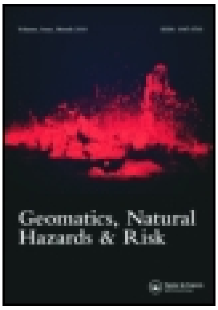


Geomatics, Natural Hazards and Risk

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tgnh20

Lightning safety of under-privileged communities around Lake Victoria

Ahurra kulyaka Mary[a] & Chandima Gomes[b]

[a] National Meteorological Centre, P. O. Box 7025, Kampala, Uganda

[b] Centre for Electromagnetic and Lightning Protection, UPM, Serdang, 43400 Selangor, Malaysia

Published online: 05 Jun 2014.

To cite this article: Ahurra kulyaka Mary & Chandima Gomes (2014): Lightning safety of under-privileged communities around Lake Victoria, Geomatics, Natural Hazards and Risk, DOI: 10.1080/19475705.2014.922506

To link to this article: http://dx.doi.org/10.1080/19475705.2014.922506

Geomatics, Natural Hazards and Risk, 2014
http://dx.doi.org/10.1080/19475705.2014.922506

Lightning safety of under-privileged communities around Lake Victoria

AHURRA KULYAKA MARY† and CHANDIMA GOMES*‡
†National Meteorological Centre, P. O. Box 7025, Kampala, Uganda
‡Centre for Electromagnetic and Lightning Protection, UPM, Serdang, 43400 Selangor, Malaysia

(*Received 17 December 2013; accepted 6 May 2014*)

This is one of the first studies on lightning incidents that take place in the neighbourhood of Lake Victoria, the largest tropical lake in the world that borders Uganda, Tanzania and Kenya. Lightning accident statistics in the region have been documented segment wise. The number of lightning occurrences in the north-western shore and that in the north-eastern shore were compared. The region has a distinctly recognizable season with high lightning accident density which runs from May to November and low lightning accident period from December to April. August peaks in lightning incidents. Lightning-related incidents are very much prevalent during the period between May and August due to the dominant south easterlies. The study reveals that the north-western part has slightly higher lightning accidents than the north-eastern part. North-eastern part records relatively high number of lightning accidents in the morning hours whereas the north-western sector experiences the same in the afternoon hours. Many features of lightning accidents and their locations have features that are in agreement with the same observed in other parts of East Africa. Following the statistics collected and incidents observed, suitable safety measures have been recommended for the communities that reside in the shores and nearby areas of Lake Victoria.

1. Introduction

Lake Victoria, which boarders Tanzania, Kenya and Uganda, is the second widest freshwater body in the world. Its extensive surface with catchment area of 184,000 km^2 belongs to the three bordering countries; the northern segment to Uganda (45% or 31,000 km^2), the southern segment to Tanzania (49% or 33,700 km^2) and small part of the north-eastern (NE) sector to Kenya (6% or 4,100 km^2). The lake occupies a wide depression near the equator, between the east and west Great Rift Valleys. The lake shore is highly indented, with many isles with varying sizes. Abundance of prehistoric remains that were found around the lake indicates that there were settlements and development of agriculture. There are many coastal settlements and large townships such as Kisumu (Kenya), Entebbe (Uganda), Bukoba, Mwanza and Musoma (Tanzania) that can be found in the region, which are connected with each other by naval routes and also with the cities on the coast of the Indian Ocean by railway lines. Figure 1 shows the location of Lake Vitoria in Africa (figure 1(*a*)) and the segments of the lake belonged to each bordering country (figure 1(*b*)). Lake Victoria provides a food basket to the whole of

*Corresponding author. Email: chandima@upm.edu.my; chandima.gomes@gmail.com

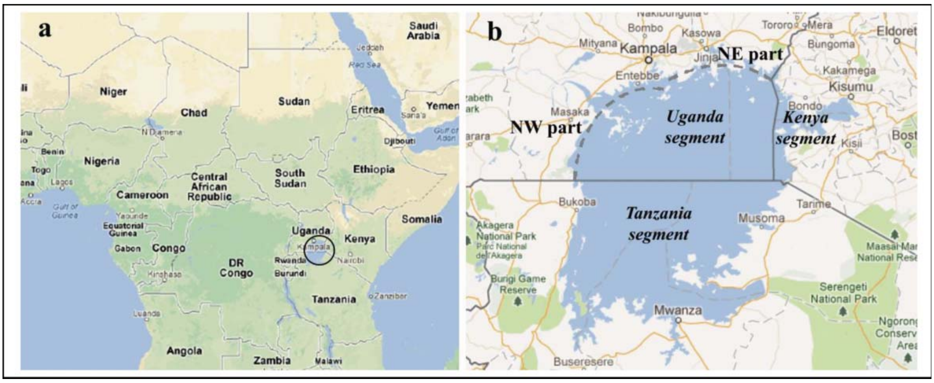


Figure 1. Geographical location of the area of investigation. (*a*) Location in the African continent (shown by black circle). (*b*) Expanded view of Lake Victoria map.

East African region. About 200,000 fishermen in the three bordering countries earn their bread and butter from the lake. The ecological significance of the lake is highlighted by the role that it plays in shaping regional weather patterns, especially with regard to rainfall and thunderstorm activities.

Every year, lightning strikes damage property and kill or injure scores of people in the lake proximity. Many of them are either fishermen or other dwellers that earn their living from the lake. Human accidents are mostly due to unawareness or ignorance of lightning safety measures by the people in the area. In most parts of East Africa, where the lightning ground flash density is high, people are most often affected by lightning as they take shelter inside unsafe structures or work outdoors during thunderstorms (Lubasi et al. 2012; Mary & Gomes, 2012). However, it should be noted that similar to the conditions in the developing countries in South Asia (Gomes et al. 2012a; Jayaratne & Gomes, 2012), due to financial constraints, people in the Lake Victoria basin could not refrain from their daily activities in order to avoid thunderstorms. The situation is worse in this region than in most parts of South Asia as the prevalent thunderstorm days per year are 287 (released by Uganda Meteorology Department and WMO). Furthermore, as it has been reported by Mary and Gomes (2012), a majority of permanent residences of people in rural Uganda are structures, extremely unsafe with regard to lightning. Hence, the lightning-safety rules developed and practiced in developed countries are not practically applicable in this part of the world.

