihazard situations, such as during floods or mudslides, lightning incidents may still be separately reported. Due to resource constraints, ACLENet does not independently verify each submission. All reports are made publicly available in their original form, leaving researchers to assess reliability and extract information as appropriate for their analyses.

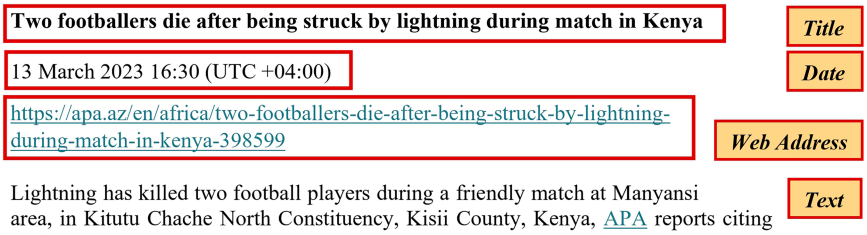


FIG. 1. A sample lightning incident report from Kenya.

c. *GLD360 network*

The Global Lightning Dataset (GLD360) network (Said and Murphy 2016) provided by Vaisala was used to create the lightning density maps in Africa. GLD360 is a terrestrial lightning-locating system (LLS) that uses a global network of GPS-synchronized passive broadband radio receivers sensitive to the very-low-frequency (VLF; <~48 kHz) band. Each sensor measures the time, azimuth, and amplitude of radio atmospherics generated by return strokes and in-cloud pulses and streams these data to a central processor. The central processor continuously ingests the data streams from each sensor and applies a location algorithm that calculates the time, location, and estimated peak current of each event. These solutions are then passed through a flash-grouping algorithm that clusters strokes and cloud pulses into flashes, assigning events within 20 km and 1 s of one another to the same flash.

Flash detection efficiency of the GLD360 varies by region and depends on several factors, including sensor availability, propagation effects in the Earth-ionosphere waveguide, sensor sensitivity, and the distribution of effective peak currents within each thunderstorm. GLD360 reliably detects more than 50% of cloud-to-ground (CG) flashes across most regions of Africa (R. Said 2026, personal communication).

d. *Supplemental data sources*

In addition to ALID, this study incorporates contextual data, such as national internet accessibility and population data, sourced from the World Bank database (World Bank Group 2025a,b). These data help to assess potential reporting bias and exposure rates across regions.

e. *Terminology*

- Fatality versus injury: "Fatality" refers to a death attributed to a lightning strike. "Injury" refers to nonfatal physical harm resulting from a lightning strike. Some incident reports include only fatalities or only injuries, while others include both.
- Casualty: We use the term "casualty" to represent both fatality and injury.
- Report: A "report" refers to a lightning casualty incident report, which is different from a meteorological "lightning report" or flash data.
- Event/incident: An "event" or "incident" refers to a single lightning strike or series of strikes in a particular time and location that caused one or more casualties. Multiple people affected by a single lightning strike are considered part of the same event.
- Child: "Child" refers to individuals under the age of 18, unless otherwise specified. Age information is extracted only when explicitly provided in the report.
- Population-normalized metrics: Rates such as "fatalities per million population" are used to account for differences in population size across countries and allow for meaningful comparison.

f. *Risk assessment framework*

We assess African lightning risk following established disaster risk frameworks (Cutter 1996; Crichton 1999):

$$\text{risk} = \text{hazard} \times \text{exposure} \times \text{vulnerability}.$$

This framework recognizes that casualty risk results from the interaction of three components:

- Hazard: The frequency and intensity of lightning occurrence, characterized through flash density (flashes per square kilometer per year) and thunder hours (annual hours with audible thunder).
- Exposure: The population and activities in lightning-affected areas, quantified through casualty data, demographic patterns, and geographic distribution.
- Vulnerability: The susceptibility to harm when exposed to lightning, estimated by infrastructure quality, lightning protection systems, socioeconomic factors, and emergency response capacity.

We characterize each component using available data from ALID, climatological observations, and supplemental sociodemographic datasets. However, data limitations, especially

for vulnerability, constrain quantitative risk scoring for many countries. For example, vulnerability includes infrastructure quality, lightning protection systems, emergency response capacity, and public awareness. These are factors that are strongly correlated with economic development. Due to the absence of direct measurements of building quality and lightning protection infrastructure across African countries, we use GDP per capita (World Bank Development Indicators) as a proxy indicator for vulnerability. Higher GDP typically corresponds to better building standards, greater capacity to implement lightning protection systems, more developed emergency response infrastructure, and higher public awareness through education systems.

For countries with ≥20 incident reports in ALID ($N = 15$), we assign qualitative risk component scores based on data-derived thresholds:

Hazard scoring (based on GLD360 climatological flash density):

- Very high (VH): >30 flashes per square kilometer per year.
- High (*H*): 15–30 flashes per square kilometer per year.
- Moderate (*M*): 5–15 flashes per square kilometer per year.
- Low (*L*): 1–5 flashes per square kilometer per year.
- Very low (VL): <1 flashes per square kilometer per year.

Exposure scoring (based on observed casualty rates per population, 2018–23):

- VH: >20 casualties per million per year.
- High (*H*): 5–20 casualties per million per year.
- Moderate (*M*): 1.5–5 casualties per million per year.
- Low (*L*): 0.1–1.5 casualties per million per year.
- VL: <0.1 casualties per million per year.

Vulnerability scoring (based on GDP per capita, World Bank 2023 data):

- VH: GDP per capita < $1,000.
- High (*H*): GDP per capita $1,000–$2,500.
- Moderate (*M*): GDP per capita $2,500–$5,000.
- Low (*L*): GDP per capita $5,000–$15,000.
- VL: GDP per capita > $15,000.

