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On the comparison of lightning fatality rates between states in Malaysia from 2008-2019

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***Abstract*— This study briefly canvasses lightning fatalities in Malaysia. Acquiring lightning fatality statics are a challenge as mandatory reporting of such events is seldom required, and as such, many lightning incidences were unreported. For that reason, numerous cases were undocumented in the official records. However, for injury prevention efforts and calling a government's attention to these as a severe problem, information on numbers, exposed locations and their backgrounds are essential to determine vulnerable areas. A theoretical approach using Gomes-Kadir equation was also tested to estimate annual lightning deaths in each state of Malaysia using lightning density and sociological factors and the results compared against known fatality data.**

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

I. Introduction

On Earth, the lightning strike on average 46 times every second, 2.9 fl km^{-2} yr^{-1} about 1.46 billion flashes per year [1]. Lightning commonly occurs within the cumulonimbus cloud that is formed densely by water vapour carried upwards by strong upward air currents. Lightning occurs intracloud, cloud to cloud and cloud to ground. Between the three types of a lightning strike, cloud to ground type was studied most as the impact is destructive to humankind compared to intracloud and cloud to cloud lightning, which happens 5 to 10 times more. Information on a cloud to ground lightning strike like flash rate density helps identify areas most vulnerable to the impacts of a lightning strike. To reduce marginal error and better accuracy to monitor lightning and thunderstorm activities National Aeronautics and Space Administration (NASA) launched the Lightning Imaging Sensor (LIS) instrument on board the Tropical Rainfall Measuring Mission (TRMM) in the 1990s. LIS was able to capture thunderstorm and lightning activities throughout night and day with a storm-scale resolution of individual thunderstorm within the field view of 600 km x 600 km with no discernible degradation in orbit for 90 seconds. The result provided insights into the nature of convective clouds, tropical oceanic temperament, global thunderstorm pattern, lightning climatology and annual estimated global flash rate density. On account of this, data collected showed high altitude, places located near large bodies of water near the tropics show high (average 30-50 fl km^{-2} yr^{-1}) to very high (higher than 50 fl km−2 yr−1) flash rate density [2]. In Asia, lightning hotspots identified were along the foothills of the Himalayan range from Pakistan to India and countries bordering the straits of Malacca like Malaysia and Indonesia. At its peak, the lightning flash rate density with a value higher than 90 fl km^{-2} yr^{-1} was found in three locations in Malaysia landing in the top 10 lightning hotspots in Asia.

Malaysia divided into two major parts; Peninsular Malaysia and East Malaysia, which is a part of the Borneo island and numerous small islands; hence, all states in Malaysia have coastal regions and near the sea. Peninsular consists of 11 states and 2 federal territories namely Perlis, Kedah, Penang, Perak, Selangor, Federal Territory of Kuala Lumpur, Negeri Sembilan, Melaka and Johor in the west coast followed by Pahang, Terengganu and Kelantan in the east coast while East Malaysia consists of Sabah and

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Sarawak located on the island of Borneo. The Titiwangsa Mountains divides West coast and east coast of Peninsular Malaysia. In East Malaysia, the Crocker Range is the highest in Malaysia splitting Sabah state in half. Malaysia is relatively flat with the highest mountain just above 4,000 meters. Malaysia exposed to the southwest monsoon and northwest monsoon have an estimated 180 to 200 thunder days per year [3] An intense thunderstorm has resulted in severe flooding and loss of life and homes mainly in the east coast of the peninsula and eastern Malaysia [4]. West of the peninsula, though affected by the monsoon, the severity of the impact is not as intense as the east [5]. Indonesia harbours the west while the east is fully open to the climatic perils coming from the South China Sea. Land-sea interaction dominates most of the thunderstorms activities in Malaysia and mostly occur during the afternoon to late evening [2, 3, 6].

