SAFETY ISSUES IN REGIONS WITH HIGH LIGHTNING OCCURRENCE DENSITY

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ABSTRACT

Lightning is a major safety issue in many regions with high lightning ground flash density. However, due to the rapid development in communication technologies and high level of public awareness, lightning threats in developed countries have been reduced notably during the last few decades. On the other hand, the number of lightning related deaths and injuries in developing countries, as reported in recent studies, is significantly high. In this paper, we discuss and analyze lightning safety guidelines suitable for developing countries with high risks of lightning hazard. Formulation of safety awareness campaigns for such countries is also addressed in detail. Safety tips and programs are proposed for both domestic and workplace environments. For bound-communities, a hierarchy of hazard control has been proposed to implement distributed responsibility scheme. Such information is essential for management of lightning safety programs and reduction of risk.

Keywords: *lightning protection, human safety, awareness campaigns, natural hazards.*

1. INTRODUCTION

Lightning is a natural hazard that takes the lives of scores of people every year. As per several reports, the total number of lightning related deaths in the world may be as high as 24,000 per year. The number of cases of injuries (those who do not succumb to their injuries) may be 10 times more than the death toll (Holle and Lopez, 2003). Gomes and Kadir (2011a) showed that it is not only the isokeraunic level (thunder days per year) or lightning ground flash occurrence density of a given region that accounts for the annual number of lightning victims in the region. Population density, literacy rate, urban-rural ratio, social and cultural behaviours, poverty index and landscape topography are additional parameters that influence the lightning accidents of human beings.

Furthermore, as the public accessibility to communication systems and mass media spreads into the remote areas of a country, news regarding lightning accidents reach outside world rapidly and efficiently (Gomes and Kadir, 2011a). Thus, the number of lightning incidents may show an apparent increment in the past few decades, specifically in the regions where modernization has been started recently. Thus, analysis of the causes and patterns of lightning accidents is a complex task, especially in regions with high lightning ground flash occurrence density.

Due to various reasons actual lightning incident statistics are hardly available in many parts of the world. However, several countries have been monitoring lightning incidents for several decades. Out of them, USA has the best documented chronological record of lightning accidents, even state-wise, for the last century (Ashley and Gilson, 2009; Curran, et al., 2000; Holle, 2009, 2010; Holle, et al., 1995, 1999, 2005; Holle and López, 2003; Lengyel, 2004; López and Holle, 1996, 1998; Lopez, et al., 1993; Roeder and J. Jensenius, 2012). The long-term lightning data analysis in USA shows a noticeable decrement in the lightning related deaths with time. During the 20th Century, the lightning related deaths were reduced from about 60 deaths per ten million per year (dptm yr^{-1}) of population to less than 3 dptm yr^{-1} (Cooper, et al., 2007; Lengyel, 2004). The transition from rural to urban by a majority of the population, conversion of a substantial number of residences from small cottages built from soft materials (wood, thatch, clay, etc.) to large buildings made of hard materials (reinforce concrete, solid bricks, etc), easy accessibility to meteorological information and notification of warning, increment in literacy rate and comprehensive awareness programs launched in many parts of the country were indicated as the prime factors that contributed to this reduction in lightning accidents (Holle, 2008).

As it has been shown by Gomes, et al. (2011), Gomes and Kadir (2011a), Mary and Gomes (2015, 2012), Lubasi, et al. (2012), the number of lightning deaths were much higher in rural areas where the literacy rates are low (in South Asia and Africa where those studies have been conducted). The rural people in most of these regions live in small huts made of natural fiber, wood and clay. They hardly get access to warning information or safety awareness knowledge hubs, thus the conclusions of Holle (2008) regarding the declination of lightning accidents in USA is justified.

