



The major lightning regions and associated casualties over India

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Abstract

Lightning, a climate-related highly localized natural phenomenon, claims lives and damage properties. These losses could only be reduced by the identification of active seasons and regions of lightning. The present study identifies and correlates the lightning-prone regions with the number of casualties reported over India at the state/union territory level. The seasonal and monthly composite satellite data of Lightning Imaging Sensor for the duration of 16 years (1998–2013) have been analyzed in this study for the identification of the major lightning-prone seasons and regions over India. The casualties due to lightning have also been estimated using data from Accidental Deaths and Suicides in India, National Crime Record Bureau report of India. The spatial distribution analysis reveals that lightning occurs mostly in hilly regions over India throughout the year (26 flash/sq. km/yr) and, however, causes lesser casualties because of the sparse population over the hilly terrain. The seasonal analysis reveals the most lightning phenomena occur during the pre-monsoon period (40–45 flash/sq. km/yr) over the northeast region of India. During the winter period, the lightning dominates over the northern parts of India such as Jammu and Kashmir. The state-wise casualties' study reveals that maximum casualties are reported in Madhya Pradesh (313 deaths), Maharashtra (281 deaths) and Orissa (255 deaths) on an average per annum. The favorable climatic conditions, such as availability of moisture content, unstable atmosphere and strong convection, cause severe cases of lightning over the regions of Orissa and Maharashtra.

Keywords Lightning flash count · Lightning hazards · TRMM/LIS · FRD · Casualty

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1 Introduction

Lightning is a naturally occurring electrical discharge in contact with air to cloud and cloud to ground. Lightning reaches the ground more than 100 times per second or 8 million times a day (Okafor 2005). Lightning also depends upon the local meteorological circumstances. For example, if two different kinds of air masses (i.e., cold–moist and dry–hot) coming from different directions are forced to rise, they flow together or converge to form the thundercloud (Lal et al. 2018). This phenomenon is usually associated with cumulonimbus clouds (thunderclouds); however, sometimes it also occurs in stratiform clouds (layered clouds with a large horizontal extent), in snow storms and dust storms and sometimes in the dust and gases emitted by erupting volcanoes. These clouds acquire an excess electrical charge, either positive or negative, that is sufficient to break down the resistance of the air (Mansell et al. 2010). Global or local lightning motion is a highly variable parameter on many timescales (Nath et al. 2009). This unpredictability is generally attributable to changes in flash rate per thunderstorm and also to the number of thunderstorms themselves. Lightning is one of the most powerful and disastrous atmospheric hazards across the world (Mills et al. 2010; Mushtaq et al. 2018). The chance of being struck by lightning depends on population density and geographical features. Global death due to lightning is likely at 0.2–1.7 deaths per one million (Aslar et al. 2001; Wetli 1996). Around 10–30% of patients struck by lightning die, and 74% of survivors present some permanent effects (Whitecomb et al. 2002). This hazard often causes loss of lives, injuries and arrangement damages (Mulder et al. 2012; Dowdy 2016; Bhardwaj et al. 2017).

Most of the regions in India experience lightning in different seasons. This study deals with the identification of the major lightning-prone regions and the seasons over India. The data from the Accidental Deaths and Suicides in India, National Crime Record Bureau (NCRB), showed that more than 2000 people in India lose their lives annually from lightning. This is huge loss of life, so this calamity can be reduced by identifying the proper area, region and the season for the lightning (NCRB 2015). This type of identification will help in generating early warning system in lightning-prone area using various predictive models.

South Asian counties are severely affected by lightning hazards (Singh and Singh 2015). Kandalgaonkar et al. (2003) studied the diurnal variation of lightning activity over the Indian region and reported a prominent peak at 1000 UTC and minimum in the morning hours. Spatially occurrence of lightning is highly variable with changing latitudes in both of the hemisphere; in tropical regions, lightning tends to occur more often when the equatorial trough passes over a region (Holle and Cooper 2016), while the South Asian regions (Indian subcontinent, Bangladesh, Pakistan, etc.) are affected by lightning during the pre-monsoon and monsoon seasons. At higher latitudinal areas, about two-thirds of lightning occurs during the three summer months (Dewan et al. 2017). Spatially most of the lightning strikes (~78%) occur over the tropical regions of the world, including land and water areas (Christian et al. 2003); however, these are highly variable with the marked changes in elevation and land–water boundaries interaction (Albrecht et al. 2016a, b; Holle and Murphy 2017).

