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Comparative Study on Lightning Fatality Rate in Malaysia between 2008 and 2017

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***Abstract*—Statistics of lightning fatalities and injuries are difficult to obtain as mandatory reporting of such events is seldom required. As a result, many cases will not be in official records. However, for injury prevention efforts and calling a government's attention to these as a serious problem, information on numbers and more vulnerable locations are important. In this study, Gomes-Kadir equation was used to estimate the annual lightning deaths in Malaysia using lightning density and sociological factors. The recorded data shows a lightning fatality rate of 12.5 deaths yr^{-1} with 4 deaths per ten-million population yr^{-1}. The empirical formula estimates 20.9 deaths yr^{-1} and 6.7 dptm yr^{-1}. Under-reporting of death events and the lack of consideration of topological factors in Gomes-Kadir equation have been highlighted as the reasons behind this discrepancy.**

***Keywords*—lightning density, flash, fatalities, lightning safety, lightning hazard, lightning injury, natural disaster**

I. Introduction

The lightning flash density was initially estimated using data from surface weather stations, which later progressed to human observers, individual flash counters and ground-based lightning location networks. Older generation equipment, limited to spatial coverage, produces low spatial resolution and low detection efficiency. In the 1990's, the National Aeronautics and Space Administration (NASA) launched the Lightning Imaging Sensor (LIS) instrument. LIS, on board the Tropical Rainfall Measuring Mission (TRMM), is able to capture thunderstorms and lightning activities during the day and night from space, producing more accurate measurements of lightning and annual estimated global flash rates. Data acquired from LIS show that tropical coastal regions, areas near large bodies of water, mountainous terrain, areas with frequent large scale convergence zones and cyclones have the highest flash rates [1].

Places located near the equator, within close proximity of large bodies of water, and coastal regions show very high flash rate density, as do those located in mountainous regions. The earth's top most lightning hotspot occurs around Catatumbo, Lake Maracaibo, a region located between Colombia and Venezuela, due to the convergence of land breeze over the hot lake and where lightning occurs up to 9 hours a day for as many as 297 days a year [1–3]. Africa has lightning hotspots concentrated mostly in the Democratic Republic of Congo as well as areas surrounding Lake Victoria and other lakes along the East African Rift Valley that have geographic characteristics similar to Lake Maracaibo. Moisture from the lakes and deep nocturnal convection driven by local land breezes enhances moisture convergence, feeding thunderclouds producing 232 fl km^{-2} yr^{-1} of lightning [1, 4, 5]. In Asia, high flash rate densities can be found in the mountainous terrain along the foothills of the Himalayan range (Pakistan and India) while other hotspots caused by hot sea breezes are found along regions bordering the narrow Straits of Malacca. High flash rate density, greater than 90 fl km^{-2} yr^{-1} is found inland along the coasts of Malaysia. Thunderstorms in Malaysia are dominated by the land-sea interaction and most thunderstorms occur during the afternoon to late evening. In general, convergence of shore breezes from the sea increase flash rate density [1, 6].

It is a challenge to map attributes, characteristics and quantify the effects of lightning. In addition, studies on the impacts of a lightning strike to humankind and social well-being, economic damage, or behaviour are still sparse due to lack of documentation and difficulties in obtaining data. In recent years, researchers have shown high interest in lightning risk, casualties of lightning and the sociological impact on human beings [6–12]. Developing countries, tend to have fewer lightning safe homes, schools, buildings, and transportation and more people working in labour-intensive agriculture and other exposed outdoor occupations than more developed countries. Such features are more prominent in rural areas of these countries, than that in

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urban areas. Mechanisms of injury from lightning include direct strike, side flash, step potential, touch potential, upward leaders, and barotrauma [13]. On average, about 10% to 20% of lightning casualties die and up to 70% of survivors suffer permanent disability from impaired hearing and eyesight, neuronal injury, and neurocognitive problems [14].

Lightning not only injures humans and livestock, but can strike airplanes/helicopters, light rail transit, electric grids, transmission lines, communication towers, and residential properties including high rise and other structures, disrupting utility services as well as destroying equipment worth billions of dollars. In most parts of the world, the majority of reported cases of injury occur outdoors, disrupting domestic routines, work, fishing, and outdoor recreational activities. From an economic perspective, especially in developing countries like Malaysia, India, Thailand and Indonesia, livelihood, often centred on agricultural activities of farming, livestock breeding and aquaculture, can be threatened by lightning [11, 15, 16] .