Australia has also developed a significantly large database on lightning hazards gathered for many decades (Golde and Lee, 1976; Coates, et al., 1993). The annual lightning related deaths in Australia has been gradually reduced from a staggering maximum value of 210 dptm yr^{-1} in the 1820s to 1 dptm yr^{-1} in

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1980s. Canada also shows a significant reduction of deaths over the time with a maximum death rate of 36 dptm yr^{-1} in the 1920s to 3 dptm yr^{-1} in the early 2000s (Hornstein, 1962; Mills, et al., 2006).

In Europe, lightning has not been considered as a grave natural hazard as the annual death rate is most often less than 10 dptm yr^{-1}. A 12 year study in Greece (1990-2001) shows that the variation pattern of lightning deaths is not consistent. During this period a minima of 1 dptm yr^{-1} have been recorded in 1998 and 2000 whereas the maximum of 10 dptm yr^{-1} has been recorded in 1999 (Agoris, et al., 2002). In the following 10 years another erratic pattern of the death rate could be observed with peak value of 8 dptm yr^{-1} was recorded in 2003, whereas no death were reported in 2005, 2007 and 2008 (Peppas, et al., 2012).

A seven year study in UK (1993-1999) reveals that the average death rate is about 0.5 dptm yr^{-1} with maxima and minima being 0.2 dptm yr^{-1} (1995 and 1997) and 1 dptm yr^{-1} (1994 and 1996). In France, the death rate has been reduced from 32 dptm yr^{-1} in 1830s to 3 dptm yr^{-1} in 1990s (Flammarion, 1904; Gourbière, 1998). Sweden records approximately 2 dptm yr^{-1} in 1980s (Eriksson and Örnehult, 1988). From year 2000 to 2009, Austria has recorded a death rate of 1.4 dptm yr^{-1} on average (Kompacher, et al., 2012). In early 90s Switzerland and Germany recorded lightning related deaths as 3.5 dptm yr^{-1} and less than 1 dptm yr^{-1} respectively (respective Federal Office statistics). More details in this regard can be found in Doljinsuren and Gomes (2015).

In South and South East Asia, Africa and South America such information is scarce except for few isolated studies (Castle and Kreft, 1974; Virenque and Laguerre, 1976; Chao, et al., 1981; Pakiam, et al, 1981; Gomes, et al., 2006 a,b; Lubasi, et al., 2012; Mary and Gomes, 2012; Mulder, et al., 2012). The statistics given in these papers are most often under estimations due to the lack of facilities and modes of collecting data efficiently. Still, the figures are much higher than those in USA and Europe.

Zimbabwe recorded 108 dptm yr^{-1} in the early 70s (Castle and Kreft 1974; Virenque and Laguerre, 1976). Sri Lanka recorded nearly 25 dptm yr^{-1} in 2003 (Gomes, et al., 2006 b). Singapore has a maximum figure of 35 dptm yr^{-1} in late 1970s (Pakim, et al., 1981; Chao, et al., 1981). In Uganda the death toll raised to 30 dptm yr^{-1} in 2011 with 19 deaths recorded by a single lightning (Mary and Gomes, 2012). Although, annual data is not available, reports in Bangladesh, Pakistan, India and Zambia reveals that almost every year there are single incidents reported in these countries during which the death toll exceeds the total annual deaths of most European countries (Lubasi, et al., 2012; Gomes, et al., 2006a,b; Gomes and Kadir, 2011a). Being a developing country, India records quite a low value of death rate; 2.5 dptm yr^{-1} (Singh and Singh, 2015) which could be attributed to the large population of the country of which a significant fraction may be living in areas of extremely low lightning ground flash density (Kuleshov and Jayaratne, 2004).