In the recent past, Uganda Department of Meteorology, World Meteorological Organization (WMO), MTN Mobile Uganda, Ericsson, National Lake Rescue Institute and the Kalangala Fishing community have launched a pilot project of mobile weather alert to provide a localized weather alert service to fishing villages on Lake Victoria. Although initiated with noble intentions, there were many deficiencies of the programme as by now, especially with regard to lightning safety. The operational time of the weather alert service is from 6 am to 6 pm. The system hardly provides any information on approaching thunderstorms and their nature. This makes it difficult for lake dwellers to suspend their daily activities as the thunderstorms appear somewhat independent from other weather phenomena.

This research project has been conducted in the above backdrop, thus the objective of this work is to summarize the features of lightning environment in the Lake

Victoria basin with the view of providing practically viable solutions to the lightning threats imposed on the local communities.

2. Methodology

Information available on the meteorological features of Lake Victoria basin has been collected and analysed to understand the thunderstorm characteristics of the region. Data and information on lightning accidents that had occurred during 2010–2012 period have been collected in a region within a distance of about 50 km from the shores of Lake Victoria. The information collected have been analysed to find the patterns of lightning incidents, occurrence statistics, spatial and temporal variability of incidents, deaths and injuries, locations of occurrence, etc. Affected people were also interviewed for further details. Sources of information were printed media reports, personnel communication and site visits. Most of the data collected were cross-examined for the authenticity.

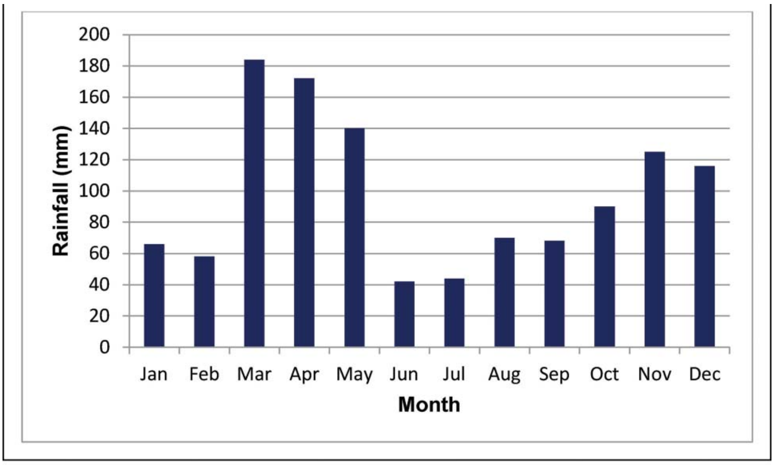
3. Information and observation

3.1. Meteorological features of Lake Victoria basin

Lake Victoria is such a large water body that it plays a significant role in governing the variation of both diurnal weather and annual climate. Atmospheric circulation in the vicinity of large inland water masses is affected by the frictional and thermal contrasts between the lake surface and the neighbouring land areas (Mukabana & Pielke 1996). For the surrounding landscapes up to about 100 km from the shore, Lake Victoria is the main source of moisture and latent heat which are the driving forces of the prevailing tropical climate (Anyah & Semazzi 2004). As per the meteorological observations (Uganda Meteorology Department), weather conditions in the lake can change abruptly, turning a mild breeze and calm surface into strong wind gusts that create 2–3-m waves that can capsize even medium-sized ferries and fishing vessels.

Figure 2(*a*) shows the mean monthly rainfall variation in the storage of Lake Victoria during a period 1998–2001 as per the data issued by Directorate of Water Development, Uganda. It can be seen that March–May and October–December are wet months with the former three-month period having higher rainfall. June–September and January–February are relatively dry months. However, even dry months are not as dry as one would expect. Even the driest month, June, gets over 40 mm of mean rainfall. Several models have been developed during the last couple of decades to predict the rainfall and water balance of the lake (Nicholson 1993, 1998; Ba & Nicholson 1998; Nicholson & Yin 2001). Figure 2(*b*) depicts the monthly variation rainfall pattern as per the long-term data (1941–1980) reported by Kizza et al. (2009). The data are pertinent to the weather stations in Jinja in the NE side and Entebbe in the north-western (NW) side. In both regions, the pattern of variation is similar and follows the mean rainfall of the entire Lake Victoria storage; however, NE part has received noticeably less rain during this period.

The mean monthly temperature of the Lake Victoria region remains mostly around 21 °C throughout the year (based on measurements at Entebbe station) with maximum and minimum values of 22.5 and 20.5 °C, which are recorded in March and July/August, respectively (WeatherSpark 2014). The lowest average temperature reaches 16 °C in July–September while highest average temperature of 27 °C is



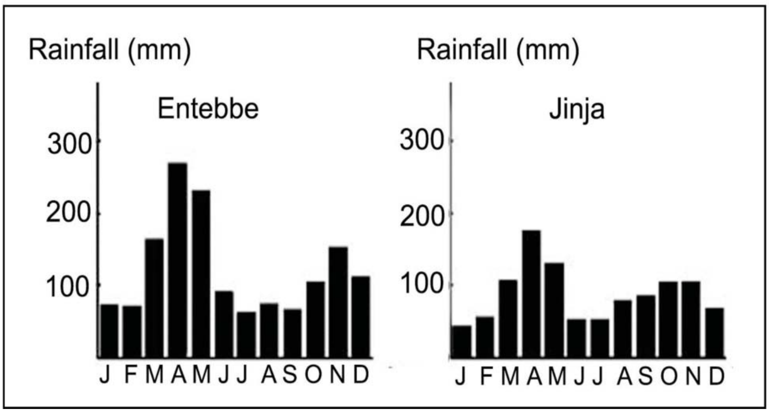


Figure 2. (*a*) Mean monthly rainfall pattern in the entire Lake Victoria storage between 1998 and 2001 (data adopted from Okonga 2003). (*b*) The long-term (1940–1980) mean monthly rainfall pattern in north-west (Entebbe) and north-east (Jinja) parts of Lake Victoria Basin (data adopted from Kizza et al. 2009).

recorded in January–March. On average, the variation of mean maximum and minimum temperatures reflects that Lake Victoria basin has mild and moderate climate which may be compared with sub-tropical and temperate climates. In contrast to this temperature variation, the rainfall pattern shows highly tropical variation almost in par with that of the rainforests in Congo basin and Amazons in South America. This uniqueness of the weather and climate configuration of Lake Victoria basin makes the analysis of thunderstorm occurrences highly interesting and scientifically inquisitive.