In India, Jammu, Kashmir and Brahmaputra valley is one of the most lightning hot spot regions (Albrecht et al. 2016a, b). There are many effects of lightning such as visual effects, accidents caused by the lightning strikes over an area of the building resulting into fire which may also cause huge damage to property and cause loss of life. Some indirect accidents also take place when lightning strikes. When lightning strikes, it causes a power

surge in the different kind of power cables or in transmission links which cause power cuts (Cummins et al. 1998). To reduce this effect, proper equipment and measures to the people of the region are provided which are more prone to lightning. This study will help us to identify the most dominant region and the season for lightning so that early measures and equipment must be provided to the peoples.

Several studies on lightning have been carried out over the Indian region (Kandalgaonkar et al. 2003, 2005; Pawar et al. 2012; Ranalkar and Chaudhari 2009; Lal and Pawar 2009; Penki and Kamra 2013) by examining the flash data collected through various techniques (either ground or satellite based). However, the correlation studies on lightning with associated casualties are very limited over the Indian region (Singh and Singh 2015; Gomes and AbKadir 2011).

Thus, the present study systematically analyzes the composite 16-year (1998–2013) lightning flash data from Lightning Imaging Sensor (LIS) onboard the Tropical Rainfall Measurement Mission (TRMM) to determine seasonal and monthly variability over India. The correlation between the fatalities due to lightning and the lightning flashes per kilometer square per year has also been estimated over India. Fatalities' data are taken from the NCRB report and the flash counts from the TRMM/LIS over different states of India. The outline of the present paper is as follows. Section 2 discusses the study area geography, climatology and demography in detail. Next, Sect. 3 discusses the instrumentation (TRMM/LIS) and datasets used in this study. Section 4 describes the methodology of retrieval of flash counts and casualty datasets calculation and correlation. Further, Sect. 5 includes the finding of the study with discussion. Finally, Sect. 6 presents a brief conclusion.

2 Study area

The study area of India is situated in South Asia. Figure 1 shows the regions and states of India. The latitudinal extent of India is 8°4' (Kanyakumari) to 37°6' N (Kashmir). Indian southern boundary extends to 6°45' N (Indira Point) which lies in the Bay of Bengal. The longitudinal boundary extends from 68°7' E (Rann of Kutch, Gujarat) to 97°25' E (Arunachal Pradesh). It is the seventh largest country in the world. It is the second most population-wise country in the world. India remains one of the most ethnically diverse countries in the world. In south, it is bounded by the Indian Ocean, southwest Arabian Sea and southeast Bay of Bengal.

Indian continent has a diversified climate. It has a subfreezing Himalayan winters to tropical climate near to the equator (south). The eastern states and west of Bengal experience humid, damp and rainy conditions. The western states (Rajasthan, Gujarat) experience a dry and arid climate. Based on precipitation and temperature, India can be divided into six climatic regions: the Himalayas, Assam and West Bengal, the Indo-Gangetic Plain, the Western Ghats and Coast, the Deccan (the interior of the Peninsula south of the Narmada River), and the Eastern Ghats and Coast. As per the Indian Meteorological Department, the four seasons are winter (December–February), pre-monsoon (March–May), monsoon (June–August) and post-monsoon (September–October). The monsoon provides almost 80% of the annual rainfall to most of the parts of the country. Therefore, this season is crucially important to farmers for agricultural production, sowing of crops, etc. The cases of lightning strikes are more likely in the pre-monsoon and monsoon seasons (India: The Impact of Climate Change to 2030; NIC 2009, April 2009).