Estimation of global lightning fatalities vary from one researcher to another [9, 17–19]. In a recent study, Holle [20] compiled a list of published lightning fatalities (4076 fatalities) and calculated fatality rates per year from 26 countries across 7 continents. Holle's findings suggest lightning fatalities are higher in developing countries with high flash rate density and more exposed populations. Roeder et al. [12] also found a positive relation between flash rate density, population and lightning fatalities in the United States. Data are missing from many countries where injury numbers are expected to be high. The objective of this paper is to refine estimation of lighting fatalities, compare the results with the number of reported cases and explore the connection between flash rate density and lighting fatalities in Malaysia.

Most individuals living in a well-developed urban area work in buildings and have accessibility to immediate medical help. Urban dwellers are generally better educated, making it easier for them to understand information pertaining to hazards. Individuals in rural communities, on the other hand, often have less education or may be illiterate [21] making it challenging to alter their perceptions on lightning hazards. Furthermore, certain cultures have a long history and strong attachment to soothsayers and mythical beliefs about lightning [18, 22, 23], leading them to judge lightning victims and their family as cursed. In addition, rural populations often lack accessibility to high quality medical facilities, easy access to digital media to obtain accurate and timely forecasting and thunderstorm warnings, and have few lightning safe homes and buildings as well as long and exposed travel paths from one area to another.

II. METHODOLOGY

National statistical information on lightning fatality is difficult to gather for various reasons. Gomes and Kadir [18] developed a theoretical approach to estimate the annual lightning fatalities using an empirical equation. The Gomes-Kadir equation has been developed by considering various factors that could affect the number of lightning victims in a given area; A demographic factor (DF) which depends on population density (PD) and urban fraction of population (UF), The lightning ground flash density (N_g) and the area of coverage (A). The evaluation of constants of the equation (β and α) has been done by means of lightning occurrence and fatality data from United States (44 states). The equation has been validated with the lightning death rate statistics in Sri Lanka [18], Brazil [24] and Argentina [25]. In this study, we check the applicability of the Gomes-Kadir equation for Malaysia, with the intention of validating it and exploring the possibility of using that in finding the death rate of other countries in the region.

Population density and rate of literacy are two sociological factors that strongly influence the rate of lightning fatalities. When population density is high, more humans are exposed to lightning threats in a given area due to the number of people within the maximum effective distance from lightning strike point. Countries with low literacy rate, especially in rural areas, have shown violation of basic lightning safety guidelines attributable to lack of awareness like working in an open area or gathering in temporary ungrounded shelters during lightning storms [26, 27]. Additionally, some people believe that nothing they do will protect against lightning since they believe it to be a result of witchcraft, seen as an omen, or other myths. Considering all factors, DF is defined as

$$DF = PD / UF \quad (1)$$

where PD is defined by the total population of the area divided by the area of the of the region in km^2. Rate of literacy has a positive correlation to UF [18]. UF is the ratio between population living in rural areas and the total population of the given region. It is also related to the rural fraction (RF) of the area by

$$UF = 1 - RF \quad (2)$$

In some countries, the value of UF can be obtained from the Department of Statistics of the country or the ministry in charge of collecting census of the population.

Data on lightning victims (fatal and non-fatal) were gathered from personal anecdotes, blogs, newspapers, electronic news, news broadcasts and local radio stories beginning in 2008 until 2017. Each reported case was cross checked for similarities and for detailed information including the year, month, time, place, type of casualty, gender, age, type and category of activity and scene setting to prevent duplication of cases. To investigate the relationship between the number of lightning strikes and lighting casualties, lighting flash rate density was taken from Malaysia Meteorological [28]. UF value was taken from Department of Statistics Malaysia where it was derived from the population distribution of each region through recent national census [29]. Location of the lightning strike point (where lightning fatality occurred) was used to identify the settlement classification of the area and verified through Malaysia's Ministry of Housing and Local Government [30].