The uniqueness of the above-mentioned weather and climate pattern of Lake Victoria is not yet fully understood. The complex topography of the regions (rifts and terrains) and heterogeneous vegetation in the middle NE parts of African continent may signify the geo-surface system in the vast neighbourhood of the lake. This geo-system may give rise to micro- and macro-scale circulations; both lake-induced circulation and monsoonal circulation that mould the climate blue print of the region. It should be noted that the large air-mass flow to and from the tropical rainforests of the Congo basin may also have a high impact on the climatic variations of the lake

(Okeyo 1987; Mukabana & Pielke 1996; Sun et al. 1999; Anyah & Semazzi 2004; Song et al. 2004).

Temperature contrasts (the result of the differential heating properties of land and water) are responsible for the formation of land breeze. They can develop best only when the synoptic or gradient winds are very light and they need partly to mostly clear skies to allow outgoing terrestrial radiation to leave. Although minimum and maximum temperatures of the atmosphere show quite a vast variation in the lake region, the water surface temperature, which has a mean of approximately 25 °C, varies within a mere difference of 3 °C during the year (Lumb 1970). However, the same variation on the land surface near the shore is 15–30 °C, thus the land–water temperature gradient may be significantly high during few intervals of the day.

Analysis of diurnal convection cycle of circulation and precipitation over Lake Victoria provides valuable information regarding the thunderstorm possibilities in the region. The nocturnal circulation reaches maximum strength usually between late night and early morning (Fraedrich 1972), as the temperature gradient between the lake surface and surrounding land surface reaches highest values. The temperature gradient in turn leads to a pressure gradient thus horizontal air masses start moving in the direction of decreasing pressure; i.e. from land to lake.

On the other hand, from late afternoon to early hours of the evening, strong breeze flows from the lake to land as the surrounding land surface is much warmer than that on the lake surface. This lake breeze circulation is much wetter than land breeze circulation (Okeyo 1987). As it is observed by many studies on Lake Victoria circulation pattern (Lumb 1970; Fraedrich 1972; Datta 1981; Okeyo 1987), as the lake breeze circulation is reaching the maturity, it will be characterized by the flow convergence over the western part of the lake.

As it has been reported by Datta (1981) and Ba and Nicholson (1998), the land breeze circulation is relatively weaker than the wet lake breeze circulation. Typically, the land breeze front is located within the western peripheries of the lake. The topographic signatures of Lake Victoria are characterized by mountain ranges marking the neighbourhood in two directions thus a quasi-permanent trough is formed in the lake proximity. Thus, stable air over the lake during the day time becomes one of the deciding factors of the strength of the lake breeze circulation. Simulations done (Anyah et al. 2006) with the topographic and breeze circulation features in the lake environment shows that there can be strong precipitation and electrification (resulting rain and lightning) can be taken place over the western parts of the lake in the early morning hours (around 3 am), whereas in the outskirts of the lake surface over the land and in the eastern sector of the lake basin, similar weather conditions may take place during the afternoon hours (around 3 pm).

3.2. *Thunderstorm environment*

Thunderstorms are generated by particle collision due to various local turbulences (updraft, down draft, vortices, etc.). Cloud electrification and charge separation in a thunderstorm give rise to lightning that brings extremely large impulsive currents to earth. Lightning currents are impulsive in nature and most often follows approximately a double-exponential wave profile. The waveform has rise-time values in the order of few hundreds of nano-seconds to few micro-seconds. The zero crossing time of the current is in the range of 40–70 μs (Cooray 2003). A single lightning flash may drive several current impulses (strokes) to ground which are separated by time intervals in the order of few to few hundreds of milliseconds. A typical first stroke may have peak current of 30 kA on average. In the extreme cases, the currents may exceed even 200 kA (Cooray 2003).

Lightning current may trigger fire or explosions when they flow through unprotected structures. They can also affect electrical equipment and systems either by direct injection into the power network (known as resistive coupling) or by inducing voltages at a distance (known as inductive coupling). A human being or animal may be affected by lightning in several ways; direct strike, side flash, step potential, touch potential, upward leaders, secondary effects, etc. (Cooper 1980; Cooray et al. 2007). Specific injuries pertinent to animals have been discussed in Gomes (2012) and Gomes et al. (2012b).

Every year, lightning kills or injure a significant number of people on or near the waters of Lake Victoria. A typical convective thunderstorm in this region is about 25 km in diameter and lasts for an average of 30 minutes (observation of Uganda Meteorology Department). Despite their small size, many thunderstorms pose extreme danger to the habitants in the lake surrounding. According to global lightning density maps issued by NASA based on the observations of NASA OTD (4/95–3/00) and LIS (1/98–2/3) instruments, Uganda, has a lightning density of 10–15 flashes/km^2/year. As per the equations that provide relation between thunderstorm days per year (isokeraunic level) and the ground flash density (Gomes & Kadir 2011), such flash density provides approximately 100–150 thunder days per year. However, this average isokeraunic level of the entire country may not be the case for the highly unique topology of Lake Victoria. This is verified by the statistics released by WMO according to which the isokeraunic level of Kampala which is almost on the shores of the lake is 285 days yr^{-1}. This closely correlate with that for the lake area observed by Uganda Meteorology Department; 287 day yr^{-1}.

3.3. Lightning incident statistics

Table 1 shows the number of incidents, deaths and injuries in the NE and NW parts of the lake. An incident refers to a lightning accident where at least one person is subjected to injury or death. In a given incident, there may be one or more injuries and/or deaths. An injury is defined as a person being subjected to a lightning accident but has not succumb to the injuries within few days. Although the wind patterns and convective systems are somewhat different in the two segments, the percentage of lightning accidents does not have a marked difference between the two regions although NW part shows slightly higher numbers in all three categories. This is in agreement with the amount of rainfall in the two regions (figure 2(*b*)), in case we assume that the rainfall has positive correlation with lightning ground flash density.

Figure 3 depicts the number of victims based on the time of the day. Interestingly, the data show that there is relatively a low number of victims in the evening hours

Table 1. Regionwise distribution of the number of accidents.