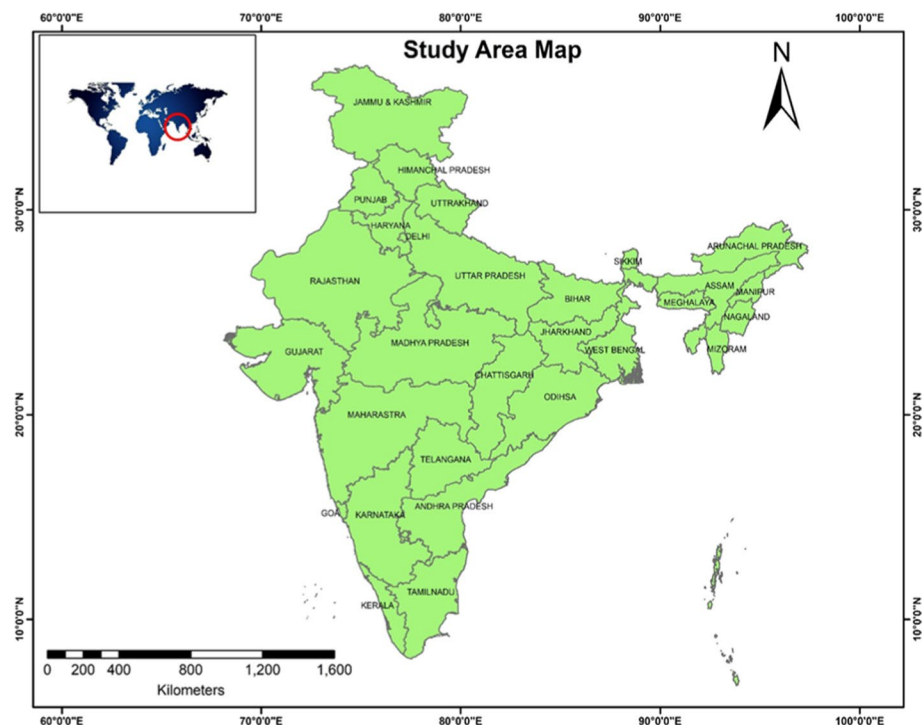


Fig. 1 Study area map

3 Instrumentation and data

The Tropical Rainfall Measuring Mission (TRMM) is a joint space mission between NASA and the Japan Aerospace Exploration Agency (JAXA) to study rainfall for weather and climate research. TRMM is the first Earth observation satellite (EOS) mission to observe tropical rainfall and associated phenomena which closely influence the global climate and environment change. Lightning Imaging Sensor (LIS) (November 28, 1997) onboard TRMM is used to remotely map the lightning flash activity based on a change in flash emission spectrum. The TRMM satellite follows a spherical orbit and flies at an altitude of 350 km, with an inclination of 35° to the equator (Boccippio et al. 2000). The data are available for the past two decades from December 1997 up to date on NASA hydro-repository. LIS uses optical lens with a narrow band filter centered at 777 nm coupled with a high-speed charge-coupled device (CCD) detection array, which locates and detects the lightning parameter with a storm-scale resolution of 3 km at the nadir and 6 km at limb view. The LIS detects and locates lightning with storm-scale resolution of 5–10 km, around over tropical region (35° S– 35° N) on global spherical orbit coverage. LIS sensor has identification efficiency varying between 69 and 88%, with a greater efficiency for the nighttime monitoring and identification. It has also the capability to observe intra-cloud and cloud-to-ground released flash during both day and night conditions. The temporal resolution of LIS field of view (FOV) of the sensor over a specific location of observation for individual storms and associated lightning discharge

flash system is 80 s, which is enough to measure lightning flash rates in storms (Cecil et al. 2014; Jayawardena et al. 2014).

The LIS 0.1-degree Very High Resolution Gridded Climatology (VHRGC) collection datasets have been used for the duration of 16 years (January 1998–December 2013). Out of the five sub-datasets of VHRGC collection, Very High Resolution Monthly Collection (VHRMC) and Very High Resolution Seasonal Collection (VHRSC) lightning climatological datasets have been used for monthly and seasonal flash rate density estimation. These gridded climatologically datasets include monthly and trimester seasonal mean flash density rate with a unit of number of flash per square kilometer over the region per unit time duration. A brief summary of the above-mentioned datasets used is shown in Table 1.

