Lightning: Public Concepts and Safety Education

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Abstract Being a spectacular atmospheric phenomenon, lightning could induce significant interest in the human mind since the beginning of history. Most often the public perceptions of many communities about lightning were marked by divinity, power, fear and punishment. The belief systems extend up to the present time, despite the development of modern science and technology. In the last two centuries, the scientific understanding of the thunderstorm and lightning phenomena gradually improved and at present we have a significant awareness of the nature of lightning, injury mechanisms and lightning-related medicine. The modern safety guidelines and safety modules for communities in lightning-dense geographical areas are based on proven scientific facts. In several developed countries, a marked decrease in the number of lightning casualties could be observed during the past century, due to the continuous safety awareness programs. However, lightning safety modules which are highly successful in one part of the world may not be that successful in another part of the world.

Keywords Hierarchical order · Lightning myths · Safe structures · Belief system · Underprivileged communities

1 Public Concepts

Lightning has most often been treated as two combined phenomena, the flash of light and the thunder, in the public perceptions. Due to its destructive effects, and high sound intensity, the ancient belief systems attributed lightning to either a powerful deity or wrath or weapon of such divinity. Thus, the God of lightning was often treated as a holy entity who punishes human beings or even animals with evil qualities or

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spirits. This perception of the people of ancient civilizations has been depicted in the sculptures, paintings and symbols of the lightning God [1, 2].

In the development of community-specific lightning safety modules, it is of utmost importance to understand the beliefs of the public on the lightning phenomenon. Failure to do so, may results in the safety modules, fail miserably in the attempts of applying to target communities, as it has been witnessed in South and South East Asia in introducing several modules which were successful in other regions. The investigations on public beliefs includes analysis of the divinity induced on lighting, the mythical powers attributed to lightning or followers of lightning deities, beliefs on the lightning and its abilities, at various societal levels and up to what extent the modern scientific knowledge is compatible with such belief systems. Consequently, it is only through the smooth integration of accepted lightning safety guidelines with the deeply rooted beliefs of the societies on natural phenomena, one can meaningfully introduce safety programs to a given society [3, 4]. Such investigations, could also produce comprehensive databases on various concepts of the lightning phenomenon that will be useful in the applications of various non-technical sciences such as sociology, fine arts, anthropology, psychology and behavioural sciences etc.

2 Ancient Belief Systems

A striking point of the beliefs of ancient civilizations on lightning as divinity is their awareness of the massive power that lightning possesses. However despite this kmowledge they could not understand the form of energy dissipation in the event of a lightning strike. It is common to all these beliefs that the thrower of the lightning bolt is a divine entity while the receiver of the thunderbolt is a sinful human being, animal or an evil entity. Thus naturally, a person struck by lightning was branded as a sinner and a structure hit by lightning was treated as a place not suitable for residence. The people treated lightning striking an important structure such as a religious place or a palace as a very bad omen. In several communities in Africa, such beliefs are deeply rooted in the public of many tribes even today [1, 2, 5–7].

The earliest form of the lightning-thunder god was the ‘thunderbird’, who created lightning and thunder either from its beak or from its wings. Engravings of the thunderbird have been found in the archaeological sites of the Bronze Age in Dodona and Minussinsk in Siberia, Dong Son in Vietnam and on pots in north Peru [8, 9].

Several native tribes who lived in North America also believed that lightning is due to the flashing of feathers of a mystical thunderbird. Thunder is the sound of the flapping wings, according to their belief [8].

As it is found in the mythology, Zeus of Greece, Jupiter of Rome and Typhon of Egypt, send lightning bolts from heaven. The Greek legends state that the thunderbolt was invented by Minerva the goddess of wisdom and gifted to Lord Zeus to punish the bad entities. According to one of the Greek legendary stories, a Cretan called Iasios was struck by lightning hurled by Zeus for attempting to ravish Demeter, the goddess of corn [10]. The ancient Roman empires practised a cult of deducing the

powers of god by visualizing and observing lightning and thunder. Since lightning was a manifestation of the gods, a location struck by lightning was regarded as sacred. Greek and Roman temples were often erected at such sites, where the gods were worshipped in an attempt to appease them [11, 12].

According to the Vedic mythology of India, Indra, the god of earth, conquered innumerable human and demon enemies and killed the dragon Vrtra, who had prevented the monsoon from breaking, by means of the power of lightning and thunder [13]. The weapon of Indra, Vajrayudh, is the lightning strike and symbolized the supreme power against evil. In many parts of India and Nepal, monuments of Vajrayudha could be seen at both Hindu and Buddhist temples. Figure 1 shows the Vajrayudha made of bronze at Swayambhunath Buddhist temple in Kathmandu, Nepal. Alongside the monument is the world-renowned lightning expert Prof. Vladimir Rakov of the USA. Interestingly this Vajrayudh itself has been struck by lightning around the year 2010, of which the damaged sign could clearly be seen. Agni, the god of fire, also uses lightning as a major weapon to demolish the enemies of divinity. Several sectors of Mythologists argue that the God Agni and God Indra may be the same entities.

The power of controlling lightning energy to harm enemies is also a popular voodoo cult in the African Continent [5, 7]. According to these studies, there are also records of people who claim that they can create lightning bolts at their will and direct towards the desired target. Practices and beliefs of such powers exist even today, in many parts of Africa.

Fig. 1 Vajrayudh, made of bronze at Swayambhunath Buddhist temple in Kathmandu, Nepal

The Holy Quran of the Islamic religion also mentioned God's power on lightning at five places. Surah 24: 43; "… And He sends down hail from the sky hail mountains (or there are in the heaven mountains of hail from where He sends down hail), and strikes therewith whom He wills and averts it from whom he wills. The vivid flash of its lightning nearly blinds the sight." (Tafsir At-Tabari).

At 46 places of the Holly Bible of Christian religion, the thunder and lightning are spoken of as tokens of God's wrath or a representation of God's glorious and awful majesty or some judgment of God on the world. Eg. Psalm 18:14; "He shot his arrows and scattered the enemies, great bolts of lightning and routed them".