Region	Number of incidents	Number of deaths	Number of injuries
NE	10	18	46
NW	15	22	50

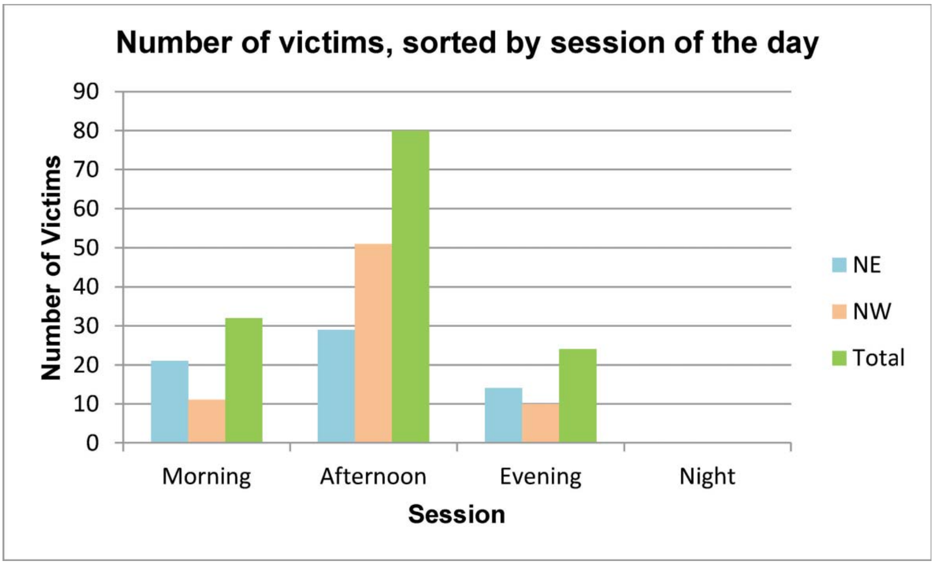


Figure 3. Number of victims (injuries + deaths) in the two regions and their total, sorted by the session of the day; morning (6 am to 12 noon), afternoon (12 noon to 6 pm), evening (6 pm to 12 midnight), night (12 midnight to 6 am).

despite the highest number of lightning occurrences are usually reported during that period. Our survey through communication with public and local authorities well explained this observation. A majority of the areas in the lake neighbourhood are yet to be provided with electricity; hence, the street lightning in the region is extremely poor. Such conditions enforce the public to refrain from outdoor activities after the sunset. This is a good example for the developers of lightning safety modules to give prominence to the lightning accident data rather than lightning occurrence data. During the night-time, the accidents are less (zero in this case) due to both low level of lightning occurrence and almost zero outdoor activities. The high number of lightning activities during the afternoon sessions coincides with the relatively high density of lightning flashes and very high outdoor activities.

The higher number of lightning accidents that occur in NE part in the morning (than that in NW during the same session) is in agreement with the convective pattern that brings relatively high number of thunderstorms towards NE compared to NW. The public in the region pay least attention to lightning safety (or any other safety measures) during the morning session as their priority of the hour is to start the activities that earn them the living. Hence, although the prevalence of thunderstorm during the morning hours are quite less, the probability of accident occurrence may be high due to this ignorance of the public on the signs of thunderstorms.

Similar to the other parts in Uganda (Mary & Gomes 2012), in the lake area too, the lightning incidents are distributed during the year in a bell-shaped curve that peaks around August (figure 4). Lightning incidents in NE is confined to the period May–October whereas that in NW is April–December. The incident-less period from December to March coincides with the less-rainy, dry period in East Africa (except December). Although the Month of September had no incidents during the period of data collection for this study, the same month shows the peak value in the occurrence of lightning accidents for the whole country as per the five-year data

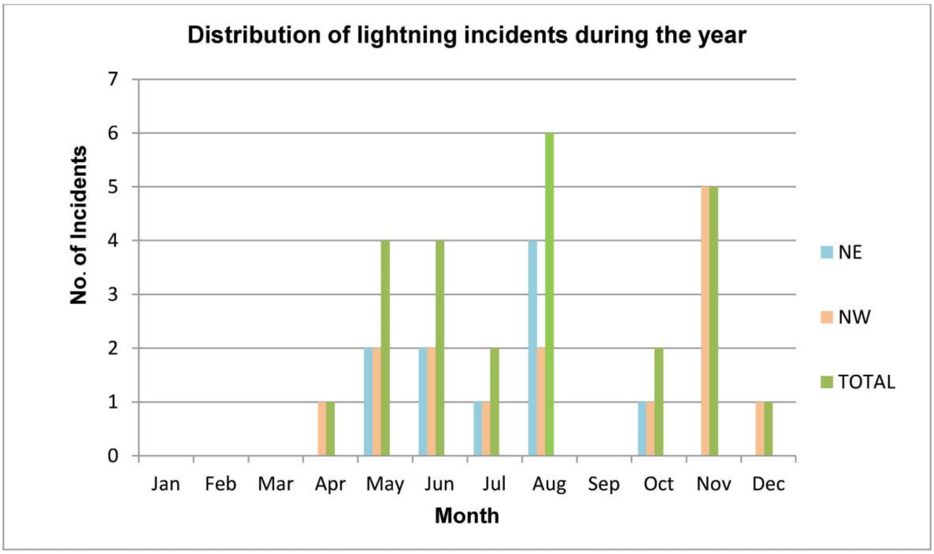


Figure 4. Monthly distribution of lightning incidents during the year.

presented by Mary and Gomes (2012). One reason for such lack of incidents may be the short period of data collection in the present study. On the other hand, the large number of incidents in September for the whole country in the information given by Mary and Gomes (2012) has been contributed by few incidents where the number of victims in each case is significantly high (including the 19 deaths by one lightning which involved 18 school students and their teacher, which is the worst recorded lightning accident in the human history).