Developing a lightning hazard map and quantifying the effects of lightning is a challenge as data is either scarce or sealed as confidential by respective organisations. Also, quantitative studies on the impact of lightning on human beings and economic damage are sparse as well as the shortage of comprehensive statistics on lightning fatalities. In recent years, researchers have shown high interest in lightning risk, casualties of lightning and the sociological impact on human beings [3, 7–11]. Developing countries like Uganda, Mongolia, India and Indonesia have fewer lightning safe homes, schools, buildings and more people working in labour-intensive agriculture and other exposed outdoor occupations than more developed countries, such attributes are more prominent in rural areas compared to urban areas. [8, 12–15]. Mechanisms of injury from lightning include direct strike, side flash, step potential, touch potential, upward leaders, and barotrauma [16]. On average, about 70% of people struck by lightning survive but suffer from permanent disability from impaired hearing and eyesight, neuronal injury, neurocognitive problems and post-traumatic stress disorder [17]. The most lightning injury takes place outdoors. From an economic perspective, especially in developing countries livelihood, often centred on agricultural activities where farming, livestock breeding and aquaculture, can be threatened by lightning [10, 18, 19]. Aside from injuring humans and livestock, lightning can strike aeroplanes/helicopters, light rail transit, electric grids, residential properties, solar power farm, disrupting utility services as well as destroying equipment worth billions of dollars.

Estimation of global lightning fatalities varies from one researcher to another [8, 20–22]. A recent study compiled a list of fatalities (from published reports) from 26 countries suggests lightning fatalities are higher in developing countries with high flash rate density. Roeder et al. [11] also found a positive relation between flash rate density, population and lightning fatalities in the United States. Most individuals living in a well-developed urban area work indoors and have easy access to immediate medical help and fully equipped hospital. Urban dwellers are generally literate, making it easier to read or understand lightning hazards and safety. Individuals living in rural areas tend to be illiterate and have a strong attachment to cultural and mythical beliefs making it a challenge to alter their perception and belief on lightning hazards beliefs [21, 23, 24]. Certain cultures go as far as believing those struck by lightning and their family to be cursed. Moreover, rural populations often lack access to well-equipped medical facilities, internet/digital media to acquire real-time weather forecasting, thunderstorm warnings and little to a non-available lightning safe rest stop along their travel paths to take shelter in the event of a thunderstorm to take shelter making them very vulnerable.

There are still many missing data globally, where the number of injuries is expected to be high. The objective of this paper is to refine the estimation of lightning fatalities, compare the results with the number of reported cases and explore the connection between flash rate density and lighting fatalities within the states in Malaysia.

II. METHODOLOGY

Data of lightning victims (fatal and non-fatal) gathered were from 2008 until 2019 (March) from personal anecdotes, blogs, newspapers, electronic news, news broadcasts and local radio stories. Cases gathered was cross-check using attributes like the year, month, time, place, type of casualty, gender, age, type of activity and scene setting of the incident happened to prevent duplication.

National statistical information on lightning fatality is challenging to gather for various reasons. There is no specific database for lightning fatality or injury. A record is kept only at the hospital or health clinic the patient registered. Gomes-Kadir developed a theoretical approach to estimate annual lightning fatalities using an empirical question. The Gomes and Kadir equation considered 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 (Ng) and the area of coverage (A). The evaluation of the constants of the equation (β and α) has been done utilising lightning occurrence and fatality data from the United States (44 states). Subsequently, the equation was tested and validated with a lightning fatality rate in Sri Lanka [22], Brazil [25] and Argentina [26]. The Gomes-Kadir equation will be used to explore the lightning fatality rate in the states of Malaysia. In this study, we will check the application of the Gomes-Kadir equation for states in Malaysia.