The lightning and thunder gods still continue in the popular beliefs of several communities in the world. Some Eastern Europeans believe that St. Elijah is the controller of lightning while some Latin Americans treat Santiago as the saint of lightning.

The following list provides the names of the divine powers treated as the God/Goddess of lightning or the power bearer of lightning [1, 2].

Tien Mu (goddess), Lei Tsu and Lei Kung in China.

Thor of Scandinavians whose name is the origin of Thursday.

Tlaloc of Aztecs in Central America (now Mexico).

Aktzin of Totonacs in Central America (now Mexico).

Jasso of Mesoamericans in Central America (Now Honduras and Nicaragua).

Chaac of Mayans in Central America (now Guatemala).

Apocatequil of Incas in South America (now Peru).

Haokah of Lakotas in North America (Now Dakota).

Perun in Slavia and Bulgaria.

Raijin and Ajisukitakahikone in Japan.

Perkunas in Latvia and Lithuania.

Teshab of Hurrians in North Mesopotamia.

Taru of Hattians in Anatolia and Turkey.

Ishkur of Sumerians in Babylonia.

Adad of Akkadian in Babylonia.

Haddad in Middle East and Minor Asia.

Taranis in Gaul and Britain.

Perendi in Albania.

Ukko in Finland and Uku in Estonia.

Oya (goddess) and Shango of Youruba tribe in Nigeria.

Azaka-Tonnerre of Voodoo in Haiti.

Haikili and Kaha'i of Hawaiians in Polynesia.

Tāwhaki and Uira of Maoris in Polynesia.

3 Recent-Past and Current Belief Systems

One of the present communities in which, the belief of lightning god (or the lightning ghost or spirit) is deep-rooted is the Nigerian Yoruba tribe. They call the lightning spirit Shango, the thrower of thunderbolts. Shango or Chango is portrayed as a fierce god having a human-like figure whose axe could throw fire (Fig. 2). Shango is most often related to fire, perhaps, as the lightning strikes are often observed to ignite houses, and trees. In this Nigerian society, a person getting a lightning strike is treated as a sinful offender of god and nobody dares to touch his body except for the closest relations [14–16]. Usually, the entire family of the lightning target is extradited from the society. Unfortunately, Nigeria is a region of very high lightning density thus the probability of a person receiving a lightning strike is higher than the world average.

The lightning-bird-god is still practised in the Bantu tribe in Africa by the name Umpundulo. The indigenous doctors of the Bantu tribe, even at present, go out in storms and command the lightning to strike far away [17].

Interestingly, man-made lightning or more accurately witch-made lightning is very much a part of African life so that the subject has already come to the scientific

Fig. 2 Shango (or Chango) the lightning god of Youruba Tribe in Nigeria

fora. At International Colloquium on Overvoltages and Insulation Coordination, held in Harare, Zimbabwe in 1995, a paper has been presented on the observations of witch-created lightning in Zimbabwe [18]. As per this study, there are several ways of "manufacturing" lightning by the witch-doctors in the country. These methods are as follows,

- Two specifically made stones, by means of traditional magic, are charmed with ritual prayers until they are ready to generate lightning. Once that part is completed another mantra is enchanted stating the name and offence of the target who should be victimized. As the chanting is over, the lightning will reach its intended target.
- The witch doctor keeps the lightning in a calabash, a vessel made of seasoned bottle gourd. As it is required, the calabash is hit more than five times while the name of the target person and his offence (for which the punishment is given by directing the lightning) is chanted. With a loud bang of thunder, one can see the lightning emanate from the calabash. Once it hits the target, the lightning is supposed to return to the calabash.
- The witch doctor makes a fire with some magic sticks while chanting mantras. The smoke that emerges from the fire makes artificial clouds, which starts lightning and thunder. The generated lightning is dictated to reach a certain target determined by the creator.
- The witch doctor climbs a tree and smears a skin of goat, buck, cattle or any other animal with herbs. When the skin is dried, it is hung on a tree branch and struck several times with a stick. The lightning emanates from the skin and goes after the target. This type of lightning is considered to be uncontrolled once you dispatch it to find the predetermined target. If the lightning bolt fails to locate the target it will come back to the sender and attack him.

Obviously, these descriptions are highly unrealistic in the views of present-day accepted science. However, the author of [18], a Ph.D. holder in science, has written the paper in a way that he himself firmly believes these lightning-manufacturing powers of the people in Zimbabwe. Many recent news reports state that even very evidently natural lightning strikes, often associated with witchcraft in Zimbabwe, do spark acrimonious witch-hunts in rural areas. Many studies show that such lightning generation by witch-craft is not confined only to Zimbabwe. It is spread over many parts of Africa [7].

The above observations regarding the mindset of the African public have been re-confirmed by the interviews conducted in the studies presented in Trengove and Jandrell [6] and Trengove [19]. As per the outcomes of their work, 40% of the interviewees have given the response "yes" to the question of whether they believe that witchcraft can control lightning. Out of the sample, 18% were not certain about such ability. In response to another query, an overwhelming 91% of the sample has said that they believe that mirrors can attract lightning. This outcome shows that even after more than three decades in modern times the beliefs hardly change in the region. The information in Trengove and Jandrell [6] and Trengove [19] reveals that Zulus (a tribe in South Africa) believe that lightning is attracted to shiny objects.

Sri Lanka, an island in the Indian Ocean, which is located south of India, it is a long-standing tradition to curse on the most hated enemies with the phrase "may lightning-without-rain fall upon you". A close look at the characteristics of positive lightning shows the scientific significance of this curse as far as its intended purpose is concerned: Most often lightning that reaches the ground in the absence of lightning is positive in polarity, as they most often emerged from the leading or trailing edge of the tower [20]. Positive lightning contains much larger peak impulse current, longer time duration of both impulse and continuing current components thus, carry enormous energy [21]. Such characteristics will fit into a curse that is meant for spelling maximum disaster to the enemy.