The deviation of the pattern of accidents from the monthly variation of rainfall pattern can be explained up to some extent by the analysis of the pattern of evaporation of the lake. As per the temperature-based model-predicted monthly average evaporation pattern in Lake Victoria (Okonga 2003), the variation of water evaporation is somewhat similar to the rainfall pattern but with much less fluctuation of the quantity. For an example during the month of August, where the accident rate is maximum, the evaporation is in par with March and November and higher than that in April–July. Evaporation governs the convective systems that generate cumulonimbus clouds in the locality that bring lightning. Therefore, evaporation may be better linked to lightning rather than rainfall in a tropical/sub-tropical region with large water masses in the vicinity. Similar observations have been done in tropical oceanic regions that have prominent monsoonal rain pattern. For an example, Sri Lanka, an island to the south of India, has a well-defined bi-monsoonal rainfall pattern, May–September (south-western) and December–February (NE), which is characterized by heavy tropical rains that bring moisture from Arabian Sea during south-western monsoon and from Bay of Bengal during NE monsoon (Information published by Sri Lanka Department of Meteorology). However, the intense lightning periods of the country, March–April and October–November, coincide with intermonsoon period during which the country experiences short bursts of "running-

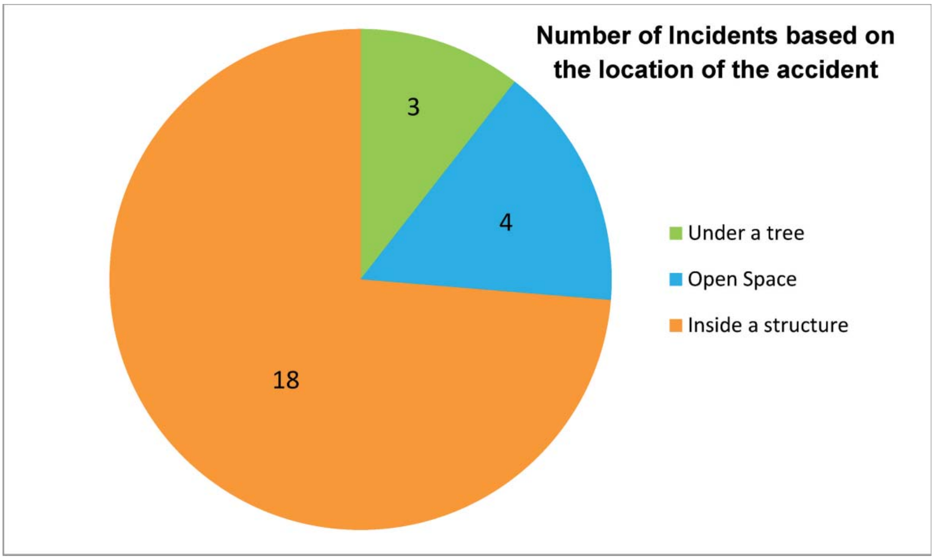


Figure 5. Location of accidents. Note that the total number of incidents is 25.

showers". Therefore, the maximum lightning-related accidents are also observed during this period of less rainfall and high thunderstorm occurrence (Gomes et al. 2006).

Figure 5 illustrates the number of incidents based on location of the accident. The distribution depicts an interesting phenomenon of accident mechanisms in Africa. In many parts of the world, the most probable location of lightning injury is either under-the-tree or open-ground (Eriksson & Smith 1986; Coorper et al. 1989; Mackerras 1992; Elsom 2000; Carte et al. 2002; Cooray et al. 2007). In contrast to such observations, in Africa, a majority of accidents occur while taking shelter inside a structure (Lubasi et al. 2012; Mary & Gomes 2012). Figure 5 reconfirms this unexpected observation. As it was explained in Mary and Gomes (2012), the nature of houses and commercial structures in many parts of East Africa is the major reason for such large number of indoor accidents in the region. Figure 6 shows a "commercial building" on the banks of Lake Victoria. Most of the houses in rural East Africa resemble similar safety lapses. These shelters are made of highly flammable thatched roofs and wooden or clay walls. There are many such structures in the lake shore which protrudes over flat and open land, making them prime targets for lightning strikes.

Most often, a lightning strike to an unprotected thatched roofed shelter results in multiple victims, both due to electricity-related effects (side flash, step potential and touch potential) and secondary effects (fire, falling materials and missiling fragments, choking hazards due to burning materials, etc.). In one such incident, five people of the same family were killed at Kadindini fishing village in Buvuma district in the NE part in August 2011. The accident took place during the morning hours when the victims were sleeping on the floor of a housing structure with grass-thatched roof. As per the description of the eye witness of dead bodies and also as per the incident environment, it was evident that the injuries were due to step potential and/or side flashes. In a similar incident, lightning killed four people inside an open shelter which

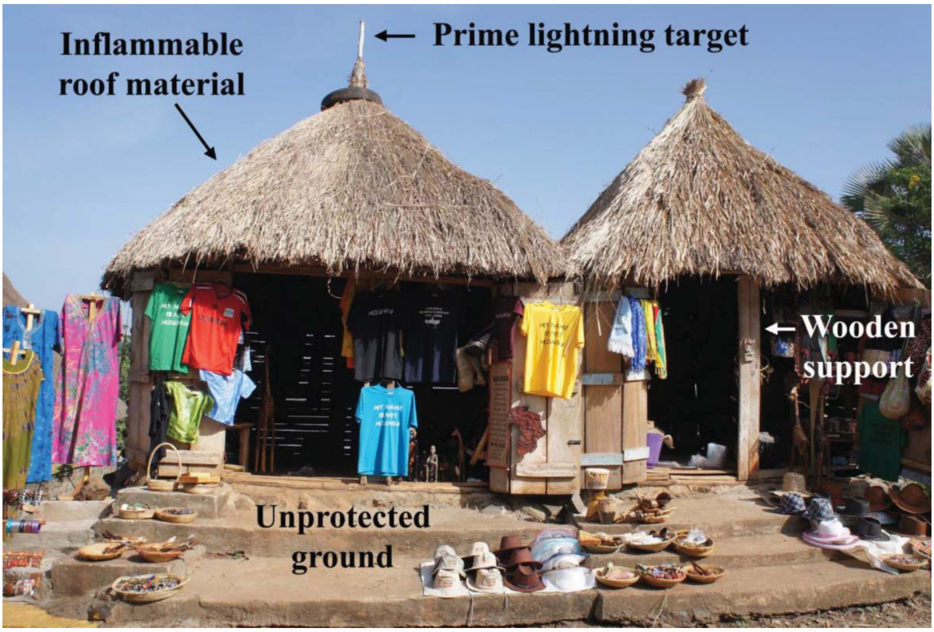


Figure 6. A structure that is used as a shop in the banks on Lake Victoria. There are serious lapses in lightning safety, thus in the event of a strike, occupants are at a very high risk of injuries.

is used as a pier (popularly known as landing sites) in Mayuge district in the shores of NE part. The incident took place in August 2012, in the morning hours, a common trend in the NE part. In this case too, the injury mechanisms may most probably be step potential and side flashes.