NCRB under the Ministry of Home Affairs, Government of India, publishes casualties' report every year based on the police-recorded data which have been obtained through all states/UT police. This report also ensures that the data are statistically consistent. Further, the report compiles the datasets into three categories, viz. natural, unnatural and other causes of accidental deaths (such as heart attacks and poisoning). The casualty due to lightning has been placed in the accident due to natural force.

4 Methodology

In this work, seasonal and monthly composite lightning data of LIS/TRMM from January 1998 to December 2013 period have been used to calculate cloud-to-ground lightning flash density (flash/sq. km/yr) over India.

The lightning phenomenon itself is a great hazard for the stock and livelihood of the population because it is related to thunderstorms that produce dense precipitation in various climatic regions, and also the heavily discharge of electrostatic current in the form of flash. With the knowledge of the structure, and variability of thunderstorms at the local, regional and global scale over the land and ocean (Christian et al. 2000), these data can be assimilated in the model for risk and hazard zone mapping.

The extraction and plotting of the flash rate density (FRD) seasonal data (NetCDF format) with a resolution of $0.1^\circ \times 0.1^\circ$, over the Indian region, are done using the raster making process and season-wise flash count range classification and state-wise distribution mapping, using the image processing software QGIS/ESRI. The seasonal division has been done with the combination of the month as winter (DJF), pre-monsoon (MAM), monsoon (JJA) and post-monsoon (SON) according to EOS/TRMM data criteria. Further, the retrieved annual mean flash rate density counts were correlated with the casualties due to lightning data, obtained from NCRB report for the same duration as shown in Table 2.

During the period from 1998 to 2013, the NCRB reports around 31,7453 total numbers of deaths attributed to nature, out of which 9.85% were due to lightning as shown in Fig. 2. The figure categorizes numerous causes of mortality due to natural calamities such as avalanche, cold and exposure cyclone, thirst, earthquake, epidemic, flood, heat stroke, landslide, lightning, forest fires and rainfall, and the rest of the events are categorized under other natural causes.

Table 1 LIS Very High Resolution Gridded Lightning Climatology data parameters

File identifier	Dataset name	Description	Units	Dimension ^a	Bin sizes	Smoothing
VHRMC	VHRMC_LIS_FRD	Mean monthly flash rate density	Flash km ⁻² day ⁻¹	760×3600×12	0.1°×0.1°×1 Month	49-day and 1°×1° box-car moving average
VHRSC	VHRSC_LIS_FRD	Mean seasonal flash rate density	Flash km ⁻² day ⁻¹	760×3600×4	0.1°×0.1°×1 trimester	49-day and 1°×1° box-car moving average

^aLatitude and longitude span, respectively, from $\pm 38^\circ$ (i.e., 760 grid points in 0.1°) and $\pm 180^\circ$ (i.e., 3600 grid points in 0.1° resolution). In both of these data, flashes and view times were divided into daily $0.1^\circ \times 0.1^\circ$ bins; a substantial smoothing is also applied. A $1^\circ \times 1^\circ$ boxcar moving average was applied to the adjacent 0.1° grid points, and a 49-day boxcar moving average was applied to the flash counts and view times before computing flash rates (Albrecht et al. 2016a, b)

Table 2 State-wise death due to lightning over India

State	Death
Andhra Pradesh	65
Arunachal Pradesh	0
Assam	24
Bihar	75
Chhattisgarh	165
Goa	0
Gujarat	50
Haryana	7
Himachal Pradesh	4
Jammu and Kashmir	3
Jharkhand	80
Karnataka	77
Kerala	111
Madhya Pradesh	313
Maharashtra	281
Manipur	0
Meghalaya	3
Mizoram	0
Nagaland	0
Orissa	255
Punjab	8
Rajasthan	60
Sikkim	2
Tamil Nadu	71
Tripura	7
Uttar Pradesh	160
Uttarakhand	4
West Bengal	128
A & N Islands	0
Chandigarh	0
D & N Havel	1
Daman and Diu	0
Delhi (UT)	1
Lakshadweep	0
Puducherry	0

5 Results and discussion

This section describes the distribution and state-wise mapping of FRD data over the Indian region to study the lightning-prone region.