A well-documented incident, from the nineteenth century in Sri Lanka provides, substantial support to the public belief of "a bad person is punished by lightning" [22]. Major Thomas William Rogers was a British National who was appointed in the 1840s as the Assistant Government Agent and the District Judge of Badulla, a mountainous district of then Ceylon, a Colony of the British Empire (Now Sri Lanka). He was an elephant hunter and is credited with killing over one thousand five hundred elephants within a short span of 4 years. One of the elephants that Major Roger's killed was from the sacred area of Kataragama, a sacred city. An old patriarch had warned him that he had done wrong in killing this elephant within the sacred boundaries of one of Lanka's holiest citadels and that he should beware of a tragic death. On the 7th of June 1845, when Roger's stepped outside from his shelter on a stormy night, onlookers suddenly witnessed a flash of lightning and saw the elephant hunter fall face forwards. In the government cemetery of Nuwara Eliya lies the tomb of Rogers, which, according to the records, have been struck by lightning twice since it was erected. The authors have visited the burial place of the subject, in 2008. The incident is still highlighting a riddle to be solved in lightning science.

4 Lightning Safety Education

There were several efforts taken at the international level during the last few years to address lightning safety issues in the developing world, especially in countries with a high risk of lightning accidents. The International Roundtable on Lightning Protection, which was held in Colombo, Sri Lanka in 2007 where the formulation and endorsement of "Colombo Declaration on Lightning Safety took place, International Symposium on Lightning Protection which was held in Kathmandu, Nepal in 2011, African Regional Conferences on Lightning Protection held in Entebbe, Uganda in 2013 and 2014 and Lusaka, Zambia in 2015, World Meeting on Lightning, Cartagena, Colombia, in 2016, Roundtable Meeting on Lightning and Thunderstorms, Agartala, India in 2019 are few such events. Several positive steps for the way forward have been taken in these programs; however, during the discussion sessions, many stakeholders cited that the lack of compiled information on lightning safety awareness programs conducted in developing regions as the main obstacle in optimizing new programs.

In the above backdrop, a comprehensive summary on the success and failure of lightning safety in regions with high lightning risk is a need at present for the benefit of lightning safety promoters, especially in the developing world. Furthermore, such information will be very useful for the safety module developers and funding agencies in developed countries, to strategize their road maps, preparation of work plans and decision making on prioritizing fund allocations. This study is done with the view of filling this void in the field of lightning safety.

Educators and community workers in developing countries are at a distinct disadvantage as they do not get opportunities to access up-to-date knowledge or training in lightning safety measures. Furthermore, the awareness promotion methodologies and techniques of imparting knowledge, practised in developed countries, may not be applicable directly in developing countries. For example, the web-based lightning safety guidance and training which has shown fruitful results in developed countries such as the USA and Australia, has not been a very successful technique of educating the public in many of the third world countries up to now [23]. However, such conditions may change in the next 5–10 years, as computer literacy among the common people is raised to a higher level.

Lightning safety programs developed for any region should consider minimizing the effects of each of these mechanisms of injury. However, in different parts of the world different types of injuries dominate as per the analysis of injury statistics [24–26].

People in the following environments should be given priority in the process of developing lightning safety promotion modules.

1. Live in areas of high lightning ground flash density
2. Permanently reside at elevated locations (hilltops, plateaus etc.), exposed areas (large landscapes with low-grown or no vegetation, rivers (boat people) etc.
3. Permanently reside in unprotected wooden, thatched and clay huts, small shelters with metal roofing on non-metal structures and canvas/polythene tents etc.
4. Often involved with outdoor activities for employment (farmers, fishermen, power and communication line repairers, outdoor labourers etc.)
5. Often involved with outdoor recreational activities (cycling, hiking, golfing, boating, adventure walking etc.)
6. Reside or work at locations (indoor or outdoor) close to metal transmission or communication towers.

5 Sheltering Under Thunderstorm Conditions

In the event of a natural random atmospheric phenomenon such as lightning, no place is 100% safe or having zero risks, however, some places are safer than others. Therefore, in the event of an approaching thunderstorm, one should seek shelter in a low-risk location that is reachable within a reasonable time. It is always recommended that one should be inside a safe shelter or safe structure during a thunderstorm period.

It is essential to define what is meant by a lightning safe shelter (safe structure). The best definition, in this case, is "A structure that protects the occupants against the five primary lightning injury mechanisms, namely direct strike, side flash, step potential, touch potential and upward leader". These mechanisms have been described in the previous chapter. As per the definition, the safe structure may not safeguard the occupants from secondary effects such as barotrauma (due to shockwave), vision imparity (due to intense light), splinters and fragments from exploding objects, falling objects (tree branches, masonry etc.), choking (due to smoke from fires ignited by lightning) etc. Hence, the occupant may pay attention to the possibilities of such secondary hazards.

One of the safest locations during a thunderstorm is inside a substantially constructed building, preferably with steel reinforcement (concrete slabs and pillars reinforced with steel), plumbing and electrical wiring with a sound grounding system. Such structures are residential complexes, fully enclosed factories, shopping malls, cinema halls, schools, office buildings, and private residences made with brick, concrete etc. If lightning strikes the building, the steel bars, plumbing and wiring will conduct the electricity more efficiently than a human body. Therefore, the chances of lightning current entering the human body through an electric spark from the roof or walls is negligibly small. The risk is further reduced if the building is installed with a properly designed structural protection system. The design and installation of a lightning structural protection system should be done by a competent engineer specialized in the subject. Such design descriptions are given in national and international standards (IEC 62305 2010; NFPA 780 2008; AS/NZS 1768 2007 etc.)

When one is inside a building, he should stay in the middle of a room or a hall. It is advisable to sit on a chair or bed and keep the feet up. If one is in a standing position, he should keep his feet close together. One should never sleep on the floor, especially inside a risky building, when thunder is roaring around. One should stay inside for at least 30 min after hearing the last thunder. Once lightning strikes a structure, the current is most likely to flow along with metal parts such as railings, fences etc. Therefore, touching or staying very close to such components should be avoided.

A structure made of non-metallic materials or having large exposed areas is not safe during a thunderstorm. The risk of injuries and death will greatly be increased if such structures are covered with combustible material (eg. wood, paper pulp, thatch, polymeric materials such as PVC or rubber, fabrics etc.) The following structures fall into the above categories, thus offer no safety from lightning. One must refrain from seeking shelter in such structures under thunderstorm conditions.