Although it was not very common, we have come across few cases where fatal injuries are resulted when boats have been struck by lightning. In one such case, occurred in May 2012 in Kyesiiga sub-county in the NW part, a partly covered fishing boat was struck while it was motoring close to the land, killing two fishermen and injuring three others.Most often people in such boats are injured due to direct strikes or side flashes from covered parts of the boat which are usually non-metal. It is also possible that fellow occupants get side flashes from those hit by direct strikes as the area of occupancy is small inside the boat.

4. Discussion

The investigations and analysis conducted in this study provide us outcomes vital in designing lightning safety scheme for less privileged communities that live in the proximity of large water masses.

4.1. Major inferences

Based on the information collected and observations made on the lightning accident environment of the northern part of Lake Victoria in the East African region, we may make the following generalized inferences.

(1) Lightning ground flash density is a key factor, but not the sole factor, in assessing the lightning threat level for human beings in a given region.
(2) Behavioural aspects of a given community plays important role in lightning safety. As it can be seen, in contrast to countries such as Sri Lanka and Bangladesh (Gomes et al. 2006), in the Lake Victoria region of Uganda, the number of lightning accidents in the evening hours is less irrespective of the high density of lightning during this period. The most probable reason may be the significantly less human activities during this period due to non-availability of lighting sources.
(3) Both behavioural aspects and convective weather patterns account for the relatively high number of lightning accidents in the morning hours in the NE part of the lake.
(4) The lightning accident distribution with respect to the time of the year shows a well-defined pattern. This bell-shaped distribution may be coincident with the lightning density distribution; however, further research is required to make firm conclusions on the high accident statistics in the mid-months of the year.
(5) The nature of the residence and commercial structures of the region will seriously be taken into account in developing lightning safety guidelines for such regions. Slogans such as "When thunder roars, go indoors" and "Seek shelter in a sturdily built building when lightning is around" etc. used in the USA, Europe and Australia should be moderated before such are applied in East African region.
(6) The people who travel in water vessels in the region are vulnerable to lightning strikes as the vessels are most often open decked and made of wood or non-metallic composites. Most often, those who use boats for fisheries industry do not take lightning warning seriously as the days earning plays a more important role than lightning safety in their perceptions.

4.2. Recommendations

The above inferences lead us to propose the following recommendations for developing safety schemes, guidelines and awareness programmes for communities in regions similar to those in the shores of Lake Victoria.

(a) One of the key safety issues in the region is the lack of proper safety structures. The word "sturdily built building" has a vague and ambiguous meaning that may vary from community to community. Instead, it is better to use the term "safe shelter" and define clearly what such safe shelters are. Sizable buildings made of brick or concrete with firm roofs made of tiles, concrete or asbestos roofing sheets, small buildings that are provided with adequate structural protection systems, whole-metal structures such as cars, buses trains, etc. and specifically made lightning safety structures can be treated as safe shelters (refer item b).
(b) As there are barely any safe shelters (discussed in item a) in the proximity of lake shore, we strongly recommend the placement of either permanent or portable lightning safety structures (Gomes et al. 2012a) at regular intervals. Such safety shelters can be designed with abandoned cargo containers, metal cages, large vehicles or vehicle bodies no longer in use, etc.
(c) Water vessels should be provided with low-cost lightning protection system similar to the scheme proposed in Gomes et al. (2012a). The boatmen should

also be advised to avoid motoring their boats in to water as best as possible in the wake of thunderstorm warnings.

(d) Residence structures with grass-thatched roofs and non-metallic walls (wooden or earthen) should be provided with low-cost lightning protection schemes proposed in Gomes et al. (2012a). Those structures with metallic roofs on wooden, grass or clay walls (or vertical supports) should at least be provided with earthing conductors to connect the roof to earth.

(e) A set of comprehensive safety guidelines should be developed preferably by a government authority and promoted among the lake shore communities by both government and non-governmental organizations.

(f) Lightning safety practicable implementations that do not significantly affect the life style of the society. Thus, guidelines to be adopted should be well affordable to the target community. Additionally, the adoption of guidelines should have downtime in the normal societal operations as small as possible.

(g) The safety guidelines should take into guidelines for low-income societies such as the target group in this study, need inclusion of feasible and account the;
- diurnal trends of lightning activities in different regions,
- behavioural aspects of the society,
- nature of sheltering structures of the public and
- specific issues pertinent to a lake-environment

(h) The promotion of awareness of the safety guidelines among the public is equally important as the development of guidelines. These promotional programmes should pay attention to the most effective modes of conveying safety message. Warning signs and billboards at public places, interviews and programmes (in local languages) in visual media, short speeches at religious congregations, etc. are effective modes of safety communications with public, as per the outcomes of surveys that have been conducted.

(i) Timing of the awareness campaigns is also important in designing the safety promotion programmes. The best time to start such events is March–April, the beginning of the lightning season. The programmes should be repeated until about October.

(j) The success of the guidelines and awareness programmes should be evaluated by continuously monitoring the lightning-related accident records in the region. Based on the results, it should be decided to continue the activities with or without modifications.

4.3. Hierarchy of hazard control

A low-income society with below par literacy rate is much tougher to be mechanized for adopting lightning safety measures compared with the same operation in developed countries (Jayaratne & Gomes 2012). However, our interviews with many human subjects during the site visits revealed that many community leaders are concerned about the human safety against lightning and they are willing to be educated. Such observations prompted us to develop a hierarchy of hazard control mechanism (Brdys et al., 2008; Scattolini 2009) that may successfully be applied to the community in Lake Victoria shore and any other similar groups. Although such mechanisms are employed in enclosed work environment (factories, harbours, cargo control divisions, outdoor sites with task boundaries, etc.), the bound-nature of communities in the lake shore may provide the operational feasibility for such mechanism (Scattolini 2009).