To investigate the relationship between the number of lightning strikes and lighting casualties, lighting flash rate density of each state in Malaysia was taken from NASA's recent Lightning Imaging Sensor observation where lightning data were recorded continuously with high precision [2]. The demographic factor (DF) takes into consideration population density (PD) and an urban factor (UF). DF is construed as,

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

PD is defined by the total population divided by the size of the region in km^2. PD has an impact on human activities and is interrelated with sociological factors that influence lightning related events. A real development may influence a person's life choices by having an impact in the form of socioeconomic, well-being, safety, infrastructure and basic facilities. UF is the ratio between people living in rural areas and the total population of a specific region. UF is also related to the rural fraction (RF) of an area by

$$UF = 1 - RF \tag{2}$$

UF value can also be obtained from government agencies in charge of gathering census-like, Institute of Geography and Statistics (Brazil), National Institute of Statistics and Census (Argentina), Census Bureau (United States) depending on respective countries. For Malaysia UF value was taken from Department of statistics, Malaysia derived from the recent census conducted periodically [27]. Location of the lightning strike where the fatality occurred was used to identify the settlement classification and verified through Malaysia's Ministry of Housing and Local Government [28].

Gomes-Kadir [21] empirical formula incorporated parameters that include sociological factor (DF) and lightning flash rate density (fl km^{-2} yr^{-1}) to estimate lightning fatality rate in an area (*A*).

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

- 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 for the calculations used to estimate lightning fatality rates in Malaysia, based on Gomes and Kadir's equation. Flash rate density of each area from the same state was totalled, and the average value was used to represent the given state. The annual ground flash density, Ng value taken from NASA [2] of each area from the same state was totalled, and the average value was used to represent the given state.

III. RESULTS AND DISCUSSION

Descriptive analysis was performed to describe aspects of the lightning event in Malaysia using SPSS statistical software. A total of 134 fatalities and 165 injury cases were reported. The ratio between fatalities and were close to 1:1. It is difficult to follow-up on the recovery or status of the injured patients caused by lightning as a database on lightning patients is non-existent, and patients' data is considered confidential. Moreover, common problems related to lightning injuries like fainting or minor physical burns and numbness is most likely to go unreported as injuries are not mandatory to be disclosed to the authorities [20, 25, 29, 30].

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). Most of the lightning fatalities happen between noon to very late evening. Almost half (44%) occurred between 3.00pm to 6.00pm followed by late evening after 6.00pm to 9.00pm (25%) and early afternoon between 12.00pm to 3.00pm (22%) (Fig. 1). As expected, the data collected almost all (91%) of lightning fatalities occur during the day when humans are particularly active and mostly outdoors (Fig. 2).

The inability to get to a safe shelter was one of the primary causes of fatalities. About a third (37%) from the list of victims took shelter in a squatter like living quarters in a plantation/construction area, barn, shed, bus stop, under a tree and open religious are like a temple.

From Fig. 3, the year 2011 has the highest recorded lightning fatality, followed by 2015 and 2012. The sizable difference is likely due to the El Nino Southern Oscillation (ENSO). 2010/2011 recorded one of the strongest El Nina, followed by an extreme El Nino in 2015/2016 [31]. During El Nino and La Nina transition climate in Southeast Asia becomes drier and hotter. The convective and advective activity during El Nino and La Nina is responsible for the abrupt change in storm intensity and enhances lightning activity. Anomalous lightning activity was observed to have increased by 56% compared to previous years [32].

Strong intensities of El Nino and La Nina phenomenon triggers extreme atmospheric instability much in the subtropics and tropics area. Malaysia is also affected by Southwest monsoon and the Northwest monsoon. The inter-monsoon period is between April and May as well as October to November. Heavy rain and severe thunderstorm occur in the afternoon during the inter-monsoon period. The intensity of lightning activity during the inter-monsoon period is reflected in Fig. 4, whereby lightning fatalities occur highest in April, May and August. Past studies have indicated that more lightning fatalities occur in rural areas [8, 14, 20, 33], but in Malaysia, the ratio is very close to 1:1. Malaysia's urbanisation rate is one of the fastest in Southeast Asia.

To date, Malaysia's is thus far more than 70 per cent urbanised [34]. Economic development and industrialisation stimulated the rapid expansion of towns. There has been much structural economic change from primary activity to secondary, tertiary and quaternary.