- Thatched roofed houses or temporary shelters
- Wooden or non-metallic structures with metallic roofs
- Beach shacks and cabanas
- Camping tents and picnic huts (irrespective of the material)
- Sports pavilions and open stages
- Carports (especially the ones having no walls)

- Rooftop terraces (even when the terrace is covered with glass or transparent polymeric materials)
- Structures with no walls or half walls (Dharma-Shala of most of the temples, most of the schools in rural areas (even in urban areas), and public gathering places such as Praja-Shala etc.)

One should not stay inside a building (even if it does not fall into the above categories), which stores (or manufactures) fireworks, gun powder, explosives, volatile fluids, poisonous or compressed gases, petrochemicals etc., if the building is not installed with a structural protection system that complies with national or international standards. The relevant government authorities should take strict measures to ensure that such structures are comprehensively protected against lightning, to safeguard the occupants and neighbourhood.

It should also be emphasized that structures with metal roofs are very much likely to attract lightning. If the roof is fixed on a structure that is not properly earthed, the occupants will be at a very high risk of getting side flashes if the structure is struck by lightning.

If no proper building is available for sheltering under lightning conditions, then an enclosed sturdy metallic vehicle such as train, car, van, bus or large ship makes a good alternative. However, convertible vehicles offer no safety from lightning, even if the top is covered with the foldable flap. Other unsafe vehicles during lightning storms are those which have exposed parts such as open cabs, golf carts, tractors, trailers, three-wheelers, motorcycles and bicycles, agricultural vehicles, construction equipment such as cranes and elevators, canoes, and open boats etc. Inside a ship, one should refrain from staying in open decks.

Inside a vehicle, one should keep the windows up, and avoid contact with any conducting paths leading to the outside or connected to the body of the vehicle (e.g. radios, body-fixed telephones and keys in keyholes etc.). One should also avoid leaning against the metal parts of the vehicles. If lightning strikes in the close vicinity, one should cover his ears with hands if a suitable ear protector (earphones, cotton buds etc.) is not around.

In recent years, several studies have been done on designing purpose made safety structures. These structures have been designed for both group protection and individual protection. The most popular group protection structure is simply the abandoned cargo containers modified to facilitate short-duration human occupancy. Such containers, being fully metallic enclosures provide total protection to the occupants even if the structure is not properly grounded. However, such ungrounded or poorly grounded structures could pose a significant threat to human beings and animals who are outside the structure but at proximity. Thus, if the structure is not properly grounded, it is strongly advised to display warning signs emphasizing the danger of reaching the structure under thunderstorm conditions. These container-type safety structures are highly practical at remote construction sites, mining fields, agro-fields, and large gathering sites etc.

Several purpose-made individual safety structures have also been tested in a few studies in the recent past. These are most often tripod or pyramid skeletal type

structures where one or two people may occupy. These structures could be used in golf courses, remote hiking and camping sites, fishing and bathing locations (at the beach, lakeshores or river banks) etc. Figure 3 shows such a safety structure being tested under high current impulses at the University of Witwatersrand, South Africa (Constructed and tested by Mr. Musa T. Mukansi and Mr. Mathew L. Woodhead).

Small boats should also be given protection in the form of a series of flexible cables starting from a purpose-installed or existing metal final and ending up at least one meter inside the water [27]. Figure 4 depicts a diagram of such a protection system. Note that these protection systems, including personal safety structures, are yet to be tested against real lightning. The most feasible way of testing them is to apply triggered lightning currents to grounded structures.

Fig. 3 Lightning safety structre for individual occupation (Constructed and tested by Mr. Musa T. Mukansi and Mr. Mathew L. Woodhead, School of Electrical and Information Engineering, University of Witwatersrand, South Africa)

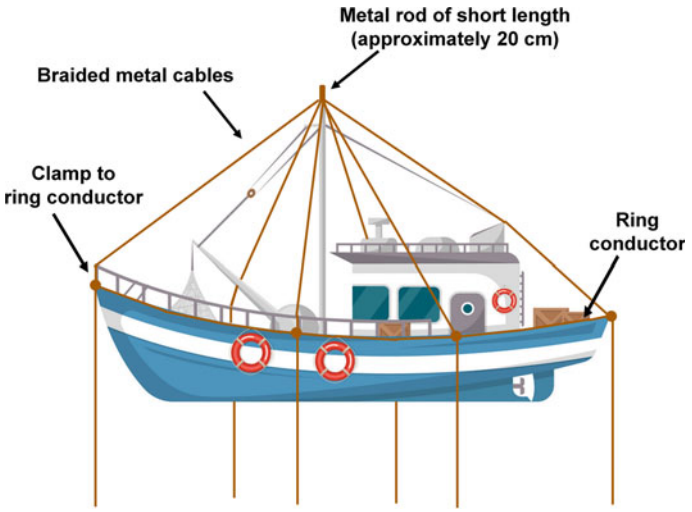

Fig. 4 Lightning protection system for a small boat. Adopted from Gomes [28]

6 Lightning Threat from Equipment

Power and communication lines are frequently struck by lightning due to their exposure to electricity from the sky. When such a service line is subjected to lightning, the current may travel along the wires and enter nearby buildings. Therefore, under thunderstorm conditions, electrical appliances should not be handled if they are connected to the power supply or communication line. For the safety of the equipment, they should be kept plugged off from the service lines. It is also advisable to remove the external antenna jack of the Television and place it outside the building. However, it should be emphasized that the unplugging of the TV antenna jack, power connection, telecommunication connection etc. should be done well in advance. Such removal should not be done after the arrival of the thunderstorm.

Corded telephones and wired microphones should not be used unless it is an emergency. However, there is no additional lightning threat of using mobile phones, cordless phones or FM microphones. Nevertheless, it should be noted that the person who handles the electronics of the public addressing system is at risk of getting a shock if the system is connected to the electricity service. Working on computers is also dangerous if they are connected to communication and electrical services. If the trip-switch (RCD) or other circuit breakers get switched off under thunderstorm conditions they should be kept at off-position until the storm is over. One should also not attend to the rectification of faulty conditions in the electrical wiring system or corded telephone systems during the thunderstorm period.