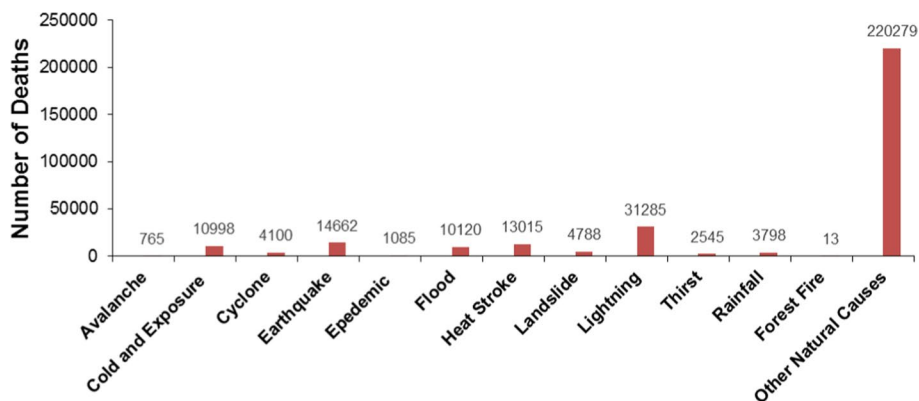


Fig. 2 Death due to various natural disasters over India in the period of 1998–2013

5.1 Seasonal variation

Figure 3 shows lightning flashes (flash/sq. km/yr) over the different regions for major seasons over India. The most prominent season for lightning is pre-monsoon (MAM) and monsoon (JJA) where lightning as high as 40–45 flash/sq. km/yr is observed in the north-eastern part of India, especially during pre-monsoon. It is a dry season with high temperature. So, this region experiences high-frequency convection activity and high cloud tops; hence, the probability of lightning event is more likely. Due to the increase in global temperature, the intensity of thunderstorms, lightning and dust storms is increasing day by day. The thunderclouds are formed due to excessive heat over Bangladesh, particularly where the water bodies are higher (nearby mountain regions). The wind convergence forms an upward movement of warm and moist air (convection), resulting in formation of precipitation with a more chance of thunderstorms. So, there are more cases of lightning not only in Bangladesh but also on the nearby northeastern states (<https://nenow.in/north-east-news/climate-change-increasing-lighting-death-bangladesh-northeast.html>). During December, January and February (DJF), maximum values ranging from 1 to 15 flashes per kilometer square per year have been observed. During DJF, the northwest part of India covering Punjab, Jammu and Kashmir and Himachal Pradesh shows light intensity for lightning 5–10 flash/sq. km/yr. Northeast regions Meghalaya and Assam are experiencing maximum lightning 10–15 flash/sq. km/yr. Kerala and Madhya Pradesh are also reported as the prone area by lightning 10–15 flash/sq. km/yr in the winter season.

March to May (MAM) is the pre-monsoon season in India. From the map, a high lightning rate can be seen over the northeast region, majorly over Assam, Meghalaya in the range of 40 to 45 flash/sq. km/yr whereas Maharashtra, Gujarat and Madhya Pradesh have the least amount of lightning. Kerala, Jammu and Kashmir, West Bengal and Orissa experience moderate lightning from 15 to 35 flash/sq. km/yr. Pre-monsoon is the season for crop cultivation in whole India. Farmers working in open fields are more prone to be struck by lightning during this season. Kerala is the first state in India to receive the rain from southwest monsoon from early June. It hits the Western Ghats of this coastal state. Similarly, Bengal and Orissa also start receiving rainfall during this time.