Overall risk is determined by integrating the three components. We assign qualitative scores (very high = 5, high = 4, moderate = 3, low = 2, very low = 1) to each component based on thresholds established from the data distribution and then calculate a multiplicative risk score (hazard × exposure × vulnerability). Scores of 60–125 indicate very high risk, 30–59 indicate high risk, and 15–29 indicate moderate risk. This multiplicative approach reflects the risk framework, wherein all three components must be present for casualty risk to manifest. High hazard alone does not create risk without exposed populations, and exposure without vulnerability produces minimal harm.

3. Results

a. Overview of reports and data coverage

The ALID used in this study includes 1290 original lightning incident reports from 44 African countries, as well as the Spanish enclave of Ceuta on the African mainland. The reports cover a primary analysis period of 2018–23, complemented by an earlier collection of hard copy reports from 2005 to 2015 that have been digitized and made available on the ACLENet website. Reports from 2024 to 2025 were excluded from this analysis to maintain a consistent observation window but remain archived for future updates. In total, the database documents 3047 lightning-related fatalities and 3703 injuries, representing 6750 casualties. Table 1 summarizes the number of reports, deaths, injuries, and total casualties by country. The largest numbers of reports and casualties come from Rwanda, Uganda, Zimbabwe, Kenya, and South Africa, where there are relatively active volunteer networks and stronger media coverage, and an English-language history that allows Google Alerts on lightning to appear more often than from many other countries.

Spatially, the distribution of lightning reports is uneven across the continent (Fig. 2a). Northern Africa and the Saharan region show few or no reports, consistent with the climatological scarcity of thunderstorms in these arid areas. Conversely, central and southern Africa, particularly near the Congo Basin and Lake Victoria, as well as South Africa, record higher frequencies of both lightning activity and casualties. Figure 2b illustrates that reporting density also correlates with internet accessibility, which remains a major driver of the data in ALID. Countries with limited internet accessibility and/or media presence (e.g., Central African Republic, Democratic Republic of the Congo) likely underreport lightning casualties, whereas nations with better digital infrastructure (e.g., Kenya, South Africa) produce more frequent updates. This imbalance highlights that observed spatial patterns in ALID reflect not only the true distribution of lightning hazards but also profound disparities in communication infrastructure, media systems, and reporting capacity, meaning the countries with the highest actual casualty burdens may paradoxically be the least represented in available data. Therefore, the spatial patterns in ALID should be interpreted not as a map of where lightning casualties occur but rather as a map of where lightning casualties are documented. Future research and intervention priorities must account for this systematic bias, ensuring that policy responses reach beyond the relatively visible cases captured in media reports to address the often-overlooked impacts on Africa's most vulnerable and least connected populations.

b. Fatalities, injuries, and casualty rates

Across Africa, lightning casualties are highly concentrated in a few countries, with Rwanda (1128 casualties), South Africa (761), Kenya (645), Zimbabwe (641), and Malawi (451) together accounting for over half of all documented casualties (see Fig. 3a). In contrast, countries in the Sahel and Maghreb regions report fewer incidents, primarily due to their dry climates and lower lightning frequency. Casualty rates normalized by population (Fig. 3b) provide a more balanced view of lightning risk. Namibia, Zimbabwe, and Malawi record the highest national rates, each exceeding 20 casualties per million people per year, roughly 15–20 times higher than typical rates in most non-African countries (Holle 2008, 2016). The pattern remains consistent even when the extreme event in Egypt is excluded

TABLE 1. Total number of reports, deaths, injuries, and casualties by country as of 31 Dec 2023. The N. after some countries indicates that we consider the country being in the Northern Hemisphere. Countries without any indicator are considered in the Southern Hemisphere. The asterisk (*) indicates the Ceuta enclave of Spain on the African continent.

Country	Reports	Deaths	Injuries	Casualties
Angola	48	137	199	336
Benin (N.)	5	8	4	12
Botswana	5	6	21	27
Burkina Faso (N.)	2	5	1	6
Burundi	4	14	30	44
Cameroon (N.)	11	17	67	84
Central African Republic (N.)	1	3	2	5
Chad (N.)	1	1	3	4
Dem Rep of the Congo	31	190	112	302
Egypt (N.)	1	469	0	469
Eswatini	3	6	13	19
Ethiopia (N.)	5	20	11	31
Gambia (N.)	6	11	8	19
Ghana (N.)	19	26	23	49
Guinea (N.)	29	68	100	168
Guinea-Bissau (N.)	3	17	19	36
Ivory Coast (N.)	7	16	5	21
Kenya	79	243	402	645
Liberia (N.)	7	14	7	21
Madagascar	3	22	15	37
Malawi	81	149	302	451
Mali (N.)	3	5	4	9
Mauritania (N.)	1	4	0	4
Mauritius	1	0	2	2
Morocco (N.)	4	7	6	13
Mozambique	28	136	26	162
Namibia	49	61	31	92
Niger (N.)	2	3	2	5
Nigeria (N.)	52	119	41	160
Rwanda	67	244	884	1128
São Tomé and Príncipe (N.)	1	0	1	1
Senegal (N.)	27	50	15	65
Sierra Leone (N.)	2	14	0	14
Somalia (N.)	3	6	6	12
Spain/Ceuta* (N.)	1	0	2	2
South Africa	270	328	433	761
South Sudan (N.)	7	13	15	28
Sudan (N.)	8	26	15	41
Tanzania	34	98	112	210
Togo (N.)	1	0	0	0
Tunisia (N.)	4	4	0	4
Uganda (N.)	164	93	349	442
Zambia	60	124	44	168
Zimbabwe	150	270	371	641
Total	1290	3047	3703	6750

(see more in section 3c), indicating that the elevated lightning risk is a regional characteristic, rather than an artifact of isolated events. Nonetheless, these high rates may be affected by selective reporting. Large-scale incidents tend to receive more media attention than isolated fatalities. Underreporting of single casualty events likely results in underestimation of total casualties. For comparison, developed countries typically record 0.1–0.5 lightning deaths per million people per year. The fact that the majority of countries record rates above 1.5 deaths per million, particularly in central and southern Africa, and that two-thirds exceed 5 deaths per million is concerning.

c. *Casualties per report, multivictim events, and single-fatality percentage*

Before discussing casualty statistics, it is critical to acknowledge a fundamental reporting bias associated with media-based databases. Multiple-casualty events usually receive disproportionate media attention, while single-fatality incidents, particularly in rural areas, often go unreported. This bias means that ALID's casualty-per-event statistics likely overestimate the true average, as isolated incidents involving one or two victims are systematically underrepresented. Despite this bias, the patterns observed in ALID remain highly informative, even when accounting for reporting bias.