If the budget permits the building should be fitted with a system of coordinated surge protective devices. Selection and installation criteria are given in many international standards including IEC, IEEE and ITU, and in some literature on easy guidance [29].

7 Dangerous Acts Indoors

There are many domestic activities that one needs to suspend in the event of an approaching thunderstorm. A number of reported lightning accidents show that hazards could have been avoided if victims have suspended activities that they were involved with. Most often, people are reluctant to give up their activities either due to ignorance/stubbornness or financial/opportunity cost.

The repairing of leakage in the roof under overcast conditions should strictly be avoided. One should not take a shower or bath or use a hot tub during an intense thunderstorm. Using the swimming pools (both indoor and outdoor) should also be avoided during the entire thunderstorm period even if the building is installed with a structural protection system. The shock wave and the intense light generated by a close-by lightning strike and the potential gradient in the water that can be developed by the lightning current, may temporarily paralyze the person who uses the swimming pool, thus drowning him to death.

8 Outdoor Safety Measures

It is important to plan the outdoor activities during the lightning season to avoid being caught up in a thunderstorm before reaching a safe shelter. The lightning season or seasons of a country depends on its geographic location. For example, in Sri Lanka, the acute lightning seasons are the inter-monsoon periods; March–April and September–October. During the acute lightning seasons, most of the thunderstorm activities take place in the evening. Therefore, one should keep an eye on the weather forecast and plan outdoor activities accordingly.

If a person becomes a tall protrusion in a certain landscape his body may be the unfortunate object that sends the first upward channel that meets the downward stream of charge from the cloud. Therefore, to avoid being subjected to a direct lightning strike one should not expose himself to the down coming stepped leader.

Under thunderstorm conditions people should not stay at high risk areas such as.

- Playgrounds, racing tracks and other outdoor recreational areas
- Paddy fields and other agricultural landscapes including gardens with low growth
- Beaches, riverbanks, open wells, bridges and open roads
- Open construction sites, worksites and aerodromes etc.
- Higher elevations such as mountain tops, and building tops etc.

- Close to isolated trees and other tall isolated objects.

To avoid such places, one should refrain from playing outdoor games and doing recreation activities, farming, boating, cycling and riding, hiking, gathering for open rallies, repairing power and other service lines etc.

One of the most important rules of outdoor lightning safety is to avoid seeking shelter under large isolated trees during thunderstorm periods. The electrical resistance of a human body; about 300 Ω is much less than that of a tree which is in the order of mega Ohms. Therefore, once a tree is subjected to a lightning strike the large current that is flowing along the tree trunk may jump to the bodies of the people who gather around the tree and passes into the earth in a low resistive path. This side flashing may kill even 5–6 people, according to the records that we have from Sri Lanka, Bangladesh and Pakistan etc. [30]. Although sheltering under isolated trees are very risky under thunderstorm conditions, in comparison with open terrains or mountain tops, seeking shelter in a uniformly grown forest patch or clumps of shrubs may be less dangerous.

When one is in contact with an object which will be subjected to a lightning strike a part of the current may flow across his body as well. This has been described earlier as the touch potential. To prevent the body from being subjected to touch potential one should keep away from flag poles, metallic masts, wire fences, metallic walls and doors, metal railings, etc.

One should also avoid taking a bath or swim in open pools, streams, rivers, lakes, sea etc., under thunderstorm conditions. A person may be drowned to death if he falls unconscious in an unattended environment while he is taking a bath or swim in such water masses (even if the water is only a couple of feet deep). One should also discontinue fishing, water skiing, scuba diving, swimming or other water activities when there is lightning or even when weather conditions look threatening.

If a person is in a small watercraft such as a boat, canoe, raft etc., move fast as possible to the land and seek a proper shelter. If such movement is not possible, try to take shelter under a bridge. In the worst scenario, be inside the cabin or any other enclosure if such location is available and take the safety position that will be described later. It is highly recommended that those who regularly use small to medium-sized boats should adopt proper lightning protection systems in the watercraft. A low-cost protection system for small boats is given in [27].

If one stays close to a tall communication or broadcasting tower he has to take extra measures in protecting himself and his equipment. This is due to the high chance of lightning current flowing near to his house or factory. In case of poor earthing at the tower base there can be a so-called “earth potential rise” in the nearby area, so that a person outside may be subjected to a “step potential” [31]. As a result, he may be injured or temporarily paralyzed. Such paralysis may lead to severe injuries and even death if he is standing close to a pit or unprotected well or taking a bath in a water pool. Thus, those who have such towers in the neighbourhood should strictly be adhere to the safety guidelines described in this paper. In addition to human and livestock injuries, there is a high probability of equipment damage in buildings in the

neighbourhood such as towers both due to ground potential rise and induced voltages [32].

9 Estimation of Timing

In many countries such as the USA, Canada and Australia lightning safety plans essentially include the so-called 30/30 rule (30/30-R). As per the 30/30-R people should get into a protective shelter (sturdily built building or an all-metal vehicle) if the illumination-to-thunder time delay (duration of time in seconds between the vision of the lightning flash and the subsequent hearing of thunder) is 30 s or less and that they should not leave their shelter of protection until 30 min after the final sound of thunder.

As light travels almost instantly compared to the speed of sound (approximately 330 m/s), a 30 s time-to-thunder corresponds to a lightning strike about 10 km away. The analysis of lightning detection data in several countries shows that at the beginning of the lighting activity, strikes can be scattered within a space of about 10–15 km [33]. Hence, at least 30 s time-to-thunder lead is necessary prior to the arrival of the thunderstorm as there is a possibility of distant strikes. A 30-min time delay, after the sound of the last thunder, is required as the trailing part of thunderstorms may carry a net residual charge in either the negative charge centre or the positive charge centres. This charge may produce lightning on the passing edge of a storm, tens of minutes after the rain has ended. Note that in a thunderstorm, rain is produced typically from the cloud base, which may be quite small in coverage compared to that of the upper parts. However, there is no solid scientific evidence to justify the validity of the 30-min delay from the last sound of thunder to restart the normal activities.