Figure 3 shows lightning strikes over India in months from June to August (JJA) which is marked as the monsoon season in India. In this season, India experiences

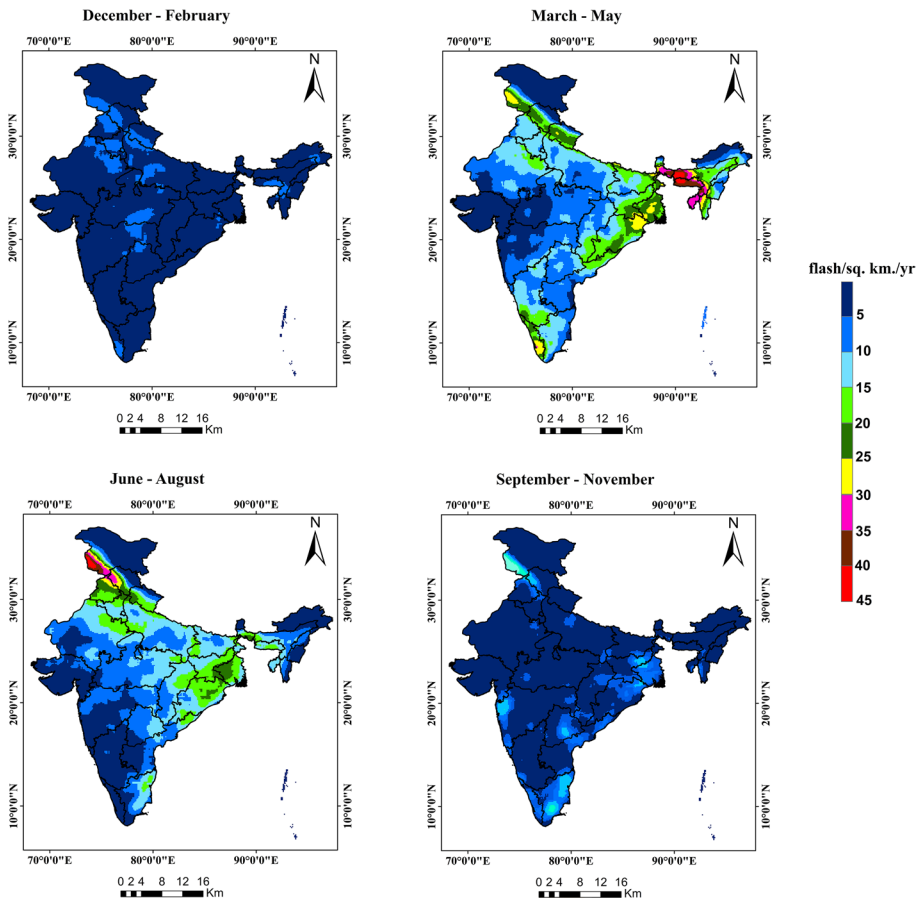


Fig. 3 Seasonal variation of lightning flashes (flash/sq. km/yr) over India

lightning strikes between 15 and 35 flash/sq. km/yr. Most vulnerable zone are the parts of Jammu and Kashmir, Punjab and Himachal Pradesh which lies in the region having lightning from 20 to 45 flash/sq. km/yr. Lightning is a form of electric discharge, and sometimes, it can hit the nearest earth surface. Mountains peaks or higher-altitude places are therefore the easy targets.

The period September to November (SON) comes after the monsoon season; therefore, this season is considered as the post-monsoon season. In this season, the maximum lightning occurs in Jammu and Kashmir which is around 15–20 flash/sq. km/yr. Figure 3 shows a clear blue throughout the map, which indicates that almost whole India experience lightning less than ten strikes.

Figure 4 shows the monthly average of maximum flashes per square kilometer. In April, it is around 23–24 flashes, whereas November, December and January show the minimum lightning values which are less than five strikes. The overall lightning is high in the months from March to September during the summer and monsoon seasons, respectively.