Table 2 summarizes casualty statistics for the ALID dataset. The average number of deaths per report, injuries per report, and total casualties per report are 2.4, 2.9, and 5.3, respectively. In contrast, developed countries such as the United States generally average about one casualty per event (Curran et al. 2000). While media bias toward multiple-casualty events may have inflated these African averages, the substantial difference is nonetheless striking and reflects real differences in exposure patterns. This difference suggests that African lightning incidents often involve multiple victims, frequently in group environments such as classrooms, churches, or communal work areas. Many of these structures lack proper lightning protection or grounding, leading to multiple casualties. Countries with particularly high casualties per report include Rwanda (16.8), Madagascar (12.3), Guinea-Bissau (12.0), and Burundi (11.0). These numbers are far above global norms and indicate the lightning-related hazards vulnerability in these countries, even accounting for the likelihood that single-casualty events are underreported.

One historically catastrophic event occurred in Dronka, Egypt, on 2 November 1994, when lightning ignited three large fuel tanks during heavy rainfall and flooding, resulting in 469 fatalities. During a set of very severe thunderstorms over the area that caused much damage and flash flooding, a flash of lightning ignited three oil storage tanks each holding about 5000 tons of aircraft or diesel fuel. These tanks were located on a railway line that subsequently collapsed as floodwaters built up behind it. The floodwaters swept the blazing fuel into the village killing a very large number of people. This event was certified as the highest mortality (indirect strike) associated with lightning by the World Meteorological Organization (Cerveny et al. 2017). Although there is a debate whether casualties caused by an indirect lightning should be counted as lightning casualties, the event is still so significant that it is counted here to bring attention to the danger of lightning and to promote lightning safety.

Although outliers such as Dronka slightly increase the regional averages, the mean number of casualties per incident remains high even when such events are excluded, indicating a persistent vulnerability. However, interpreting these averages

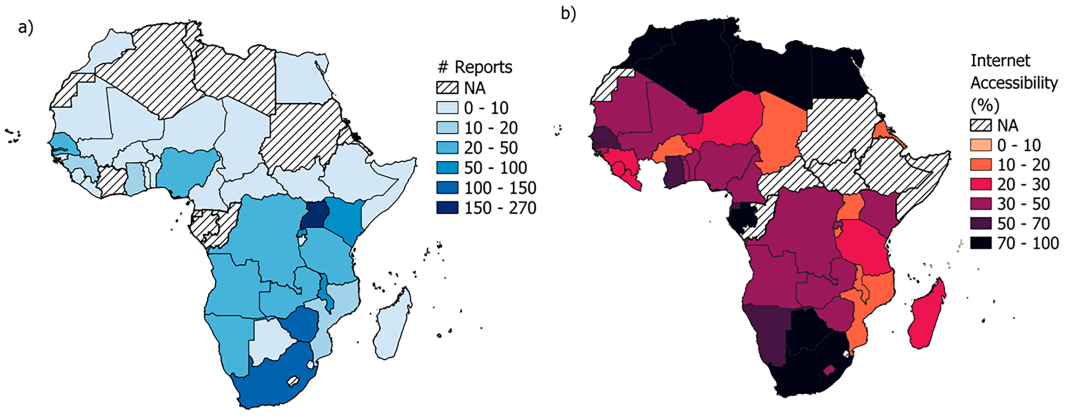


FIG. 2. (a) Map of lightning casualty reports for each African country as of 31 Dec 2023; (b) map of internet accessibility as percentage for each Africa country as of 31 Dec 2023.

requires caution. Incomplete media coverage, differing levels of press freedom, stability, and varying awareness can all bias results. Most significantly, media preferentially reports dramatic multiple-casualty events, meaning ALID systematically underrepresents single-fatality incidents that characterize most developed-nation lightning casualties. This reporting bias means the true average casualties per African lightning incident are likely lower than ALID suggests, but the frequency of group casualties remains genuinely elevated compared to global norms. Countries with advanced reporting systems might appear to have more complete documentation but may still miss rural single-victim events. Similarly, the injury-to-death ratio of 1.2 indicates that many victims do not survive, likely reflecting challenges in emergency medical response, long transport distances to hospitals, and limited postinjury care. Lack of knowledge of lightning injury avoidance behaviors may be a contributing factor to many lightning fatalities and injuries.

A striking finding from the ALID database is that only 12.9% of African lightning incidents involve a single fatality (Table 3). By comparison, more than 90% of incidents in the United States and United Kingdom involve just one death (Curran et al. 2000; Elsom and Webb 2014). Singapore has a single fatality figure of 72% (Pakiam et al. 1981). Note that the 72% is from a paper in the early 1990s when cellphone and advanced technology were not available. Even in Bangladesh, where lightning is a leading natural hazard, about half of recorded events involve single fatalities (Dewan et al. 2017). This significant difference persists even under conservative interpretations. If we assume that ALID captures only 50% of single-fatality events but 90% of multiple-casualty events, the corrected single-fatality percentage would rise to approximately 20%–25%, which is still far below the 90%+ observed in developed nations. This suggests that African lightning casualties occur more frequently in group settings, reflecting insufficient lightning protection in public gathering places such as schools, churches, and communal work areas where many people congregate.

d. Relationship between lightning activity and casualties

Two complementary metrics are used to characterize Africa's lightning climatology: lightning flash density (flashes per square kilometer per year) and thunder hours (the number of hours per year during which thunder is audible at a location). Flash density provides a direct measure of lightning frequency, while