Several studies have revealed that most people affected by lightning are struck not at the most active stage of a thunderstorm but before and after the storm peak. This can be explained scientifically as in many cumulonimbus clouds that produce lightning, the anvil of the cloud from which lightning can be emanated, is several tens of kilometres shifted from the rain base due to the wind shear. Most importantly this part of the thundercloud houses the positive charge that drives positive cloud to ground lightning. As per the literature [20] such positive lightning may drive much larger impulse currents (in the order of 500 kA) and long continuing currents (currents in the order of about 1 kA flowing for a considerably longer period). Furthermore, if the lightning strikes before the rain the chances of triggering fire is also larger due to the dry conditions that may prevail. Therefore, such lightning poses a much higher threat to human beings, animals and property than their negative counterparts.

The above facts show that many people are unaware of how far lightning can strike from its parent thunderstorm. Therefore, one should not wait for the rain to start seeking shelter and should not leave shelter just because the rain has ended.

Although, application of 30/30-R is successful in developed countries such as the USA, Canada and Australia, the same may not be the case in many developing

countries, especially in communities that work on a daily wage basis. Interviews conducted by authors in Bangladesh and Sri Lanka reveal that a majority of low-income societies are not ready to give up or delay their professional activities for more than 5–10 min, even though they have an understanding of the risk they pose (experience of authors in the two countries during the awareness programs conducted). Hence, a suitable rule or guideline should be adopted region-wise to replace 30/30-R, if it is practically nonviable in a given region.

10 Safety Position

If one cannot go elsewhere and is compelled to stay outdoors in a severe thunderstorm (as he may be far away from a proper shelter), he should move to the safest location available (away from open fields, higher elevations, water etc.) and adopt the safety position described below.

The person should crouch down, put the feet together and place hands over ears to minimize hearing damage from thunder and duck the head as much as possible (Fig. 5). One should make sure that he does not take the safety position at a place that has a chance of falling material (very close to a large wall or underneath an overhanging roof), flooding (dry river beds, floodplains, pits etc.), land sliding (eroded slopes, newly filled lands and close to wells etc.) or explosion (close to underground ammunition dumps, minefields etc.).

Each person in a group, in a safety position, should at least be 2-3 m away from one another, thus if one unlucky person is struck, the others are protected and can provide first aid to the victim.

In the event of very close thunder activities, one better not use earphones and headsets. All removable metallic parts on the body such as backpacks, caps with metal

Fig. 5 Lightning safety position

tips, wristwatches, metallic badges etc. and any metallic items such as golf clubs, fishing rods, agricultural tools, tennis rackets, umbrellas etc. should be removed or dropped aside. The reason for getting rid of such metal objects is to avoid getting side flashes and also to prevent heat from being trapped into a single point in the event of a lightning strike to an unfortunate person [34]. There are several records where people have been severely injured as metal parts on the body garments were melted due to the heat of the lightning current and stuck into the body. However, one should note that there are no scientific evidence to conclude that metal parts attached to the body have any influence on the probability of a direct strike to a human being [34].

It will be advantageous to wear shoes or slippers made of insulation material (such as rubber, clothes, leather, plastic, etc.), as that will minimize the effects of being subjected to step potential. Studies that have been done in Bangladesh reveal that step potential may lead to the death of people more often than one would expect [24]. It should be repeated that such footwear also does not influence the probability of the person being subjected to direct lightning strikes.

11 Safety at Workplace

Lightning safety should be an integral part of the safety plan of workplaces in areas of high lightning occurrence density. This is specifically important in the industrial and service sectors where.

- considerable outdoor activities are involved; power distribution, communication (tower related sites, line maintenance etc.), building construction, road and other civil constructions, defence, police, dockyards, transportation, airport and aviation, hydro projects, fisheries, plantations, metal crushers, playgrounds, Golf courses, swimming pools etc.,
- large masses of employees are engaged; garment industry, hotel industry, hospitals etc.
- a high-risk environment exist; firework industry, explosive manufacturing, petrochemical industry, compressed gas distribution etc.

The employees of such sectors should be given a mandatory short training program together with demonstrations on lightning safety and protection on annual basis. Typically a three-hour program will be sufficient to enlighten the awareness of workers. Such training program should include.

- basic concepts of lightning
- human safety concerns
- techniques of lightning protection of equipment and properties
- training on first aid
- maintenance and record-keeping, troubleshooting and regular inspection.

The following measures can be taken to improve the lightning safety environment of the workplace.

- Installing of proper structural and surge protection systems to the buildings.
- Displaying of "do"s and "should-not-do"s under thunderstorm conditions, at frequently-visited places of employees; restaurants or lunch/refreshment rooms, reception, restrooms, recreation centres etc.
- Installing of lightning warning systems at vulnerable places.
- Displaying of warning signs at dangerous locations such as playgrounds, swimming pools, outdoor recreation centres, beaches, isolated trees, open spaces, flag poles, close to down conductors of the structural protection system, etc. Few such warning signs are
  "Do not use XX under the lightning conditions". XX: Playground, swimming pool etc.
  "Keep away from this XX under the lightning conditions". XX: flagpole, down conductor, tree etc.
  "Don't go out of the building under the lightning conditions". In beaches, gardens, hotels etc.
  It is highly meaningful to incorporate these warning signs (displayed in both English and native languages) with a lightning warning system.
- Covering of the locations of the earthing pits (of down conductors or power) with a few-centimeter layer of gravel or crushed rock (area of radius about 2 m around the pit).
- Planning of outdoor events such as repairing of power and communication lines, plantation activities, construction work etc., according to the weather forecast or information obtained from a lightning detection system. This is specifically important in the case of repairing power systems where a lineman is lifted by an insulated-boom crane to be in contact with low voltage or high voltage overhead lines. As far as the bucket is insulated from the body of the crane (and in most cases, the bucket is temporarily bonded to the line as well) the lineman is safe from electrocution due to power frequency currents. However, in the event of a lightning strike to the line, the bucket will become a floating electrode that facilitates the lightning current to flow into the ground in the form of an aerial spark & a resistive flow combination. In other words, a lightning generated spark may leap through the insulation of the bucket (bridging the gap electrically) so that the lightning current may pass through the body of the lineman into the ground (killing or injuring him).