Lightning death details in selected countries have been summarized in Table-1 where most information

Table-1: Number of deaths reported in several countries per year normalized to 10 million of the population

Reference	Country	Number of deaths per 10 million per year (dptm yr^{-1})
Cooper, et al. (2007)	USA	3
Coates, et al. (1993)	Australia	1
Mills, et al. (2006)	Canada	3
Peppas, et al. (2012)	Greece	3
Gourbiere (1998)	France	3
Eriksson and Ornehult (1988)	Sweden	2
Kompacher, et al. (2012)	Austria	1.4
Elsom (2001)	UK	1
Virenque and Laguerre (1976)	Zimbabwe	108
Gomes, et al. (2006b)	Sri Lanka	25
Pakiam, et al. (1981)	Singapore	35
Mary and Gomes (2012)	Uganda	30
Doljinsuren and Gomes (2015)	Mongolia	15.4
Singh and Sigh (2015)	India	2.5

has been adopted from Doljinsuren and Gomes (2015). The table shows that even with limited information available one may clearly conclude that the number of lightning accidents in developing countries is markedly higher than that in developed countries. Chronological data in several developed countries show that the number of fatal lightning accidents is in a declining trend for the last many decades. In countries such as USA, the decimation is almost exponential. Unfortunately, there is no such information to infer any conclusions on the lightning accident trends in developing countries.

There were several efforts taken at international level during the last few years to address lightning safety issues in the developing world, especially in countries with high risk of lightning accidents. The International Roundtable on Lightning Protection, which was held in Colombo, Sri Lanka, in 2007 (Arora and Gomes, 2008), the formulation and endorsement of “Colombo Declaration on Lightning Safety” (Colombo Declaration, 2007), International Symposium on Lightning Protection which was held in Kathmandu, Nepal in 2011 (Sharma, 2012), African Regional Conference on Lightning Protection in Entebbe, Uganda in 2013 (NAM S&T Newsletter, 2013), & International Symposium on Strategic Interventions to Mitigate Hazards of Lightning, in Lusaka, Zambia, in 2015 (NAM S&T Newsletter, 2015) 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 a main obstacle in optimizing new programs (authors were stakeholders).

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 developing world. Furthermore, such information will be very useful for the safety module developers and funding agencies in developed countries, in order 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.

2. INFORMATION AND DISCUSSION

2.1 Lightning Threat

Lightning may affect human beings and animals in several ways. There are five well known primary mechanisms which accounts for most of the injuries. They are direct strikes, side flashes, step potential, touch potential and upward leaders (Cooper and Holle, 2010; Cooper, et al., 2008; Kitagawa, et al., 1996; Mackerras, 1992).

There are secondary causes of lightning related injuries such as:

a. burning of surrounding materials due to high elevation of temperature (Krawchuk, et al., 2019; Lubasi, et al., 2012);
b. discharge of toxins or smoke from burning materials (Elsome, 2001; Celiköz, et al., 1996; Holle, 2012);
c. explosion of components and materials due to shock wave and fire (Tibesar, et al., 2000);
d. drowning in water due to momentary paralysis caused by step potential (Agoris, et al., 2002; Holle, 2007);
e. missiles created by splits and fragments (Elsome, 2001);
f. falling of detached materials from buildings and trees (Cooray, et al., 2007; Elsome, 2001; Holle, 2012);
g. shockwave that may damage eardrums and skin and also cause falling of victim from higher elevations (Cooray, et al., 2007; Tibesar, et al., 2000; Graber, et al., 1996; Chandimal and Gomes, 2012);
h. intense light that may cause optical damage (Gourbiere and Lapeyre, 2002; Norman, et al., 2001; Espaillat, et al, 1999; Noel, et al., 1980); &
i. sound, distorted environment (e.g. death of people and animal) and pain of injuries that may cause psychological effects (Cooper, 1980; Cooper, et al., 2007; Panse, 1975; Cooray, et al., 2007).

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, practiced in developed countries, may not be applicable directly in developing countries. As an example, the web based lightning safety guidance and training which has shown fruitful results in developed countries such as USA and Australia, has not been a very successful technique of educating the public in many of the third world countries up to now (Jayaratne and Gomes, 2012). However, such conditions may change in the next 5-10 years, as the 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 (Mary and Gomes, 2012; Gomes, et al., 2006; Holle, 2009, 2010).

