A SIMPLE MODEL FOR DETERMINING THE POTENTIAL RISKS OF LIGHTNING STROKES OVER THE CITIES OF NAIROBI AND MOMBASA

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Abstract

This study examines the cloud to ground lightning discharges over the cities of Nairobi and Mombasa including their environs. Ground based and Satellite-derived meteorological data were utilized in this study and included thunder events, total rainfall, number of rainy days, maximum rainfall in 24 hours, relative humidity, minimum and maximum temperature, wind speed and direction and Cold Cloud Duration (CCD).

In the context of disaster management, the synergistic approach to risk management involves four closely related phases, one of which is the scientific analysis of specific hazard. This is the phase addressed in this study. A risk indicator based on physical and statistical characteristics of thunderstorms at the two locations was developed by examining the patterns of deviations from the mean thunderstorm events and their frequencies. Various aspects of the lightning risks at the two areas are described and discussed.

Model results indicate that higher risks of lightning stroke occurred during the long rains season (March to May) as compared to the short rains (September to November) season. This was attributed to higher frequency of thunderclouds during the long rains season. The rain generating mechanisms during the long rains were observed to have higher frequencies of thunder events. The dry season (December to February and June to August) exhibits lowest lightning stroke risks.

It is hoped that the results from this study may be of use to the various sectors of economy that need to take into account the dangers/risks of lightning strokes into their day to day operations so as to minimise or avert disasters from lightning strokes. Some of the sectors that may benefit from the results of this study include the Kenya Oil Refinery Depots, Kenya Power and Lighting Company, the Chemical and construction industries among others.

Résumé

Cette étude examine les décharges de foudre entre les nuages et le sol sur les villes de Nairobi et Mombasa y compris leurs environs. Dans cette étude, on a utilisé les données météorologiques terrestres et satellitaires, y compris les événements pluvio-orageux, les pluies totales, le nombre de jours de pluie, les pluies maximales en 24 heures, l'humidité relative, les températures maximales et minimales, la vitesse et la direction du vent et la Durée des nuages à sommet froid (DNF).

Dans le contexte de la gestion des calamités, l'approche synergique à la gestion des risques implique deux phases intimement liées dont l'une est l'analyse scientifique d'un risque spécifique. C'est la phase qu'on traite dans cette étude. On a développé un indicateur de risque basé sur les caractéristiques physiques et statistiques des orages dans les deux endroits en étudiant les configurations des déviations de la moyenne des événements pluvio-orageux et leur fréquence. Différents aspects des risques de foudre dans les deux régions sont décrits et discutés dans cette étude.

Les résultats du modèle montrent que les risques les plus élevés des coups de foudre existent pendant la grande saison des pluies (mars à mai) en comparaison avec la petite saison des pluies (septembre à novembre). On attribue cela à une plus grande fréquence de nuages orageux pendant la grande saison des pluies. On a observé que, pendant les grandes pluies, les mécanismes pluviogènes avaient une plus grande fréquence d'événements...
Il est à espérer que les résultats de cette étude pourront être utilisés dans différents secteurs de l’économie où la prise en compte des dangers/risques de coups de foudre est essentielle dans les opérations quotidiennes afin de minimiser ou d’éviter des désastres émanant des coups de foudre. Quelques uns des secteurs qui pourraient bénéficier des résultats de cette étude sont les dépôts des raffineries pétrolières kenyanes, la société kényane d’énergie et d’électricité, et les industries chimiques et de construction, parmi tant d’autres.

1.0 Introduction

Lightning is a phenomenon manifesting large electric sparks produced in and around thunderclouds prevalent during thunderstorm occurrences. A thunderstorm is a very intense rainfall event accompanied by thunder, the sound resulting from the stroke caused by the electric sparks. Thunderstorms are, therefore, invariably accompanied by lightning.

Thunderstorms generally occur within moist, warm (maritime tropical) air masses that have become unstable either through surface heating or forced ascent over mountains. Cumulonimbus (Cb) clouds normally develop out of a cluster of small cumulus towers. Measurements have shown that small cumulus clouds are usually electrically inactive. The first indications of cloud electrification occur during the vigorous vertical development of large towers accompanied by precipitation.

Studies have shown that there are three characteristic stages in the life cycle of a typical thunderstorm cell. The initial cumulus stage usually lasts for about 15 minutes. During this period, the cell grows laterally from 2 to 4 Km in diameter to 10 or 15 Km, and vertically to 8 or 10 Km. The mature stage begins when rain reaches the ground and usually lasts for 15 to 30 minutes. The mature stage is the most intense period of the thunderstorm. Lightning is most frequent during this period and turbulence is most severe. The cloud reaches its vertical development near the end of this stage, usually reaching about 10 Km and sometimes penetrating the tropopause to altitudes greater than 15 Km.