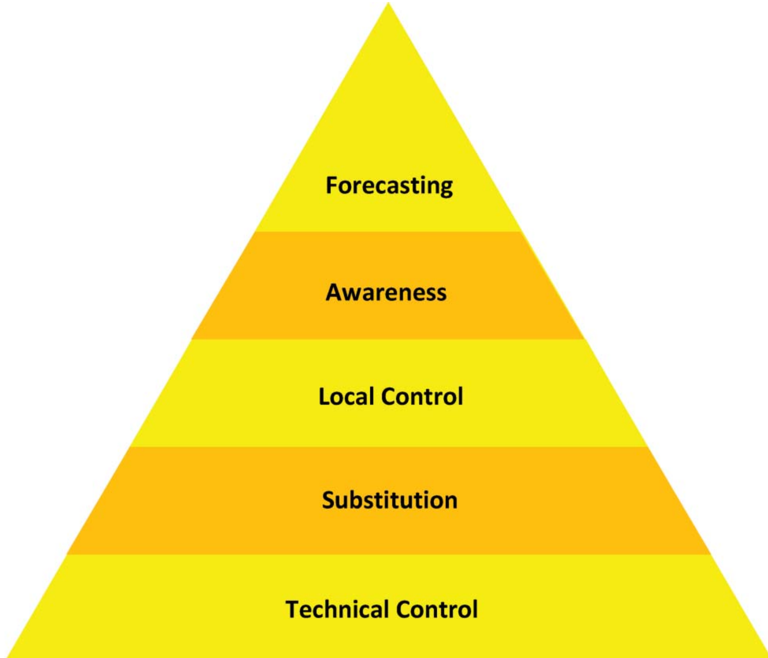


Figure 7. Hierarchy of hazard control.

A group of people, even very large in number, engaged with similar type of employment or routinely practices can be treated as a bound-community. Such community is often composed of many interacting subsystems and sub-processes. Thus, the safety of such social system with respect to any natural hazard cannot be easily ensured either by centralized control alone or individual control alone. However, the bound-nature of the community either by profession or by other mass activities makes it viable for implementation of safety measures to the community through distributed responsibility of control. We make hierarchal hazard control approach for lightning safety of this community under such backdrop.

Based on our inference and recommendations given in previous sections, we would like to propose the hierarchy of control map for the lightning safety of Victoria Lake shore community, given in figure 7.

4.3.1. Forecasting. The government (through Department of Meteorology) or a relevant private sector that owns region-wide lightning detection system should provide thunderstorm forecasting and lightning nowcasting information to the concerned community. This should be done in collaboration with mass media, especially audio-visual media such as radio and television. Even electronic media such as Internet is fast reaching in remote communities. The need of providing accurate information in local languages is a key factor to successful adoption of safety measures following such news broadcast.

4.3.2. Awareness. The experience in several other parts of Uganda (Mary & Gomes 2012), Zambia (Lubasi et al. 2012), Bangladesh and Sri Lanka (Gomes et al. 2006) shows that thunderstorm forecasting, safety guidelines, protective structures, etc. have no impact on community protection unless the society is well aware of the danger of lightning and safety measures that should be taken. The promotion of awareness even for a single community is not a once and for all process. Such promotion should be done on periodic basis. Local authorities, governmental institutions (police, educational institutes, hospitals, etc.) and non-governmental organizations take part in this process with the help of local community leaders.

4.3.3 Local control. Although a general consensus can be reached among the community to act on the thunderstorm forecasting information, in most of the cases of regular non-dramatic natural hazards, public needs local directives in starting safety procedures. Such directives or leadership are more prominently felt in low-educated societies than in their opposite counterpart. During floods in Thailand and Malaysia, and debris flow in Pakistan and Iran, it has been observed that a majority of victims have not followed even simple safety guidelines due to the lack of initiatives by local leadership. In lightning safety in a bound-community, such local control can be achieved by lightning warning systems located at regular intervals in a way that they can be seen at distance. The most appropriate location for such warning system is the lake shore. These warning systems may preferably be in the form of coloured lights (green-red or green-orange-red sequences). Alternatively large signal systems in different colours can be erected if electricity supply is an issue. However, such signal systems are invisible during night-time. The other mode of local control is the training of group leaders on executing rules on activity stop/start (e.g. 30/30 rule) and following safety measures (e.g. avoiding shelter under large trees, going into safety position, indoor guidelines, etc.). Such group leaders may be boat-lords, heads of fisher communities, village-heads, religious leaders, teachers, responsible civil servants, doctors, police, etc. The important aspect of group leaders is that the concerned group should have a natural tendency to follow the orders of such leader.

4.3.4. Substitution. In a low-income society, it will not be that easy to prevent people from attending their bread-earning activities as such stoppage may deprive them their daily wage. Thus, there should be a substitution for them during the stoppage of the work. Such substitution will highly be subjective as the alternative tasks are community dependent. One example of such substitution is to direct the fishermen to mend torn fishing nets or damaged fishing equipment, boats, etc. inside a sturdy structure when they are prevented from going out into the lake. Planning of such substitutions and providing of directives to take up the substitute work should be done by selected community leaders.

4.3.5 Technical control. As a standard solution for those who seek shelter in places of low risk and a last resort solution for those who are not willing to give up their outdoor activities under any cost, lightning protection systems can be implemented and viable protection measures can be adopted appropriately. These can be implemented at community level, most probably with the help of external experts. These may include low-cost structural protection systems (Gomes et al. 2012a) at all buildings in the community (if possible) or at least at several selected structures where mass gathering is possible, less complicated protection system for small water vessels such as fishing boats (Gomes et al. 2012a), insisting on wearing rubber sole boots to minimize step potentials, etc. Placement of metal structures specially made for lightning protection along the shore at regular interval is strongly recommended as such structures could be developed at quite low cost. Properly designed such structures can be placed at several locations in the lake (off shore) with the aid of anchors; thus, fishermen in unsafe boats can get inside such structures in the event of acute thunderstorms.

5. Conclusions

A comprehensive investigation has been conducted, both by reviewing the existing literature and information collected during site visits to the area of focus, the neighbourhood of Lake Victoria, the largest tropical lake in the world, that boarders Uganda, Tanzania and Kenya.

Lightning accident statistics, documented segment wise in the northern parts of the lake, bordering Uganda, reveal a number of factors that should be considered in developing safety programmes to curb lightning-related disasters in the region.

The region has a distinctly recognizable season of high lightning accidents which starts in the month of May and stretches all the way up to November/December followed by a low lightning accident period from December/January to April. August records the highest number of lightning incidents. The statistics show that the NW part of the lake has slightly greater number of lightning accidents than the NE part. Accidents in the NE part in the morning hours are relatively higher; may be due to the thunderstorm patterns in the region. The impact of housing structures, human behavioural pattern and thunderstorm occurrence patterns on the accident density has been discussed in detail.