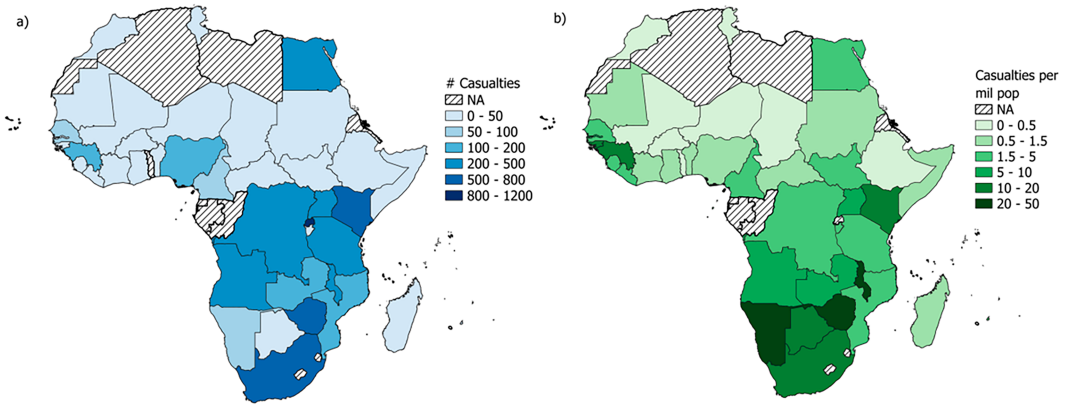


FIG. 3. Map of (a) number of casualties for each African country as of 31 Dec 2023 and (b) casualties per million population for each African country as of 31 Dec 2023.

TABLE 2. Deaths per report, injuries per report, casualties per report, and injuries per death in Africa.

Deaths per report	Injuries per report	Casualties per report	Injuries per death
2.4	2.9	5.3	1.2

thunder hours offer a perspective on thunderstorm exposure that correlates closely with human risk.

The highest lightning densities (≥16 flashes per square kilometer per year) occur across the Congo Basin, the Lake Victoria region, and some of eastern and southern Africa, where persistent deep convection, high humidity, and strong vertical instability dominate (Albrecht et al. 2016; Virts et al. 2013). These same regions are often associated with the higher casualty rates. Within this region, the Democratic Republic of the Congo (DRC) stands out as one of the global lightning hotspots, with flash densities exceeding 100 flashes per square kilometer per year in localized areas (Albrecht et al. 2016), yet the DRC has very few reports likely due to decades of civil strife, disease, and other factors that may cause lightning incidents to be underreported or deprioritized.

On the other hand, northern Africa experiences much lower lightning frequency, particularly across the Sahara Desert, where arid conditions and a lack of convective moisture limit thunderstorm development. However, localized lightning activity (approximately 1–6 flashes per square kilometer per year) is observed along the northwestern Mediterranean coast, including northern Morocco, Algeria, and Tunisia. This activity peaks primarily from fall to early spring, when strong cold fronts and maritime air intrusions produce severe convective storms (Anderson and Klugmann 2014). Despite this, lightning-related casualties in these regions remain relatively low, possibly due to low population densities.

In general, lightning casualties across Africa in Fig. 5 follow the climatological distribution of lightning activity. Seasonal and hemispheric patterns are further illustrated in Fig. 4, which compares lightning density (left panel) with average thunder hours (right panel). In the Northern Hemisphere as shown in Fig. 5, casualties peak between May and September, coinciding with the rainy season and the northward shift of the intertropical convergence zone (ITCZ; Nicholson 2018). A smaller rise can be seen in November, which was caused by the Dronka disaster in Egypt. In the Southern Hemisphere, the majority of casualties occur between November and March, the austral summer that has peak thunderstorm activity. Nearly 90% of casualties in the Southern Hemisphere occur within this 5-month period, with Rwanda, South Africa, Kenya, and Zimbabwe accounting for the majority of incidents. These patterns show a strong seasonal variation between lightning occurrence and reported injuries across Africa, despite differences in reporting infrastructure.

TABLE 3. Single fatality per incident percentages in different countries/areas.

Countries	Single fatalities (%)	Reference
England and Wales	98	Elsom and Webb (2014)
United States	91	Curran et al. (2000)
Singapore	72	Pakiam et al. (1981)
Bangladesh	50	Dewan et al. (2017)
Africa	12.9	This study

While these hemispheric patterns provide a useful continental-scale overview, they necessarily simplify the regional complexity of African lightning climatology. Africa's large geographic extent produces diverse seasonal regimes. Northern Mediterranean regions are influenced by extratropical storm systems (Galanaki et al. 2018), West African Sahel countries experience monsoon-driven peaks (Grist and Nicholson 2001), equatorial regions often exhibit bimodal seasonal cycles (Nicholson 2017), and southern African countries show strong austral summer concentration (Gijben 2012). Although the seasonal migration of the ITCZ provides the dominant large-scale forcing mechanism, its influence is neither spatially uniform nor continuous because it is modified by topography, regional circulation patterns, and oceanic boundaries (Nicholson 2018). A more detailed examination of the relationship between lightning climatology and casualties would, therefore, require country-specific or regional analyses with more homogeneous seasonal characteristics, which is beyond the scope of this continental database study. Nevertheless, the hemispheric framework captures the primary large-scale seasonal patterns governing lightning casualties across Africa while acknowledging the continent's substantial climatological diversity.

e. Demographic patterns

Of the 6750 individual casualties documented across 1290 incident reports, demographic information is severely limited, with only 24% of the reported individuals having any reported age or gender data. Specifically, 938 casualties (14% of total) were identified as children under 18 years of age, and 696 (10% of total) casualties were identified as adults with gender reported. Of the 696 adult individuals, 409 (59% of those with known gender) were reported as male and 287 (41%) were reported as females. The 76% unknown rate for demographic information reflects the typical brevity of media coverage, which often reports casualty numbers without identifying individuals. This high rate of missing data introduces significant uncertainty into demographic patterns. It is possible that reporting is nonrandom. For example, child casualties in dramatic school incidents may receive more detailed coverage than adult casualties in isolated rural events. Therefore, while children dominate among casualties, the true continental child casualty percentage remains uncertain.