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

States	N_g	Total population (million)	*A*	PD (km-2)	UF	DF
Johor	20	3.59	19,210	187	0.72	260
Kedah	10	2.1	9,428	223	0.55	405
Kelantan	10	1.75	15,100	116	0.42	276
Labuan	6	0.1	9,163	11	0.82	13
Melaka	10	0.88	1,663	531	0.87	610
N Sembilan	13	1.11	6,685	167	0.56	298
Pahang	13	1.65	36,138	46	0.5	92
Penang	10	1.68	1,049	1,602	0.9	1,780
Perak	13	2.5	21,036	119	0.69	172
Sabah	8	3.6	73,631	49	0.54	91
Sarawak	13	2.67	124,449	21	0.53	40
Terengganu	20	1.18	13,035	90	0.59	153
Selangor	20	6.03	8,104	801	0.91	880
Wilayah	20	1.8	2,243	800	1.00	800
Perlis	13	0.25	821	310	0.49	633

Many areas that rely on primary economic activity have expanded into the secondary economic sector, especially through the development of many industrial zones. Economic growth and work opportunities caused an influx of population increasing population density. As the town grows, expansion eventually reaches the rural area. Although agricultural activity has declined, it is still a contributor to the national gross domestic product and remains the primary source of income for those living in rural areas [27].

TABLE II. REPORTED LIGHTNING FATALITIES BASED ON AREAL CLASSIFICATION

Areal classification	Percentage
Rural	51
Urban	49

Excessive urban growth may lead to escalating economic cost, whereby the rate of urban growth is not at par with the development of basic needs.

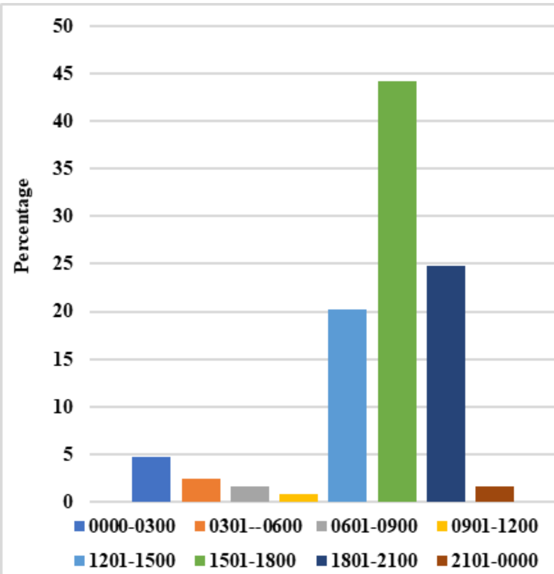

Fig. 1. Time of lightning occurrence.

Unplanned rapid urbanisation causes urban diseconomies as well as side impacts that include urban poor, lack of adequate shelter, amenities and infrastructure [35, 36]. The urban poor often holds more than one job to make ends meet often working long hours. Due to the high cost of living or working environment, some urban poor or construction workers live in squatter homes or shelter such are often crammed living conditions built with inflammable or cheap material that is accident prone and vulnerable to hazards like lightning [34].

Table III depicts the distribution of lightning fatality rate per year per million people for the ten years of data collection. Labuan, Perlis and Melaka are the only states in Malaysia with a population below 1 million. With that being said, Labuan's lightning fatality rate is 1.1 fatality rate per million; however, the low number of populations stretches the number of years per fatality. Furthermore, states like Terengganu, Melaka, Johor, Sarawak, Kedah and Negeri Sembilan has a higher fatality rate compared to the national lightning fatality rate of 0.4 per million people. In contrary, Wilayah Persekutuan (100% urbanised), Selangor (91.4% urbanised) and Penang (90.8% urban) [37] is well developed and sufficiently equipped with up to date healthcare, infrastructure, transportation and essential amenities.