The empirical formula developed by Gomes and Kadir [18] include lightning density of the region (fl km^{-2} yr^{-1}) and sociological demographic factors (DF) as parameters [18] to estimate lightning fatality rate of a given region with area A.

$$\sigma = \beta\,(AN_g)^{\alpha}\,DF \qquad (3)$$

- σ no of lightning related deaths per region per year
- A area of the region in km^2
- N_g lighting ground flash density in km^{-2} $year^{-1}$
- DF demographic factor in km^{-2}
- β 1.67×10^{-5} (constant)
- α 0.6 (constant)

Table 1 contains data used to estimate lightning fatality rate in Malaysia, based on Gomes-Kadir equation. The annual ground flash density, N_g has been computed by applying the isokeraunic data of Malaysia (extracted from the isokeraunic map of Malaysia, issued by the Department of Meteorology Malaysia) into the equation $N_g = 0.1\ T_d$ [18] where T_d is the no of thunder days per year. Population and urban fraction has been obtained from the documents available at United Nations Population Division and are pertinent to the statistics of 2016.

III. RESULTS AND DISCUSSION

Descriptive analysis was performed using SPSS statistical software to describe the characteristics of lightning events in Malaysia. A total of 125 lightning fatalities were reported between 2008 and 2017. As a side note, when compared to the number of non-fatal lightning injuries (157 cases) as a whole, the ratio between lightning fatality and lightning injury in Malaysia is almost 1:1, most likely due to under-reporting of injuries, a common problem in lightning injury data collection [17, 24, 31, 32]. As expected, more than half of the reported cases (67%) occurred between 12:00 and 18:00 and 22% occurred between 18:01 and 00:00 (Fig. 1). Aligned with other studies, most lighting victims were involved in outdoor activities (Fig. 2) with an unusually high proportion of males (95%).

TABLE I. DATA USED FOR CALCULATING THE ANNUAL DEATH RATE IN MALAYSIA

Parameter	Value
Average T_d	139 thunder-days yr^{-1}
N_g	13.9 fl km^{-2} yr^{-1}
Total population	31.2 million
Total land area	330,803 km^2
PD	94.3 km^{-2}
UF	0.75
DF	125.7

This disparity could potentially be accounted for by adolescent girls or women being at home caring for the family or from decreased agricultural employment pushing women to find work in cities or start their own business to support their families [33–35]. Victims tended to be young adults, aged 21 to 30 (Fig. 3) years old, consistent with studies done outside Malaysia [9, 36].

Past studies also indicate more lightning fatalities occur in rural areas compared to urban areas, whereas in Malaysia the percentage is almost the same as shown in Table II. Although Malaysia is 75.5% urbanized [29], the infrastructure remains lacking in lightning safety [16] and socio economic activities are still mostly outdoors [8].

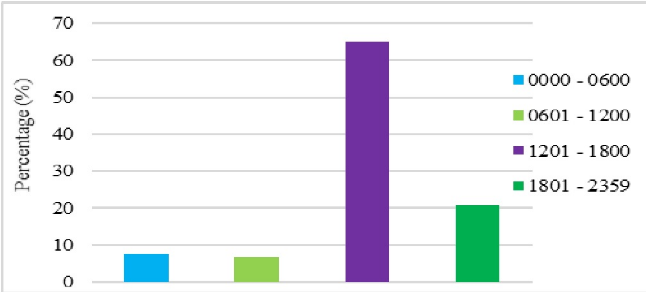

Fig. 1. Time of lightning occurrence.

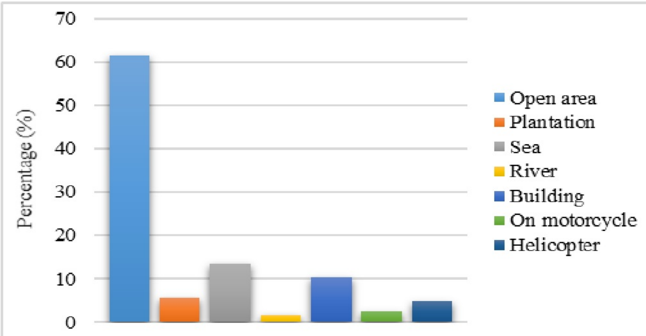

Fig. 2. Scene setting of lightning occurrences.