As per the outcome of information and data analysis, safety measures, guidelines and awareness promotion strategies have been recommended for the communities that reside in the shores and nearby areas of Lake Victoria. A viable road map to implementing hierarchy of hazard control specifically designed for the lake shore community has also been proposed. Such strategies can be applied to many other similar environments in the world.

Acknowledgements

Authors would like to thank Uganda Meteorological Department and Centre for Electromagnetic and Lightning Protection Research (CELP), Malaysia, for the facilities and support provided to make this study a success.

References

Anyah RO, Semazzi FHM. 2004. Simulation of the sensitivity of Lake Victoria basin climate to lake surface temperatures. Theoretical Appl Climatol. 79:55–69.

Anyah RO, Semazzi FHM, Xie L. 2006. Simulated physical mechanisms associated with climate variability over Lake Victoria Basin in East Africa. Mon Weather Rev. 134:3588–3608.

Ba MB, Nicholson SE. 1998. Analysis of convective activity and its relationship to the rainfall over the Rift Valley lakes of East Africa during 1983–1990 using the METEOSAT infrared channel. J Appl Meteorl. 37:1250–1264.

Brdys MA, Grochowski M, Gminski T, Konarczak K, Drewa M. 2008. Hierarchical predictive control of integrated wastewater treatment systems. Control Eng Pract. 16:751–767.

Carte AE, Anderson RB, Cooper MA. 2002. A large group of children struck by lightning. Ann Emerg Med. 39:665–670.

Cooper MA. 1980. Lightning injuries: prognostic sings for death. Ann Emerg Med. 9:134–138.

Cooray V. 2003. The lightning flash. London: IET.

Cooray V, Cooray C, Andrews CJ. 2007. Lightning caused injuries in humans. J Electrostat. 65:386–394.

Coorper CJ, Darvaniza M, Mackerras D. 1989. Lightning injury: a review of clinical aspects, pathophysiology and treatment. Adv Trauma. 4:241–287.

Datta RR. 1981. Certain aspects of monsoonal precipitation dynamics over Lake Victoria. In: Lighthill J, Pearce RP, editors. Monsoon dynamics. Cambridge, UK: Cambridge University Press; p. 333–349.

Elsom DM. 2000. Deaths and injuries caused by lightning in the United Kingdom: analysis of two databases. Atmos Res. 56:325–334.

Eriksson AJ, Smith MA. 1986. A study of lightning fatalities and related incidents in Southern Africa. Trans SA Inst Elec Eng. 77:163–178.

Fraedrich K. 1972. A simple climatological model of the dynamics and energetics of the nocturnal circulation at Lake Victoria. Q J Roy Meterol Soc. 98:322–335.

Gomes C. 2012. Lightning safety of animals. Int J Biometeorol. 56:1011–1023.

Gomes C, Ahmed M, Abeysinghe KR, Hussain F. 2006. Lightning accidents and awareness in South Asia: experience in Sri Lanka and Bangladesh. Proceedings of the 28th International Conference on Lightning Protection (ICLP); Kanasawa, Japan.

Gomes C, Kadir MZAA. 2011. A theoretical approach to estimate the annual lightning hazards on human beings. Atmosp Res. 101:719–725.

Gomes C, Kadir MZAA, Cooper MA. 2012a. Lightning safety scheme for sheltering structures in low-income societies and problematic environments. 31st International Conference on Lightning Protection; Vienna, Austria.

Gomes C, Ahmed M, Žele D. 2012b. Lightning and fish mortality: case study from Bangladesh. 31st International Conference on Lightning Protection; Vienna, Austria.

Jayaratne C, Gomes C. 2012. Public perceptions and lightning safety education in Sri Lanka. 31st International Conference on Lightning Protection; Vienna, Austria.

Kizza M, Rodhe A, Xu C, Ntale HK, Halldin S. 2009. Temporal rainfall variability in the Lake Victoria basin in East Africa during the twentieth century. Theor Appl Climatol. 98:119–135.

Lubasi FC, Gomes C, Ab Kadir MZA, Cooper MA. 2012. Lightning related injuries and property damage in Zambia. 31st International Conference on Lightning Protection; Vienna, Austria.

Lumb FE. 1970. Topographic influences on thunderstorm activity near Lake Victoria. Weather. 25:404–410.

Mackerras D. 1992. Occurrence of lightning death and injury. In: Andrews CJ, Cooper MA, Darveniza M, Mackerras D, editors. Lightning injuries: electrical, medical, and legal aspects. London: CRC Press.

Mary AK, Gomes C. 2012. Lightning accidents in Uganda. 31st International Conference on Lightning Protection; Vienna, Austria.

Mukabana JR, Pielke RA. 1996. Investigating the influence of synoptic scale winds and mesoscale circulations and diurnal weather patterns over Kenya using a meso-scale numerical model. Mon Weather Rev. 124:224–243.

Nicholson SE. 1993. An overview of African rainfall fluctuations of the last decade. J Clim. 6:1463–1466.

Nicholson SE. 1998. Historical fluctuations of Lake Victoria and other lakes in the northern Rift Valley of East Africa. In: Lehman JT, editor. Environmental change and response in East Africa lakes. MA: Kluwer Academic Publishers; p. 7–35.

Nicholson SE, Yin X. 2001. Rainfall conditions in equatorial East Africa during the nineteenth century as inferred from the record of Lake Victoria. Clim Change. 48:387–398.

Okeyo AE. 1987. The influence of Lake Victoria on the convective activities over the Kenya Highlands. J Meteor Soc Jpn. 65 (special volume):689–695.

Okonga JR. 2003. A review of estimation of rainfall and evaporation over Lake Victoria. Kampala, Uganda: Publication of the Directorate of Water Development.

Scattolini R. 2009. Architectures for distributed and hierarchical model predictive control – a review. J Process Control. 19:723–731.

Song Y, Semazzi FHM, Xie L, Ogallo LJ. 2004. A coupled regional climate model for Lake Victoria basin of East Africa. Int J Climatol. 24:57–75.

Sun L, Semazzi FHM, Giorgi F, Ogallo LA. 1999. Application of the NCAR regional climate model to NORTH EASTERN Africa. Part II: simulation of interannual variability of short rains. J Geophys Res. 104:6549–6562.

WeatherSpark. 2014. Average Weather for Entebbe, Uganda. Madison, Wisconsin. Available from: https://weatherspark.com/averages/29319/Entebbe-Central-Region-Uganda.