Lightning protection is installed as part of building construction. Also, residential development is systematically designed to include proper installation of mechanical, electrical and plumbing systems. The majority of the population work indoors following regulated office hours of 8 am to 5 pm. Most of the cases reported in Selangor and Wilayah Persekutuan were foreign workers working outdoors in construction and cleaning services during a thunderstorm or while taking shelter in a squatter house.

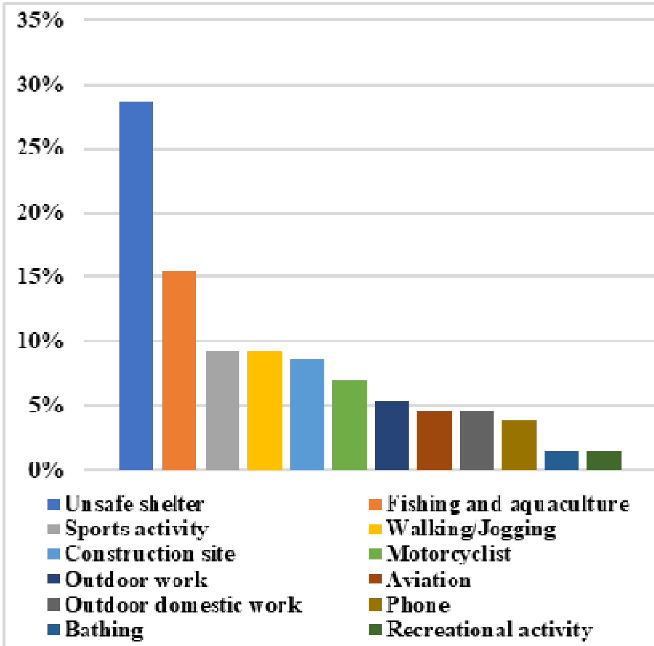

Fig. 2. Scene setting of lightning occurrences.

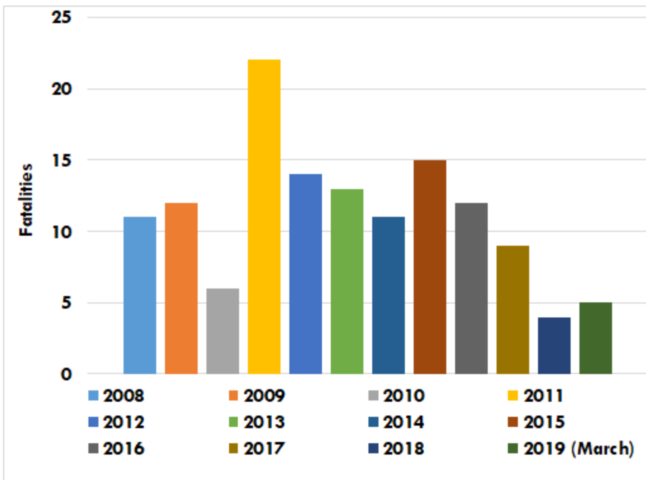

Fig. 3. Lightning fatalities from 2008 to 2019 (March).

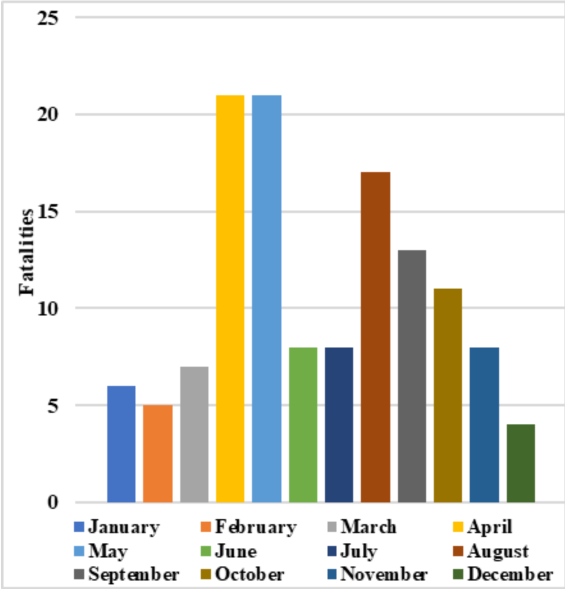

Fig. 4. Lightning fatalities according to month

A few isolated cases were attributed to recreational activities like jogging, gardening, and taking a stroll. Sabah has the second largest land area in Malaysia with almost half of the state consisting of the rural area (46%) [37].