12 Organized Lightning Safety Promotion

Lightning safety has been promoted at various levels by individuals and organizations in South Asia for several decades. However, due to the disorganized manner that such programs have been conducted, the maximum benefits of the investment and efforts could not be harvested [23]. Observations of authors in Bangladesh, Sri Lanka and India reveal the following shortfalls of disorganized and unplanned lightning awareness campaigns.

a. Overlapping of target groups: There were occasions that the same village or same school has been approached by multiple organizations for the lightning safety programs. This is often observed following an occurrence of a catastrophic incident in a given area. Repeated programs of a similar type may wear out the audience and deprive other parts of the community of acquiring awareness.
b. Overlapping of safety promotion modes: Similar media programs, quiz competitions and seminar series etc. at the same time in a given region may be less effective.
c. Lack of opportunities for background studies: It is very important to do the success-failure analysis of previous programs prior to the launching of similar programs in a given region.
d. Difficulties in validating program outcomes: It is much easier to evaluate success-failure rates of programs when data can be shared through collaboration.
e. Lack of confidence and trust of the public: It will be quite an uphill task to build up public trust and confidence when promoters reach masses at the individual or solitary organizational level. On the other hand, the same task may be quite viable by approaching at the organized institutional level.
f. Promotion of inadvertent misinformation: Lightning protection is plagued with many products and technologies that are rejected by the international scientific community and many reputed standards due to their lack of scientific acceptability. However, vendors of these products may infiltrate unsuspecting safety promoters and include misinformation into the safety programs with the view of boosting their fraudulent products [35].

Therefore, it is proposed to establish lightning centres (LCs) in each developing country to address the needs and issues of the respective regions. The LC may serve the public in the region in many ways.

LCs need not be charity organizations. They may generate income and achieve personal/team goals. However, it is strongly advised to decide the financial model of the LC from the right beginning and get the consent of all the stakeholders. The objectives of the LC may be;

To reduce lightning accidents in a target region.

To reduce property damage in a target region.

To increase the scientific knowledge among both the scholars and the public.

The decision-makers of each centre should plan out the best ways of disseminating knowledge and promoting awareness in each region. It is also important to share the experience of each centre with others. The following general activities have been recommended to be conducted by the regional lightning awareness centres; however, the activities should not be restricted to the given list.

- Publishing awareness material in local languages (with diagrams and pictures) and distributing them among schools, public service sectors etc.
- Conducting lightning safety seminars and demonstrations/training on first aid for school children, social workers etc.
- Educate the private and government sector in lightning protection techniques and the importance of industrial lightning safety.

- Displaying of banners, posters, cut-outs on lightning safety in highly lightning prone areas.
- Conducting awareness programs for community leaders such as religious heads, doctors (both western medicinal and indigenous), public servants of local authorities and officers of the police.
- Training youths in the region to practice lightning protection as self-employment (especially on low-cost protection measures).

The above points are categorized in concise form in Fig. 6. Note that all LCs may not be able to put all these points into practice in their roadmap due to various financial and strategic constraints. Similarly, depending on the public needs, some LCs may include region-specific additional objectives and activities.

Modes of promoting lightning safety are strongly dependent on the cultural, social and economic backgrounds of a given region. Hence, it is not a good practice to use everywhere a generalized formula in developing lightning safety modules. As it is described in the literature [23] lightning safety modules used in the USA were not very successful in South Asia. Even within South Asia, modules successfully practised in one country was not that fruitful in another country in the region [23].

Another point of significance is the attitudinal trends of certain nations. For example, as it was reported by [23], in Sri Lanka, the level of awareness on lightning safety and protection among the public is quite high due to various programs conducted over the years, however, as a majority simply neglect or overlook the safety advice due to ignorance or stubbornness, lightning accidents in the country is in the increasing trend for the last decade. Jayaratne and Gomes [23] attribute this to the decade long attitudinal practices of the island nation regarding hazard safety.

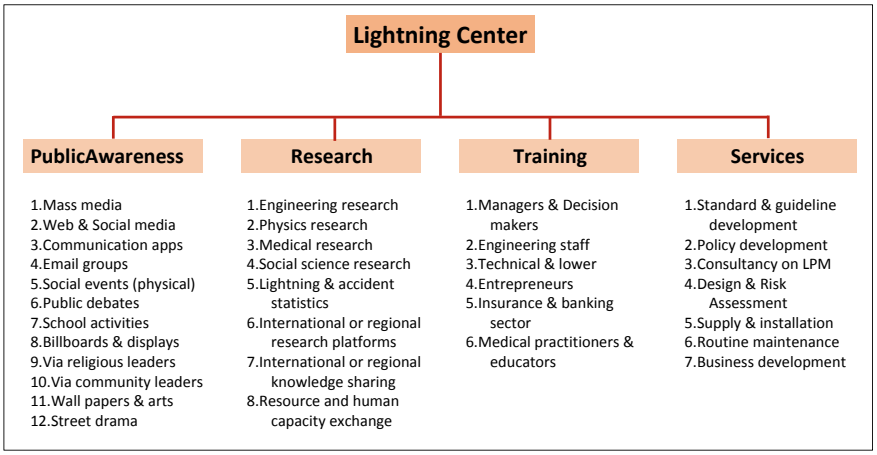

Fig. 6 Major goals and activities that an LC may include in their roadmap

The LAC should consider these regional and local factors into account in developing awareness programs for the people within their territorial coverage.