Nonetheless, the concentration of documented casualties among children is striking. Although Africa's youth population structure (median age of 19) partly contributes to this pattern, it alone cannot explain such a high proportion. The high percentage of the incidents involving children shows the vulnerability of the educational infrastructure, particularly unprotected schools. In many rural areas, schools are single-story structures with ungrounded wiring and inadequate lightning

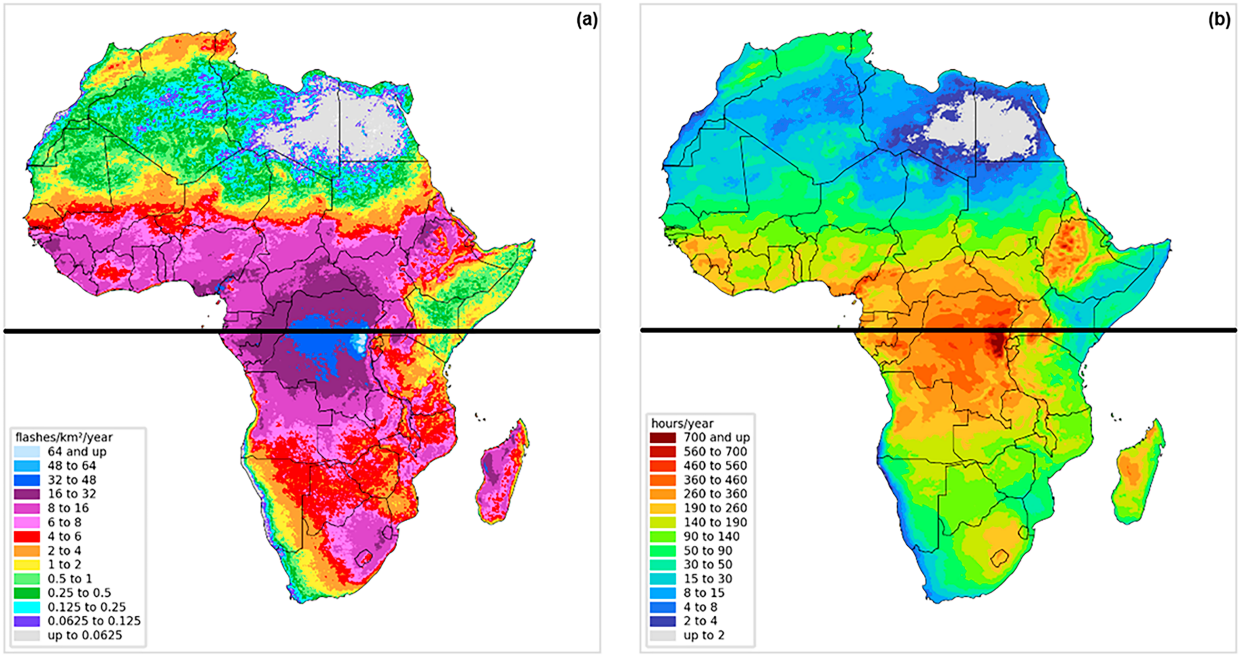


FIG. 4. (a) Average annual lightning density and (b) average annual thunder hours, as detected by the GLD360 network between 2015 and 2024. The thick black line indicates the equator.

protection, which can potentially cause massive casualties when there is a direct strike. Additionally, classrooms meant for half that number may accommodate 50–80 students. Notable examples include the Runyanya Primary School disaster in Uganda on 28 June 2011, which killed 18 children and injured 38 others (Cooper et al. 2024). International Lightning Safety Day was established to commemorate the incident and raise global awareness about lightning dangers and promote safety, especially in developing countries where lightning fatalities are a significant issue. This was not the only massive lightning casualty event. More recently, on 31 July 2024, lightning struck Oweko Primary School in Uganda's Nebbi District during a football event, injuring 77 pupils, one teacher, and one staff member (Akantambira 2024). These events represent the persistent vulnerability of educational facilities and the urgent need for lightning-safe construction and grounding standards.

The U.S. lightning safety slogan, "When Thunder Roars, Go Indoors," often does not apply to many African environments. In fact, nearly half of all lightning casualties in Africa occur indoors (Fig. 6). Approximately 22% of such incidents happen in homes or residences, 11% happen in schools, and another 11% happen in churches. The remaining cases occur outdoors, primarily in unspecified outdoor settings (20.6%). In addition, casualties occur while sheltering under trees

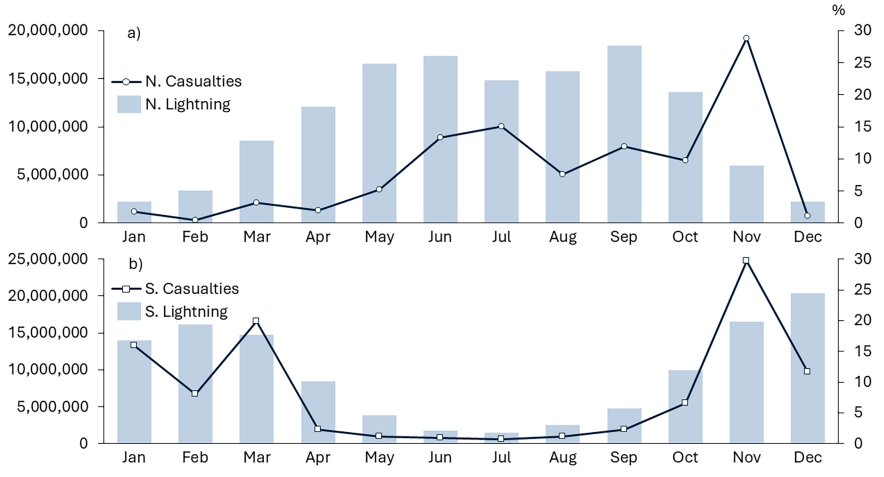


FIG. 5. Monthly casualties and lightning strokes detected by GLD360 (Holle et al. 2018) for (a) African countries in the Northern Hemisphere and (b) African countries in the Southern Hemisphere.