TABLE III. REPORTED LIGHTNING FATALITIES BASED ON AREA CLASSIFICATION

States	Average population for ten years	The fatality rate per year per million
Labuan	93,500	1.1
Terengganu	1,120,000	1.1
Melaka	860,000	1
Johor	3,525,000	0.7
Sarawak	2,615,000	0.7
Kedah	2,045,000	0.5
Negeri Sembilan	1,060,000	0.5
Kelantan	1,670,000	0.4
Perak	2,420,000	0.4
Perlis	240,000	0.4
Selangor	5,920,000	0.3
Pahang	1,570,000	0.2
Penang	1,650,000	0.2
Wilayah	1,730,000	0.2
Sabah	3,505,000	0.1

Sabah economy is based solidly on primary economic activity, mainly agriculture, oil palm and rubber, mining and quarrying. There are many small communities in remote areas difficult to reach with poor road accessibility [38]. Considering all factors, the low fatality rate could be due to unreported cases by the local population.

A. Empirical analysis of Malaysian data

The equation was tested using data from states in Malaysia in Table I to estimate the number of fatalities. The value obtained is as shown in Table III. The estimated and reported fatality rate was normalised per 1 million populations.

The significant fluctuation between reported value and estimated value may reflect a disagreement between the predicted model and reported fatalities. Further, although the number of fatalities is often under-reported, the marginal difference is too high, 60% less than the estimated figures by Gomes-Kadir equation.

The scale of states data could be too small or inept to be calculated using Gomes-Kadir equation. The demographic factor could be one of the possible parameters that deviated the estimated fatality rate from the reported fatality rate. DF factor for each stated was overwhelmingly large when compared to the country's overall DF factor [39].

This study also hints that the equation may be modified, taking into account smaller areas, high demographic factor, landscape features, and both natural or built environments. This study supports the possibility of introducing topographic factor (both natural and built environments) to Gomes-Kadir equation in an attempt to improve precision for a broad spectrum of settings.

TABLE IV. COMPARISON FATALITY RATE PER MILLION PER YEAR IN STATES IN MALAYSIA

State	Fatality rate per million		Difference in values (%)
	Reported	Estimated	
Labuan	1.1	11.1	90
Terengganu	1.1	3.6	69
Melaka	1.0	3.5	71
Johor	0.7	2.8	75
Sarawak	0.6	1.5	60
Kedah	0.5	3.4	85
Negeri Sembilan	0.5	3.8	87
Kelantan	0.4	3.6	89
Perlis	0.4	8.3	95
Perak	0.4	2.1	81
Selangor	0.3	3.2	91
Penang	0.2	6.1	97
Wilayah Persekutuan	0.2	4.6	96
Pahang	0.2	2.5	92
Sabah	0.1	1.1	91

TABLE V. REPORTED AND ESTIMATED LIGHTNING FATALITIES IN OTHER COUNTRIES

Countries	Fatalities per year	
	Estimated	Reported
Brazil	47	132
Colombia	64	76
Malawi	95	1008
India	1002	1755
Turkey	24	28
Austria	3	1
Sri Lanka	95	49
Malaysia	26	12.9
Uganda	143	205
Mongolia	1	5
Bangladesh	5	114
South Africa	29	264

IV. CONCLUSION

The number of lightning fatality is related to flash rate density, social demographic factors, and area of development. The poor and urban poor are most vulnerable to the lightning hazard. While Gomes-Kadir was able to estimate lightning fatalities for Malaysia, Sri Lanka, Colombia, Malawi and Turkey close to reported rate, we suggest refinements taking into consideration smaller areas, high demographic factor and topographic factor.

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