The final and dissipating stage begins when the downdraft has spread over the entire cell. With the updraft cut off, the rate of precipitation diminishes and so the downdrafts are also gradually subdued. Finally, the last flashes of lightning fade and cloud begins to dissolve (Miller and Anthes, 1985).

The charge distribution in a thundercloud is such that the (bottom) lower part of the cloud is generally negatively charged and this causes a region of the ground beneath the cloud to become positively charged. As the thundercloud (storm) moves along, the region of positive charge is most dense on protruding objects, such as isolated trees, poles, buildings, etc. the difference in charge density causes the electric potential between the cloud and the ground. Consequently, the insulating properties of air sometimes break down when the charge difference becomes sufficiently large (about 3 million volts per meter over 50m length) causing a lightning discharge. A single lightning strike may involve a current as great as 100,000 amperes (Ahrens, 1994). The lightning stroke can heat the air through which it travels to an incredible 30,000°C and this extreme heating causes the air to expand explosively resulting in a booming sound called thunder.

The mechanisms of the lightning discharge can be divided into three major categories:
- Cloud-to-cloud discharges
- Cloud-to-ground discharges
- Phenomena on the ground end of the cloud to ground discharges

The focus of this study, from practical point of view, targeted only those phenomena that are associated with lightning strokes that are in contact with human installations.

The mechanisms of lightning strokes to the ground show that these strokes start from the cloud in the form of stepped leader (Berry et. al., 1945; Pierce, 1974; Malone, 1951). The steps have an average of 50 m. Frequently the first discharge shows branching produced by a stepped-leader process. Branching is
always in the direction of propagation of the leader. In general, subsequent leaders do not show branching, choosing the path where ground has been reached, resulting in a return stroke. In many cases more than one branch may reach the ground simultaneously. In other cases, ground is reached at a different point on subsequent discharges, following and completing a branch established on the first discharge.

Protection mechanisms, with respect to lightning hazards in cities, are a function of whether or not protection is justified depending on the value and nature of the building and its contents, the frequency of occurrence of lightning storms, the degree of shielding offered by other structures, as well as the availability of fire fighting equipment. This work seeks to contribute to the understanding of the lightning risks in the Kenyan cities of Nairobi and Mombasa, for use by various sectors of economy that require taking care of lightning risk considerations.

Risk management (Wilhite, 2000) basically involves four phases, namely: Scientific expertise which is necessary to identify and monitor specific hazards. Risk is the product of hazard and vulnerability. Secondly a combination of regulatory advice and thirdly scientific judgement is required to evaluate the risks and setting particular standards for different interest groups and hence to set guidelines for actual regulations. In the context of this integrated systems scenario, this work basically addresses the first phase with purely a scientific benchmark.

2.0 Data

The ground based and satellite data were obtained for the period 1989 to 1995. Meteorological data, from ground based stations, namely: Jomo Kenyatta International Airport (JKIA), Wilson airport, Dagoretti Corner, Kabete, Muguga, Mombasa and Mtwapa, were utilized. These stations were considered representative of the cities of Nairobi and Mombasa. Monthly data values of the following parameters were obtained: Thunder events, total rainfall, rainy days, maximum rain in 24 hours, relative humidity at 03, 06 and 12 GMT, minimum and maximum temperature, wind speed and direction.

Satellite-derived Cold Cloud Duration (CCD) data were also considered for the same stations on the following basis. Thunder clouds are usually very thick and have very high tops. This implies that the temperature at the cloud tops are very cold and due to the thickness, visible light shining on them would be effectively reflected. METEOSAT Satellite-derived Cold Cloud Duration (CCD) uses these two characteristics to identify clouds. CCD is the time taken by a cloud of a certain cloud top temperature in staying over a given region. The identification is done through Visible (VIS) radiation, which recognises cloud thickness, and Infra-red (IR) radiation, which monitors cloud top temperatures. CCD has been extensively used in identifying thunderstorm clouds and can, therefore, be used as proxy information on thunder clouds and hence lightning (Lillesand and Kiefer, 1994).

3.0 Lightning characteristics over the study areas

Homogeneity analyses considerations for the two cities, in the context of horizontal extent of thunder clouds and their formation mechanisms, indicate that a cloud base has a diameter of about 10 Km and the area influential to the cloud formation mechanism has a diameter of about 20 Km. This means that a thunder cloud observed at Nairobi’s industrial area will influence the locality in a statistically almost the same way as if the cloud was observed in JKIA. Therefore, Nairobi’s industrial area can be classified in the same homogeneous region with JKIA. Thunderstorms, precipitation and lightning data for JKIA station are thus representative of the Nairobi city. In the same way Mombasa airport station is representative of Mombasa city.