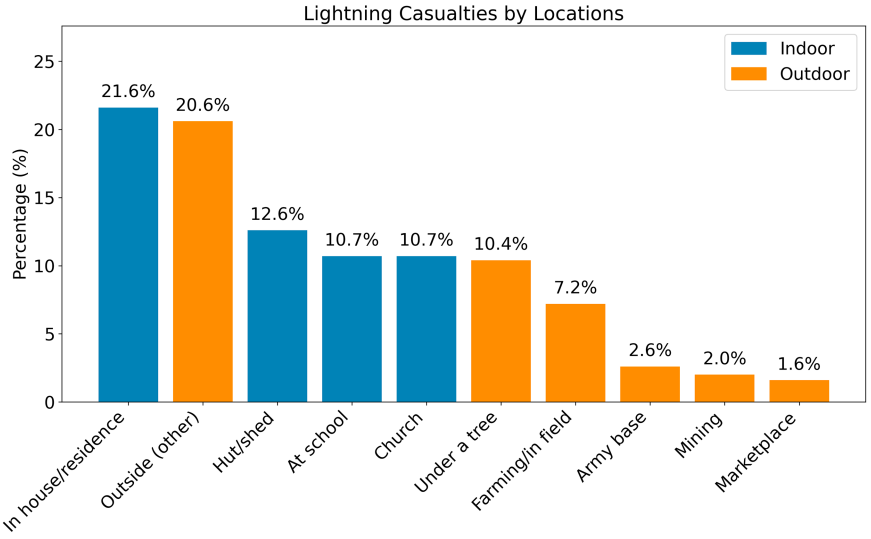


FIG. 6. Lightning casualties by locations.

(10.4%), as well as during labor-intensive activities such as farming and herding (7.2%), at military bases (2.6%), and open-market trading (2%). This is very different from developed countries, where lightning deaths are mostly associated with outdoor recreational activities (e.g., hunting, fishing, hiking; Jensenius 2025), while being indoors is typically effective. In much of Africa, however, indoor situations cannot be considered "safe," as many homes and buildings are made by concrete block or mud-brick huts with thatch or metal sheeting for roofs which do not provide protection from lightning. In many rural areas, workers are often caught outside during storms with no access to lightning-safe structures, further increasing vulnerability. This finding shows the urgent need to adjust lightning safety guidelines for environments where "going indoors" does not ensure safety. In Angola, among the 33 cases with reported locations, 15 occurred inside the victim's home, 7 occurred outdoors, 3 occurred in grass-covered huts or houses, 3 occurred during work-related activities, 2 occurred under trees, 1 occurred in a backyard, 1 occurred in a marketplace, and 1 occurred on a roof. This is very different from the situations in the United States, where most of the buildings and homes are lightning safe and widely available within walking distance. The U.S. people staying home during thunderstorms would be safe. However, in countries like Angola, people can be injured by lightning when they stay at home because their home is not lightning safe or lacks a well-maintained lightning protection system that meets international standards (IEC 62305). In addition, most cases involved more than one casualty, and these casualties were usually from the same family. One report relates two sisters who were killed when walking to a neighbor's home for better safety because they were afraid of sheltering from the thunderstorm at their own home.

f. Risk assessment

Integrating the hazard, exposure, and vulnerability components documented in earlier sections enables risk characterization for countries with sufficient data (≥20 incident reports). Table 4 summarizes risk components and overall risk classifications for 15 countries meeting this threshold.

Five countries emerge as very high risk (DRC, Guinea, Malawi, Rwanda, and Uganda,), exhibiting elevated values across multiple components. Malawi demonstrates the highest overall risk, combining moderate lightning hazard (flash densities of 30–40 km^{-2} yr^{-1}) with very high exposure (21.4 casualties per million annually) and very high vulnerability (GDP per capita of $733). The DRC presents a critical assessment challenge. Despite experiencing some of the world's highest lightning flash densities (80–100 km^{-2} yr^{-1}) and severe infrastructure vulnerability (GDP of $806.8), the DRC shows only moderate documented exposure, possibly due to underreporting. A population of ~95 million exposed to extreme hazard with minimal protective infrastructure almost certainly experiences casualty rates comparable to or even exceeding other very high risk countries, but civil conflict, limited communication infrastructure, and absent systematic surveillance prevent documentation. The DRC's very high risk classification based on available data should be interpreted as a minimum estimate; actual risk is likely extreme.

The remaining 10 countries are classified as high risk, with varying combinations of risk components. Several patterns emerge from this group:

High hazard with moderate-to-low exposure: Nigeria experiences high lightning flash densities (>20 km^{-2} yr^{-1}) and high vulnerability but low documented exposure (2.1 casualties per million) and high hazard, suggesting underreporting rather than low casualty rates, given the country's large population and limited lightning protection infrastructure.

Moderate hazard with very high exposure: Zimbabwe and Namibia both show casualty rates exceeding 30 per million despite moderate flash densities, indicating that population exposure patterns and vulnerability factors drive risk independent of lightning frequency. Namibia's relatively lower vulnerability score (GDP of $5,573) compared to Zimbabwe suggests that

TABLE 4. Integrated lightning risk assessment for 15 African countries with ≥20 incident reports in ALID. Hazard is characterized by climatological flash density, exposure by observed casualty rates normalized by population, and vulnerability by reported country GDP. Overall risk is determined by multiplicative integration of the three components (risk = hazard × exposure × vulnerability).