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

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

2.2 Sheltering under Thunderstorm Conditions

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

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, 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. 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, 2014; 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 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 minutes after hearing the last thunder. Once lightning strikes a structure, the current is most likely to flow along 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 structures under thunderstorm conditions such as:

- 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 is in compliance with national or international standards. The relevant government authorities should take strict measures to ensure that such structures are comprehensively protected against lightning, in order 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 which 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 key in the keyhole 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.

2.3 Lightning Threat from Equipment

Power and communication lines are frequently struck by lightning due to their exposure to lightning. When such 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 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 a 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 condition they should be kept at off-position until the storm is over. One should also not attend for 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 is given in many international standards, manuals (IEC 62305-4, 2010; IEEE C62.41, 1991; ITU-T REC K.21, 2005; ITU-T REC K.20, 2003) and in some literature on easy guidance (Gomes, 2011).

2.4 Dangerous Acts Indoors

There are many domestic activities that one needs to suspend in the event of an approaching thunderstorm. There are many 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 and the small step potentials that can be developed by the lightning current injected into the nearby earth, may temporarily paralyze the person who uses the swimming pool, thus drowning him to death.

2.5 Outdoor Safety Measures

It is important to plan the outdoor activities in advance 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 an example, in Sri Lanka the acute lightning seasons are the inter-monsoon periods; March-April and September-October (however, during the last few years the occurrence of lightning has become rather erratic and spread all over the year). 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 his 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, in order to avoid being subjected to a direct lightning 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, river banks, open wells, bridges and open roads;
- Open construction sites, work sites 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 obviously refrain from playing out door 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 Ohms 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 earth in a low resistive path. This side flashing may kill even 5-6 people, according to the records that are available from Sri Lanka, Bangladesh and Pakistan, etc. (Gomes and Kadir, 2011a). 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. In order to prevent the body 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 bath 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 swimming 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 one is in a small watercraft such as a boat, canoe, raft etc., move fast as possible to the land and seek a proper shelter. In the event that 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 latter. 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 Gomes, et al. (2012). 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” (Gomes and Diego, 2012). 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 adhered 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 towers both due to ground potential rise and induced voltages (Chandimal and Gomes, 2012).

2.6 Estimation of Timing

In many countries such as 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 a 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 30s or less and that they should not leave their shelter of protection until 30 minutes after the final sound of thunder.

As light travels almost instantly compared to the speed of sound (approximately 330 m/s), a 30s time-to-thunder corresponds to a lightning 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 (Christian, et al., 2003). Hence, at least 30s time-to-thunder lead is necessary prior to the arrival of thunderstorm as there is a possibility of distant strikes. A 30-minute time delay, after the sound of last thunder, is required as the trailing part of thunderstorms may carry a net residual charge either in the negative charge centre or in the positive charge centers. 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 30 minute delay from 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 kilometers shifted from the rain base due to the wind shear. Most importantly this part of the thundercloud houses positive charge that drives positive cloud to ground lightning. As per the literature (Cooray, 2015) 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 the 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.

Figure-1: Safety position in the event of a severe thunderstorm (if you are caught outdoor). Squat down and duck your head. Close the ears with palms to protect them from the bang due to close lightning. Wearing footwear such as shoes with rubber, PVC, leather soles, etc., or rubber slippers may be advantageous (to minimize hazards due to step potential; but not to prevent or even reduce the chances of getting direct strikes).

Although, application of 30/30-R is successful in developed countries such as USA, Canada and Australia, the same may not be the case in many developing countries, especially in communities that work on daily wage basis. As per the outcomes of interviews conducted by authors in Bangladesh and Sri Lanka, a majority of low-income society are not ready to give up or delay their professional activities for more than 5-10 minutes, 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.