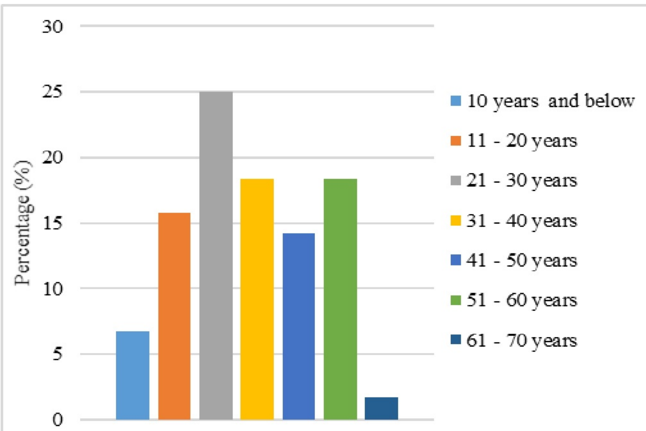

Fig. 3. Age groups of victims.

TABLE II . REPORTED LIGHTNING FATALITIES BASED ON AREA CLASSIFICATION

Areal classification	Percentage
Rural	51
Urban	49

Figure 4 depicts the state-wise distribution of lightning related deaths for the 10-year period of data collection. Although Johor state is 71.9% urbanized, the population living in rural areas rely on agricultural and fishing activities to sustain their living similar to Sarawak [37]. Johor's higher lightning fatality was due to an isolated case where a group of people were struck by lightning while taking shelter in a shed in a palm oil plantation. In contrary, Selangor (91.4% urbanized) [37], is well developed and equipped with lightning protection, records less number of cases. Most of the city dwellers work indoors during the afternoon when lightning most often occurs. Cases reported in Selangor were mostly to foreign workers who were struck by lightning while they were working outdoors in the construction and service industries. Despite having higher isokeraunic days than Kelantan (T_D = 116) and Kedah (T_D = 138), Melaka (T_D = 147) has lower reported cases of lightning fatalities which may be due to Melaka's more developed infrastructure and the higher percentage of people working indoors. Similar to Melaka and Selangor, Kuala Lumpur is fully urbanized with sturdily built structures with many having some sort of lightning protection system. The distribution of isokeraunic level and the number of lightning fatalities clearly shows that the lightning ground flash density is only one factor determining the lightning risk to human beings in a given region.

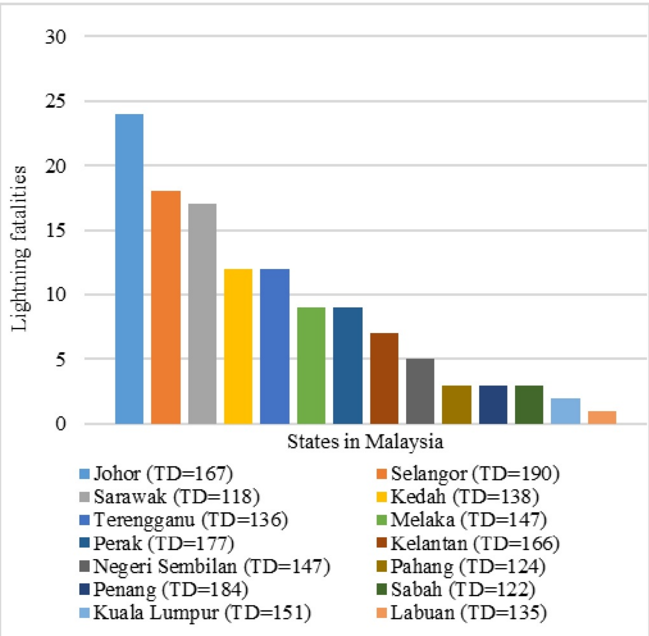

Fig. 4. Lightning fatalities in Malaysia. The isokeraunic level (T_D) for each state is given in the legend within parenthesis

For the 10-year period, the recorded data provides an annual death rate of 12.5 deaths per year. Normalized to 10 million population, this rate becomes 4 deaths per ten million per year (dptm yr^{-1}). Table III compares this value with that of several other countries. Most of the information in Table III has been extracted from the data compilation presented by Doljinsuren and Gomes [9]. The year of the publication of data, given in Table III, provides an idea of the timeline of the information. Note that Malaysia is reaching a dptm yr^{-1} value that has been recorded by the developed countries a decade or two ago, despite the much higher lightning ground flash density in Malaysia compared with European and North American countries. This may be due to the rapid development of Malaysia during the last few decades that has resulted in more substantial and lightning safe buildings and higher literacy rate among the population. It is of interest to know the death rate of neighbouring Singapore in the recent past.