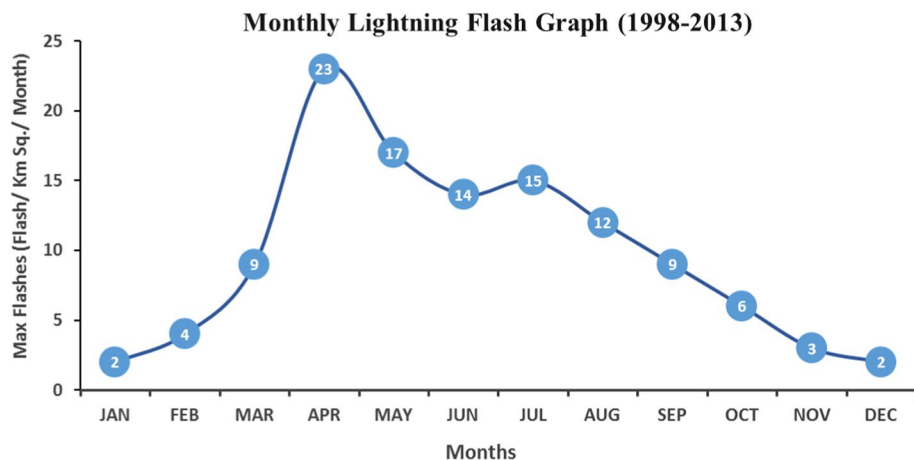


Fig. 4 Monthly variation of lightning flashes (flash/sq. km/month) over India in 1998–2013

5.2 Analysis of fatalities by lightning

Lightning is one of the most dangerous natural calamities which take more the 2000 lives per year in India. In our study, we have seen that most of the lightning takes place in the northeast region, northwest parts of India and some parts of Kerala and Orissa. We have taken the NCRB reports of India from 1998 to 2013 state-wise and analyzed the fatalities in India by lightning.

Figure 5a indicates the yearly lightning map over India (1998–2013) and represents the fatalities by lightning (Fig. 5b) which took place in the past years (1998–2013). From the map, we may interpret that most of the states lie in the range < 50 person deaths per annum, whereas most of the deaths are recorded in Madhya Pradesh, Maharashtra and Orissa which lie in the range greater than 250. The correlation between the fatalities by lightning and the lightning striking region is shown in Fig. 6.

Figure 6 does not exactly show the direct or indirect relations between lightning flashes and the fatalities. Interestingly, the results corroborate the high number of deaths in Maharashtra, Madhya Pradesh, Orissa, Bihar and Uttar Pradesh with the average lightning index of 5–35 flash/sq. km/yr, whereas the areas having high flashes per kilometer square per year are Assam, Himachal Pradesh, Jammu and Kashmir, and Meghalaya where fewer fatalities are recorded.

The maximum casualties are found in Madhya Pradesh (313), Maharashtra (281) and Orissa (255) per annum. The reason behind less death in Jammu and Kashmir, Assam, Meghalaya, Himachal and Kerala is that all these states are hilly areas and that most of the lightning strikes in the hilly parts of given states; however, most of aforementioned hilly regions have low population density. Therefore, the lightning falls on the ground where there is very low population, resulting in low death rates in all those areas (Curran et al. 2000). Similarly, the Madhya Pradesh, Orissa and Maharashtra have high fatality rates due to lightning because of the highly dense populated area. A single strike of lightning may take much life in that region. All of these states have plain terrain; therefore, a lightning strike is less as compared to the hilly regions. But due to the high