2.7 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 (Figure-1). 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 safety position, should at least be 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 tips, wrist watches, metallic badges etc. and any metallic items such as golf clubs, fishing rods, agricultural tools, tennis rackets, umbrella 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 being trapped into a single point in the event of a lightning strike to an unfortunate person. 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 evidences to conclude that metal parts attached to the body have any influence on the probability of direct strike to a human being.

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 (Gomes, et al., 2006b). It should be repeated that such footwear also has no influence on the probability of the person being subjected to direct lightning strikes.

2.8 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, defense, police, dock yards, 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; fire work 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, and
- 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, rest rooms, recreation centers, etc.
- Installing of lightning warning systems at vulnerable places.
- Displaying of warning signs at dangerous locations, such as playgrounds, swimming pools, outdoor recreation centers, 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 lightning conditions". XX: Playground, swimming pool etc.
  - "Keep away from this XX under lightning conditions". XX: flagpole, down conductor, tree etc.
  - "Don't go out of the building under 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 meters 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 ground in the form of aerial spark-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 ground (killing or injuring him).

2.9 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 (Jayaratne and Gomes, 2012). 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 similar type may wear out the audience and deprive other parts of the community 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 public:* It will be quite an uphill task to build up public trust and confidence when promoters reach masses at individual or solitary organizational level. On the other hand the same task may be quite viable by approaching at organized institutional level.
f. *Promotion of inadvertent mis-information:* Lightning protection is plagued with many products and technologies that are totally rejected by 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 (Gomes and Kadir, 2011b).

Therefore, it is proposed to establish lightning awareness centers (LAC) in each developing country to address the needs and issues of the respective regions. Large countries such as India, China, etc.

need more than one LAC in addressing lightning safety issues in the country. The LAC in each country should develop modalities to take the message of lightning safety to the public. In different regions these modalities may be different. For examples; As per the experience of the South Asian Technology research and Information Centre (SATRIC) and the Technology Assistance for Rural Advancement (TARA), the awareness programs conducted for children at secondary school level were very successful in Sri Lanka while folk songs and street dramas on lightning safety became a very powerful awareness promotion tool in Bangladesh; but not vice versa (Gomes, et al., 2006b).

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 centers; 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 police;
- Training youth in the region to practice lightning protection as a self-employment (especially on low-cost protection measures).

Modes of promoting lightning safety are strongly dependent on 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 literature (Jayaratne and Gomes, 2012) lightning safety modules used in USA were not very successful in South Asia. Even within South Asia, modules successfully practiced in one country was not that fruitful in another country in the region (Jayaratne and Gomes, 2012).

Another point of significance is the attitudinal trends of certain nations. For an example, as it was reported by Jayaratne and Gomes (2012), 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 advices due to ignorance or stubbornness, lightning accidents in the country is in the increasing trend for the last decade. Jayaratne and Gomes (2102) attribute this to the decade long attitudinal practices of the island nation regarding hazard safety.

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

2.10 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 and Gomes, 2012). 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 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 communities in high lightning risk regions. Although, such mechanisms are employed in enclosed work environment (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 (Scattolini, 2009).

A group of people, even very large in number that engaged with similar type of employment or routine 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. A hierarchal hazard control approach is needed for lightning safety of such community under this backdrop.

The first attempt of formulating hierarchy of hazard control was done by Mary and Gomes (2015), where they have applied the concept to the fisheries community along the shores of Lake Victoria in Uganda. In this study, we expanded 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 Figure-2. Such bound communities should have a common parameter that integrate 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 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 even 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.