Country	Hazard (events km^{-2} yr^{-1})	Exposure (casualties per million population)	Vulnerability (GDP per capita)	Risk score	Risk category
Angola	*H* (19.6)	*H* (9.1)	*M* ($3,129.5)	48	*H*
DRC	VH (57.2)	*M* (2.9)	VH ($806.8)	75	VH
Guinea	*H* (23.5)	*H* (11.7)	*H* ($1,877.3)	64	VH
Kenya	*L* (2.9)	*H* (11.7)	*H* ($2,362.9)	32	*H*
Malawi	*M* (14.6)	VH (21.4)	VH ($671.5)	75	VH
Mozambique	*M* (12.6)	*M* (4.8)	VH ($626.9)	45	*H*
Namibia	*M* (6.2)	VH (31)	*M* ($4,875.9)	45	*H*
Nigeria	*H* (18.4)	*L* (0.7)	*H* ($1,224.3)	32	*H*
Rwanda	*M* (9.4)	VH (80.8)	*H* ($1,123.7)	60	VH
Senegal	*M* (8.5)	*M* (3.6)	*H* ($1,954.7)	36	*H*
South Africa	*M* (12.6)	*H* (12)	*L* ($6,597.7)	24	*M*
Tanzania	*M* (10.2)	*M* (3.2)	*H* ($1,318.8)	36	*H*
Uganda	*H* (16.6)	*H* (9.1)	*H* ($1,206.3)	64	VH
Zambia	*H* (16.4)	*H* (8.1)	*H* ($1,317.9)	64	VH
Zimbabwe	*M* (10.8)	VH (39.2)	*M* ($3,021.4)	45	*H*

economic resources alone do not eliminate risk when exposure is high.

Very high vulnerability with moderate hazard and exposure: Mozambique demonstrates how infrastructure deficiencies can increase risk even with moderate hazard and exposure levels. With moderate hazard (4–6 km^{-2} yr^{-1}) and exposure (4.8 casualties per million), Mozambique shows how insufficient infrastructure transforms moderate lightning activity into significant casualty risk.

Figure 7 presents spatial distributions of (Fig. 7a) risk scores and (Fig. 7b) the dominant risk factors summarized in Table 3. It highlights both the spatial variation in overall risk and the predominant factors contributing to risk in different locations. Spatial patterns in risk align partially but not completely with climatological lightning distribution. The highest-risk countries experience both substantial lightning activity and limited economic resources for protective infrastructure. However, the imperfect correlation between hazard and overall risk demonstrates that lightning frequency alone does not determine casualty outcomes. Countries can exhibit high casualty rates despite moderate hazard (e.g., Zimbabwe, Namibia) when exposure and vulnerability are elevated, while others with high hazard maintain moderate risk through reduced vulnerability. South Africa's relatively better infrastructure, despite high lightning exposure, makes it the only country classified as having a moderate overall risk in the analysis.

4. Discussion

The ALID is the largest and most comprehensive publicly accessible record of lightning-related casualties across Africa to our knowledge. Although incomplete, it provides a valuable foundation for understanding the spatial and temporal distributions of lightning impacts on the continent. The database continues to grow through the efforts of ACLENet staff and multilingual volunteers who collect and translate reports

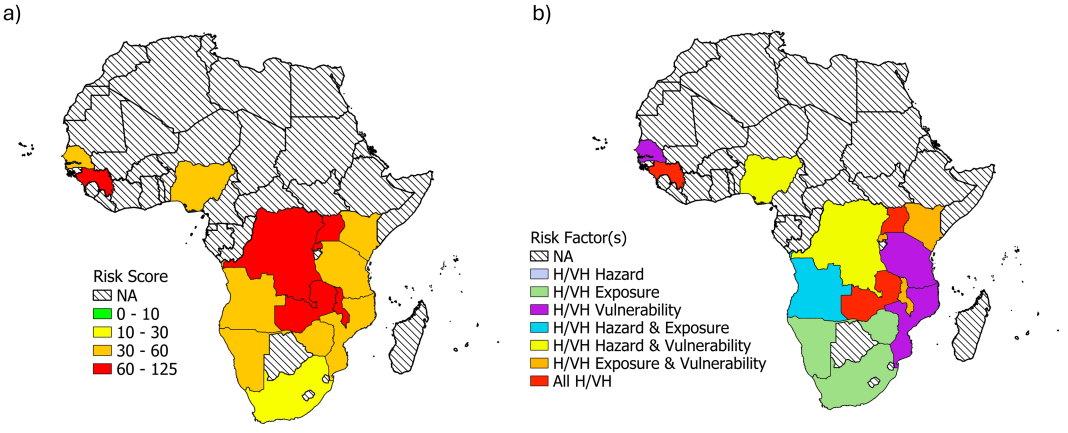


FIG. 7. Map of (a) risk scores and (b) dominant risk factors, both derived from the data presented in Table 3.

from diverse sources, including newspapers, radio broadcasts, and online platforms. Sustained citizen engagement and regional partnerships remain essential for improving data coverage, particularly in underrepresented linguistic and geographic areas.

Despite significant progress, the ALID dataset inevitably reflects uneven reporting across countries. The number of available reports varies widely due to differences in population density, lightning exposure, internet accessibility, language accessibility, media instability, and cultural factors. In some small countries such as Gambia and Guinea-Bissau, few reports are available simply because of limited population or low flash density. In contrast, regions with active media networks such as Kenya and South Africa contribute disproportionately to the dataset. Cultural perceptions of lightning also influence reporting. In several communities, lightning strikes are associated with misfortune or divine punishment, discouraging victims' families from speaking publicly. In other areas, limited internet access and media instability due to civil unrest, disease outbreaks, or weak journalistic capacity further constrain the data collection. The large linguistic diversity of Africa remains a major obstacle to full coverage as many languages are not searchable for reports. Although Arabic reports have recently been incorporated, additional volunteer translators are needed for local and regional languages.

These data limitations create critical challenges: what ALID documents reflect both actual risk patterns and reporting capacity, and separating these remains fundamentally difficult. Several of our key findings require careful interpretation in light of these "unknown unknowns." While the DRC and Congo Basin experience flash densities exceeding 80–100 km^{-2} yr^{-1} and categorized as very high risk, it only represents a moderate risk in exposure (2.9 casualties per million population), and the overall risk score is less than Malawi, Guinea, and Uganda. This creates an "invisibility paradox," where the regions we identify as high risk may not be the highest-risk regions but rather the highest-documented regions. The real continental casualty number likely substantially exceeds our documented 700+ annual casualties but by what factor remains unknowable without systematic health sector surveillance.