A. *Empirical analysis of Malaysian data*

The equation was applied to obtain the number of deaths per year in Malaysia using data in Table I. The value obtained was;

$$\sigma = 20.9 \text{ deaths yr}^{-1}$$

Thus, the estimated death rate normalized to 10 million populations is 6.7 dptm yr^{-1}. This reflects that the recorded values are 40% less than the estimated figures by Gomes-Kadir equation. Considered the large fluctuation of annual number of deaths this may be considered as a good agreement between the model predicted and recorded number of deaths. Further, it should be noted that the recorded number of deaths could always be an underestimation due to the missing data. Some fatalities, especially those in rural areas and the victims that succumb to their injuries a few days after the incident, may not be reported in the media.

Apart from the above argument on the prediction of higher number of death rate, we would also discuss the applicability of Gomes-Kadir equation based on previous observations as well. Doljinsuren and Gomes [9] shows that the lightning related fatality rate predicted by Gomes-Kadir equation highly deviates from actual value in Mongolia (predicting a much lower estimation of death rate), the country with the smallest population density in the UN list of sovereign states. The country is characterised by the steppe climate and vast barren lands or grasslands with isolated hills. The authors of [9] suggest that the lack of consideration of topographical features in Gomes-Kadir equation may be the major reason for the discrepancy in predicted and actual results. This study also hints that the equation may be modified taking into account the landscape features and both natural or built environments. In areas with excessively large low-grown landscapes or bare lands with low population density, the equation tends to provide lower estimation of death rates than that is actually reported. On the other hand, in areas where sturdy buildings and structures are prevalent and the population density is significantly high the equation provides a much higher estimation of death rates than the actual value. Therefore, we strongly recommend the introduction of a topographic factor (both natural and built environments) to Gomes-Kadir equation in an attempt to improve precision for a wide spectrum of settings.

To further test this hypothesis, we used the currently available Gomes-Kadir equation to estimate the lightning death rate in Singapore, the country that borders the southern tip of Malaysia.In the absence of lightning density data in Singapore, we adopted the isokeraunic level 167 thunder-days yr^{-1}, pertinent to Johor, the Malaysian state bordering Singapore.

TABLE III. NUMBER OF DEATHS PER TEN MILLION PER YEAR IN SEVERAL COUNTRIES.

Year of publication	Country	Death rate (dptm yr^{-1})
2018	Malaysia (this study)	4
2015	Mongolia	15.4
2018	USA	1
1993	Australia	1
2006	Canada	3
2012	Greece	3
1998	France	3
1988	Sweden	2
2012	Austria	1.4
2001	UK	1
1976	Zimbabwe	108
2006	Sri Lanka	25
1981	Singapore	35
2012	Uganda	30

With the values published in relevant UNO and World Bank documents; PD = 8188 km^{-2}, area = 720 km^2, UF = 1; the calculated lightning death rate for Singapore is 38.6 deaths yr^{-1} or 68.8 dptm yr^{-1}. The value may be meaningful with the same high population density living in the structures available in the pre-80s but highly unlikely to be the true figure at present as Singapore is now a highly developed country with nearly universal availability of lightning safe structures within meters or a short walk at any time of the day. With this observation, we re-confirm the need for the adjustment of Gomes-Kadir equation taking into account the topological features due to both natural and built environments.

IV. CONCLUSION

The number of lightning fatalities is related to the flash rate density, population and level of development for an area. While Gomes-Kadir equation was able to estimate the number of fatalities reasonably well for Malaysia, we emphasize the need to further refine the equation considering topological features of the region of concern to obtain more accurate results.

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