The spatial and temporal patterns of lightning are discernible from the responsible thunderclouds. The close relationship between thunderstorm events and lightning occurrences imply that the more the thunder events the more the precipitation and the higher the frequency of lightning (e.g. Figure1). This is confirmed by analyses of atmospheric stability index (Maximum temperature divided by Temperature range) as shown in Figure 2. Thundercloud development strongly relies on atmospheric instability. The stability index is a good guide of the mean monthly atmospheric stability. It should be noted, however, that on a day to day basis, two air masses may have the same stability index but differ appreciably in actual stability.
Figure 1: Plot of average lightning reports versus average monthly total precipitation

Figure 2: Plot of average lightning reports versus average monthly stability index

Figure 3: Variation of lightning events with CCD for Nairobi
Statistical analyses (Table 1) below show that the average monthly total rainfall has a high correlation with CCD data. Thus satellite data may be used as proxy information on thunderclouds and hence lightning as explained in section 3.0 above. Figure 3 above shows this relationship for the Nairobi area.

<table>
<thead>
<tr>
<th>Weather parameter</th>
<th>THUNDER</th>
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<tr>
<td>Thunder</td>
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<td>Rain_Days</td>
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<tr>
<td>Max_24hr</td>
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<tr>
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<tr>
<td>Maximum Temperature</td>
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<tr>
<td>Minimum Temperature</td>
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<tr>
<td>Mean Temperature</td>
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</tr>
<tr>
<td>Temperature Range</td>
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</tr>
<tr>
<td>Relative Humidity_0300</td>
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<tr>
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<td>0.087</td>
</tr>
<tr>
<td>Relative Humidity_1200</td>
<td>0.159</td>
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<tr>
<td>Wind_Speed At 0600</td>
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<td>Wind_Speed At 1200</td>
<td>0.12</td>
</tr>
<tr>
<td>CCD</td>
<td>0.508</td>
</tr>
</tbody>
</table>

*Table 1: Correlation analysis results of thunder events versus other weather parameters. The bolded values are significant correlated at 95% significance level.*

Consequently, thunderclouds occurrence information, as observed from satellite is useful for the spatial and temporal patterns of lightning. Thus CCD data are used to describe the unique features of lightning at the two locations. Figure 4 is an illustration of the mean monthly variability of thunderclouds over Mombasa. Maximum frequency is observed in April while the minimum is in July. This also applies for Nairobi.

The long rains season was characterised by higher frequencies of thunder events. The short rains, on the contrary, are characterised by fewer number of thunder events.

5.0 A simple lightning risk indicator model for Nairobi and Mombasa

The synergistic approach to Risk management basically involves four phases, which of necessity are closely related. Scientific expertise is necessary to identify and monitor specific hazards, while a combination of regulatory advice and scientific judgement is required to evaluate the risks to weight up the ramifications of setting particular standards for different interest groups and hence to set guidelines for actual regulation, including enforcement and persecution (Wilhite, 2000). In the context of this integrated systems scenario, this work basically focuses the first phase which quantifies the risk.

Risk index ($R$) is given as

$$R = \delta \zeta$$

where, $\delta$ = Hazard

$\zeta$ = Vulnerability

Hazard if computed by evaluating the frequency of the lightning strokes

Vulnerability is assumed constant if each vulnerable sector is considered in the model separately. Examples of vulnerable sectors in Kenya include installations of Kenya Oil Refinery Depots, Kenya Power and Lighting Company, the Chemical and construction industries.
Risk indicator (R) in this case, therefore, is based on purely statistical characteristics of lightning occurrences as derived from thunderstorms report at the two locations. This is because the vulnerability is assumed to be a constant in time. This is arrived at by graphical frequency analysis as shown in the Figures 5a and 5b below.

![Figure 5a: Spatial patterns of the lightning risk indicator over Nairobi](image)

![Figure 5b: Spatial patterns of the lightning risk indicator over Mombasa](image)
The risk indicator is based on the frequency of occurrence of thunder activities over a given region. The minimum for this indicator is Zero. It varies from 0 to 100 for Nairobi and from 0 to 80 for Mombasa in this analysis. Higher values indicate higher risks of lightning strokes and vice versa. Higher lightning stroke risks are expected during the months of March to May for both locations. This corresponds with the long rains season over both locations. This agrees with the finding by Ouma (2000) that the long rains experience disproportionately higher thunderstorm events than the short rains.

6.0 Conclusion

The results of these analyses indicate that higher lightning strokes occur during the long rains season (March to May) as compared to the dry (December to February and June to August), and the short rains (September to November) season, for both Mombasa and Nairobi. This is attributable to the highest frequency of thunderclouds during the long rains season. Protection considerations are a function of whether or not protection is justified depending on the value and nature of the building and its contents, the frequency of occurrence of lighting storms, the degree of shielding offered by other structures, as well as the availability of fire fighting apparatus. Protection of structures containing inflammable or explosive materials require that extra precautions be taken to prevent sparks, no matter how minute, from occurring within the protected area.

6.0 References