These unknown unknowns also directly constrain the risk assessment framework applied in this study. First, only 15 of 44 countries have more than 20 reports. Second, reporting biases (including media preference for multiple-casualty events and geographic disparities in communication infrastructure) may underestimate true exposure, particularly in rural- and conflict-affected regions. Third, vulnerability assessment relies on GDP per capita as a proxy for infrastructure quality. While GDP generally correlates with building standards and protective capacity, individual countries may have better or worse lightning protection infrastructure than GDP alone suggests. Fourth, temporal coverage is limited (2018–23 except for South Africa), potentially missing longer-term patterns.

Despite these limitations and substantial uncertainties, the framework provides a systematic basis for interpreting ALID findings and examining the factors associated with Africa's lightning casualty risks. Several conclusions appear robust: 1) Africa experiences disproportionate lightning casualty challenges, 2) group casualties predominate over single-victim events, 3) indoor environments are not lightning safe, 4) educational infrastructure is vulnerable, and 5) seasonal patterns track thunderstorm activity. We cannot reliably conclude as follows: 1) absolute continental casualty challenge (likely 2–5 × higher than documented), 2) risk in underreported regions (e.g., DRC, Chad likely worse than data suggest), or 3) precise casualty-per-event averages. These unknown unknowns do not invalidate ALID's findings but frame their interpretation. The database characterizes patterns among documented events and identifies vulnerability factors while acknowledging that the full scope remains partially obscured.

Our findings show the importance of integrating lightning safety into broader disaster risk reduction. Two factors essential for lightning casualty prevention are availability of lightning-safe structures and behavioral education. Understanding and improved forecasting of thunderstorm activity across Africa can also contribute to protecting vulnerable populations. Ground-based and satellite lightning detection networks expansion would improve situational awareness, while public early warning systems could help communities take timely shelter (United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States and United Nations Office for Disaster Risk Reduction 2024; Gijben 2012). Beyond technological solutions, education remains a key priority. Training teachers, health workers, and local authorities in lightning safety practices can significantly reduce casualties, particularly among children in schools without proper protection. The U.S. examples have shown that education of the media in lightning science and emphasizing their importance in spreading lightning safety information and dispelling myths is also an important factor (Trengove and Jandrell 2010; Trengove 2012; Trengove and Jandrell 2015). Establishing national reporting systems, similar to those used in developed countries, would strengthen data consistency and allow health and disaster agencies to evaluate long-term trends. ALID demonstrates that meaningful progress is possible through collaboration among volunteer scientists, citizen volunteers, and local media. Continued support from governments, universities, the press, and international partners will be essential to maintain and expand the database, ensuring that Africa's lightning risks are better understood, documented, and mitigated in the years ahead.

5. Conclusions

The African Lightning Incident Database (ALID), compiled by ACLENet, currently represents the most comprehensive publicly available record of lightning casualties across Africa. As of 31 December 2023, it contains 1290 verified incident reports from 44 countries and territories. Although incomplete, ALID demonstrates the value of sustained volunteer collaboration and multilingual data gathering in a region where official statistics remain scarce. The database provides a vital foundation for understanding the scope and characteristics of lightning impacts across the continent.

Analysis of ALID data reveals several key patterns. Through 2023, reported incidents resulted in 3047 fatalities and 3703

injuries in Africa. Casualty rates vary widely, with several central and southern African nations exceeding 20 deaths and injuries per million people annually, up to 20 times higher than in most non-African countries. Unlike in developed regions, where the majority of lightning events involve single victims, the majority of African incidents reported multiple casualties (only 13% single victims). The average of 5.3 casualties per event indicates that many strikes occurred in unsafe environments. Nearly half of all incidents occurred indoors, reflecting the widespread absence of lightning-safe structures. Children accounted for 57.4% of known victims, a disproportionate number compared to their proportion of the population, showing their greater vulnerability. Seasonal trends followed hemispheric lightning activity, confirming strong links between thunderstorm climatological activities and casualty occurrences.

The integrated hazard–exposure–vulnerability framework highlights that lightning casualty risk across Africa is shaped not only by lightning frequency but also by the interaction between population exposure and societal vulnerability. Countries classified as very high risk generally combine elevated lightning activity with high exposure and limited protective infrastructure, although the relative contribution of each component varies substantially between countries. The analysis also demonstrates that high casualty risk can occur even in regions with only moderate lightning hazards when vulnerability and exposure remain high, while improved infrastructure and protective capacity can reduce risk despite frequent lightning activity. These findings emphasize that lightning casualties in Africa are not solely a climatological problem but also reflect disparities in infrastructure, communication systems, and access to lightning protection. The framework further identifies substantial reporting gaps, particularly in conflict-affected and underserved regions such as the DRC, where documented casualty rates likely underestimate the true scale of risk.

Despite limitations related to underreporting and uneven media coverage, ALID provides the empirical evidence required to quantify risk and prioritize targeted interventions addressing each component. Building standards must be improved to reduce vulnerability, particularly for schools and public gathering spaces. Public education campaigns must move beyond generic "go indoors" messaging to region-specific guidance acknowledging infrastructure limitations. Early warning and reporting systems must be strengthened to reduce hazard impact in data-sparse regions. The database establishes a critical baseline for future research, enabling comparison across regions. Continued expansion of ALID through local partnerships, volunteer engagement, and multilingual monitoring will be essential to improving data completeness and guiding lightning safety efforts across the continent.

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Data availability statement. The African Lightning Incident Database (ALID) is permanently archived and publicly available via Zenodo at https://zenodo.org/records/20127798. Individual reports are also accessible through the ACLENet website at https://aclenet.org/programs/research/country-news/directory-of-countries.html.

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