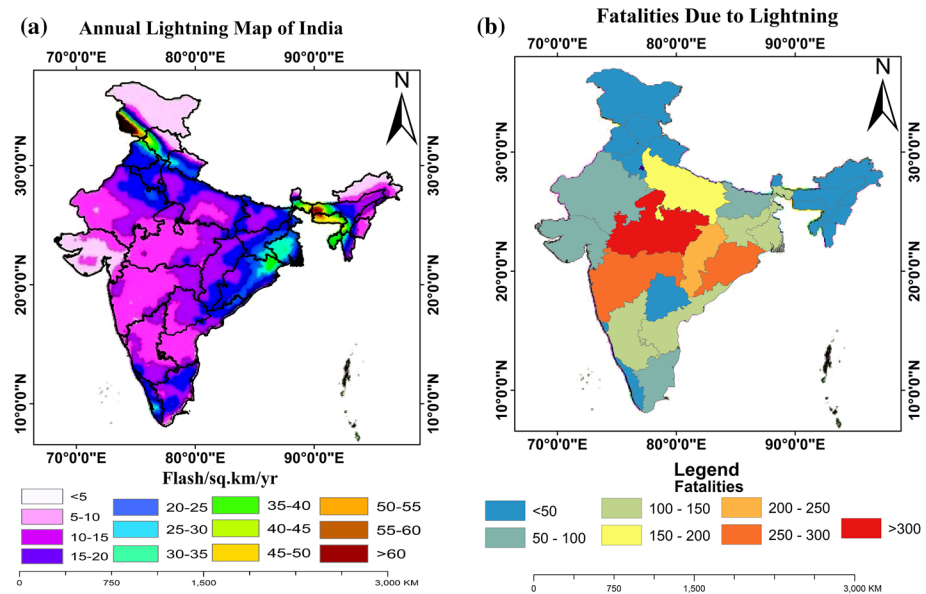


Fig. 5 Annual lightning flashes (a) and fatalities by lightning (b) over India

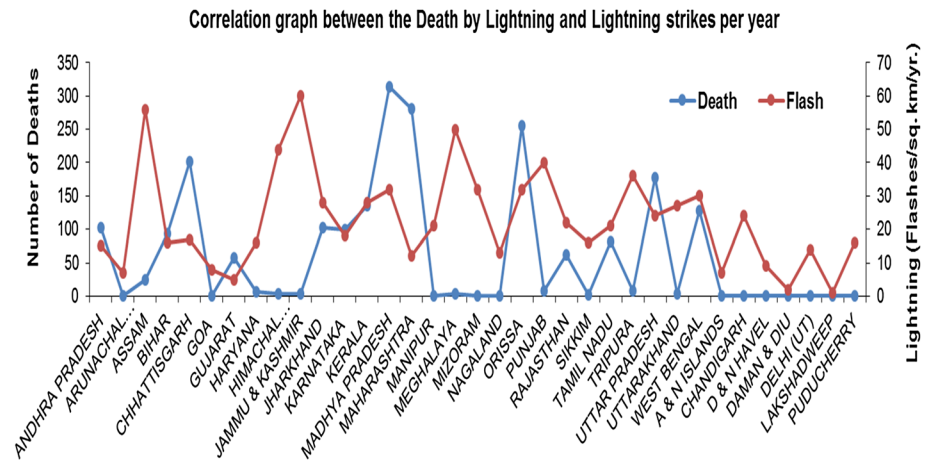


Fig. 6 Relation between fatalities by lightning and the lightning strikes per year

population density of all these areas, even lesser lightning flashes take the life of many people due to high chances of being struck by lightning, resulting in high death rates.

6 Conclusions

This study systematically analyzed the Lightning Imaging Sensor (LIS) onboard the Tropical Rainfall Measurement Mission (TRMM) composite data from 1998 to 2013 over India to determine seasonal and monthly variability. The correlation between the fatalities due

to lightning and the lightning flashes per kilometer square per year has also been estimated over India. Fatalities' data are taken from the NCRB report, and the flash count extracted from the TRMM/LIS helped us to see the correlation between fatalities due to lightning and the lightning strikes over the different states of India. The study reveals that most lightning-dominant regions over India are Jammu and Kashmir, Assam, Meghalaya, Himachal Pradesh, Punjab and Tripura throughout the year with a lightning flash with FRD of > 25 flash/sq. km/yr while Arunachal Pradesh, Goa, Gujarat, Daman and Diu and Lakshadweep have lower frequency of lightning flash with FRD of < 10 flash/sq. km/yr. The study reveals that most lightning-dominant regions over India are Assam, Jammu and Kashmir, Kerala and Orissa throughout the year with a lightning flash of more than 25 flash/sq. km/yr. The lightning dominates during the pre-monsoon season which starts from March and May having maximum lightning around 45 flash/sq. km/yr. Monsoon season which starts from June to August experiences high precipitation and maximum lightning flashes of 40 flash/sq. km/yr in north regions of Jammu and Kashmir.

The lightning takes place mostly in the hilly regions of the different states such as Kerala, Jammu and Kashmir, Assam, Himachal Pradesh and Meghalaya. One of the interesting results of the study states that as the hilly regions' population density is low, there are very few deaths recorded by the lightning in these areas. From 1998 to 2013, the total numbers of deaths attributed to nature are 317,453, out of which 9.85% were due to lightning. We also found the annual lightning death is 1955 per annum.

On the other hand, states such as Maharashtra, Madhya Pradesh and Orissa are having high population density, a single strike may result in a higher fatality rate due to lightning.

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