Table 1 depicts the timeline and related concerns of developing an LC. Note that, usually the concept of LC is developed by a single person, who may be most suitable as the driver (or leader) of the LC. However, there were cases where the concept developer preferred to be sideline giving the driving seat to abler individuals. Therefore, there is no firm rule that the concept developer should be the leader. Once the road map is developed, it is very advantageous to stick to the timeline of the roadmap as much as possible. It is advisable to develop both a short term (say one year) and a long term (say five years) roadmap where the former is more detailed

Table 1 The typical timeline and relevant concerns that an LC may follow

Timeline activities	Concerns
A driver (LC Leader) by volunteering	• Key person that initiates and drags the cart forward • Should be multiplied at least to two with time. Very risky to move on with one driver
Decision on the LC platform	• The institute under which the LC is established • Usually, the institute where the driver is affiliated • Could be standalone but usually as a business entity
Selection of the core team	• Select a team that has the least personal conflicts • Better have a couple of people at decision-making level • Could be standalone but usually as a business entity
Agreement on the LC model	• Business Entity, University/institute funded, NOGO/INGO/GO funded, not for profit earning but income-generating, totally charity based etc • Sometimes it may be a combination, also could be changed with time
Development of the roadmap and time plan	• Prepare six-month, one-year and three-year roadmaps and time plans • It's advisable that the driver prepares it and discuss it with the core team • Be realistic in both activities and time frames
Selection of the advisory team	• First, decide the roles of the advisers (it should be solid and useful) • Select a list of advisers and ask for their consent providing them with the document regarding the expectations from them
Formal establishment of the LC	• It is very important that the LC is officiated • It is good to inaugurate the LC with a regional or international event • Even a nominal physical location makes a big impact on the success of LC

and specific. The LC can develop short-term roadmaps periodically following the long-term roadmap as the guideline.

13 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 [23]. However, the interviews conducted by the authors in several South Asian countries with a number of potential victim communities, revealed that many social and religious leaders are concerned about human safety against lightning and they are willing to be educated. Such observations prompted us to develop a hierarchy of hazard control mechanisms that may successfully be applied to the communities in high lightning risk regions. Although such mechanisms are employed in enclosed work environments (factories, harbours, cargo control divisions, outdoor sites with task boundaries etc.), any community with reasonable size and common interests (fisher communities. farmers, livestock-based communities, highlanders etc.) may provide the operational feasibility for such mechanism.

A group of people, even very large in number that engaged with a similar type of employment or routinely practices can be treated as a bound community. Such a community is often composed of many interacting subsystems and sub-processes. Thus, the safety of such a social system concerning 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 the implementation of safety measures to the community through distributed responsibility of control. A hierarchal hazard control approach is needed for the lightning safety of such a community under this backdrop.

The first attempt at formulating a hierarchy of hazard control was done by Gomes and Gomes [1, 2], where they have applied the concept to the fisheries community along the shores of Lake Victoria in Uganda. In this study, we expand this concept in a broader perspective to make the applications more generalized. Based on the inferences and recommendations given in previous sections, the following hierarchy of control map is proposed for the lightning safety of a bound community, as shown in Fig. 7. Such bound communities should have a common parameter that integrates them into similar practices or activities; e.g. by profession (fisheries, farming, outdoor construction, mining, highway cleaning etc.), by social and religious norms (congregation, pilgrims, outdoor rituals, mass rallying etc.) and by recreational activities (group hiking, outdoor sporting, amusement and adventurous activities etc.).

Forecasting: The government (through the Department of Meteorology) or a relevant private sector that owns a 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 the internet

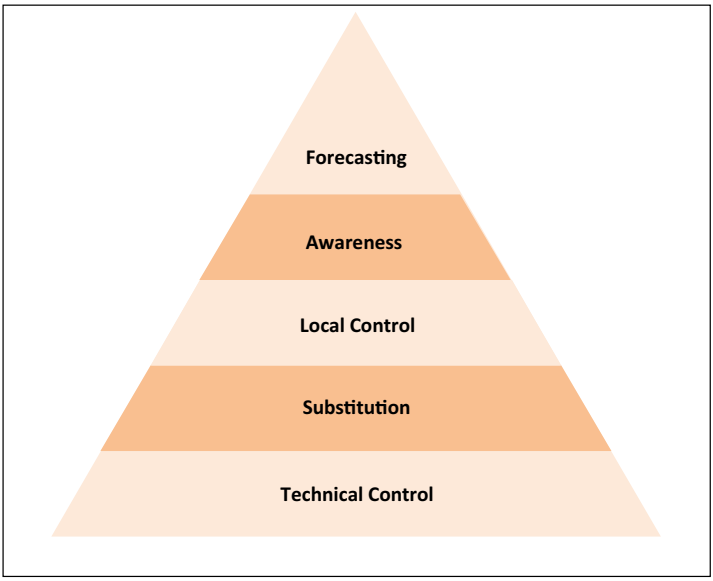

Fig. 7 Hierarchy of hazard control mechanism (adopted from [1] with modifications)

is fast reaching even remote communities. The need of providing accurate information in local languages is a key factor to the successful adoption of safety measures following such news broadcasts.

Awareness: The experience in Uganda [36], Zambia [3], Bangladesh and Sri Lanka [24], 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 a periodic basis. Local authorities, governmental institutions (police, educational institutes, hospitals etc.) and non-governmental organizations may take part in this process with the help of local community leaders.

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, the 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 haven't 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 a warning system is the lakeshore. 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 the electricity supply is an issue. However, such signal systems are invisible during nighttime. The other mode of local control is the training of group leaders on executing rules on activity stop/start (eg. 30/30 rule) and following safety measures (eg. avoiding shelter under large trees, going into safety position, indoor guidelines etc.). Such group leaders may be landlords, heads of 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 a leader.

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 of 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 farmers in an agricultural community to an indoor activity such as harvest sorting, stock taking, group discussions on weeding etc., that can be conducted inside a sturdy structure when they are prevented from going out into the farm fields. Planning of such substitutions and providing directives to take up the substitute work should be done by selected community leaders.

Technical Control: As a standard solution for those who seek shelter in places of low risk and the last resort solution for those who do 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 the community level, most probably with the help of external experts. These may include low-cost structural protection systems [27] at all buildings in the community (if possible) or at least at several selected structures where the mass gathering takes place, less complicated protection system for small water vessels such as fishing boats [27, 28], insisting on wearing rubber sole boots to minimize step potentials etc. Placement of metal structures specially made for lightning protection in the farming fields, worksites etc. at regular intervals is strongly recommended as such structures could be developed at quite a low cost. Properly designed such structures can be placed at several locations even at offshore locations with the aid of anchors, thus, fishermen or workers at water-based employment in unsafe boats can get inside such in the event of acute thunderstorms.

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