Awareness: The experience in Uganda (Mary and 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 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, 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

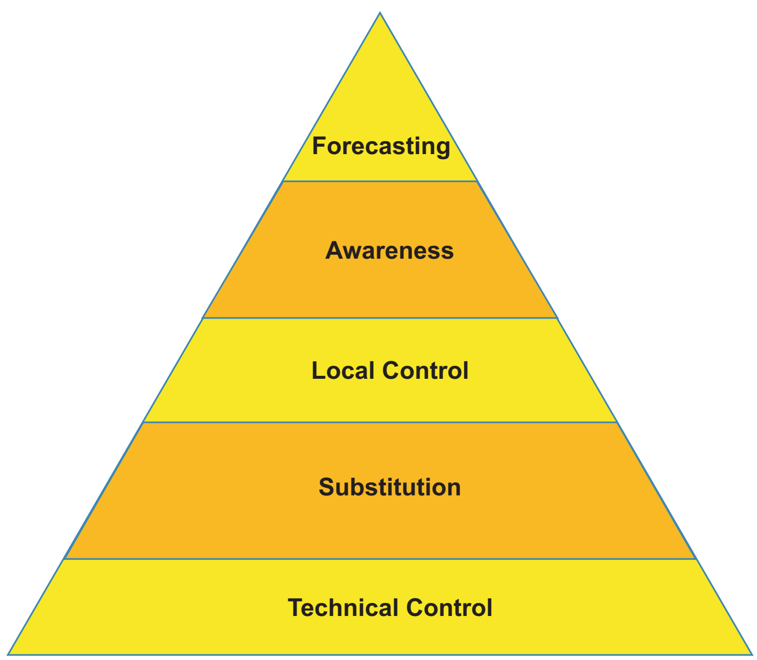

Figure-2: Hierarchy of hazard control for a bound community

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 nighttime. 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 land-lords, 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 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 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 of 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 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., 2012; Gomes and Kadir, 2015) 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., 2012), insisting on wearing rubber sole boots to minimize step potentials, etc. Placement of metal structures specially made for lightning protection in the farming fields, work sites etc. at regular intervals is strongly recommended as such structures could be developed at quite low cost. Properly designed such structures can be placed at several locations even at off shore 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.

2.11 Future Trends

The future trends in lightning density and lightning accident rate may not have a clear positive correlation. Thunderstorms are generated by the rising parcels of moist air. The convective processes which lift water vapour upwards are fueled by the solar radiation. Hence, with the rise of global temperature and sea surface temperature, one can easily predict increment of number of thunderstorms per year in the world. As it is predicted by Romps, et al. (2014), the number of lightning strikes will increase by about 12% for every degree of rise in global average air temperature. The global average surface temperature was elevated by 0.6 °C to 0.9 °C between 1906 and 2005, and the rate of temperature increase has nearly doubled in the last 50 years (Hansen, et al., 2010). With these results one can anticipate approximately 10-12% increment in global thunderstorm activities in the next 100 years.

On the other hand, predicting the trends of lightning casualties is much more complicated. According to the theoretical studies done by Gomes and Kadir (2011a), lightning casualties have positive correlation with lightning ground flash density and population density, whereas it has a negative correlation with urbanization and rate of literacy. In most regions of the world all these factors increase with time in different proportions. In USA the rate of lightning related deaths has decreased almost exponentially during the last century (Holle, et al., 2005) and many other developed countries show somewhat similar trends. On the other hand India shows some increment of lightning fatalities over the years (Singh and Singh, 2015). Unfortunately, the lack of long term data prevents us making any conclusion on the fatality trends in other developing countries.

However, the fast development and rapid spread of internet through which the knowledge flows into the doorstep of developing nations and the improvement of lightning safety techniques and their technology transfer to the root levels may result decrease in lightning fatalities in the future despite increment in thunderstorm activities.

3. CONCLUSIONS

It is shown that lightning safety awareness promotion in a given region should be done in an organized institutional level to harness maximum outcomes. A safety module developed for the region should be unique to that region. Various socio-economic factors such as literacy rate, urban-rural ratio, cultural and religious practices, poverty level, professional practices etc. and environmental factors such as isokeraunic level, level of exposure of the region, housing and workplace sheltering, topology of the region etc. should be taken into account in developing the safety module. A hierarchy of hazard control has been proposed for bound-communities to implement distributed responsibility for lightning safety.

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