CORRELATION ANALYSIS OF LIGHTNING AND FLASH FLOOD EVENTS USING PEARSON MODEL IN SOUTHEAST PENINSULAR MALAYSIA

NORAISHAH BINTI BAHARI

UNIVERSITI TEKNOLOGI MALAYSIA

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NORAISHAH BINTI BAHARI

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ABSTRACT

Flash flood is a natural disaster that causes many casualties and economic losses. It has become prevalent in Malaysia, where several events have been reported showing a possible correlation between lightning, rain, and flash floods. Previous researchers have studied lightning activity during flash floods in Spain, Italy, and Greece. The lightning and rainfall intensity and other variables, which is radar data associated with flash flood events, are analyzed between January to April 2022 for 7 different days of events within a distance of 100 km from Universiti Teknologi Malaysia, Johor. The data supplied by Tenaga Nasional Berhad Research Sdn. Bhd., Department of Irrigation and Drainage, and Malaysia Meteorological Department were evaluated for statistical discrepancies, which is a different approachable method, by limiting the criteria for each data source. This research aims to investigate the relationship between the number of lightning occurrences with the amount of rain in 24 hours by applying the Pearson correlation coefficient (r) and determine the relationship strength between lightning and rainfall intensity parameters by implementing the rainfall-lightning ratio change to rainfall-lightning rate, which is commonly used to evaluate the relationship between rainfall and lightning. This study found that the r-values between lightning and rain range from 0.4 to 0.9, which correlates well with rainfall and is considered an acceptable correlation. The different values due to the number of lightning and rain occurrences are inconsistent for each independent case. Another significant finding from this study shows that 2 hours before the events, the increase in lightning number is related to the rainfall intensity. In order to further scrutinize these correlations, several parameters, such as radar and lightning, are gathered since a gauging station may miss enormous rainfall intensity associated with a relatively local flood event. According to the findings, lightning data may be utilized in association with rain. Therefore, the accuracy of the existing flood forecasting system may be improved.

ABSTRAK

Banjir kilat adalah bencana alam yang menyebabkan banyak korban jiwa dan kerugian ekonomi. Ia telah berlaku di Malaysia, di mana beberapa peristiwa telah dilaporkan menunjukkan kemungkinan hubungan antara kilat, hujan, dan banjir kilat. Penyelidik sebelum ini telah mengkaji aktiviti kilat semasa banjir kilat di Sepanyol, Itali, dan Greece. Kekerapan kejadian kilat dan hujan dan pemboleh ubah lain yang merupakan data radar yang berkaitan dengan kejadian banjir kilat dianalisis antara Januari hingga April 2022 selama 7 hari kejadian yang berbeza dalam jarak sejauh 100 km dari Universiti Teknologi Malaysia, Johor. Data yang dibekalkan oleh Tenaga Nasional Berhad Research Sdn. Bhd., Jabatan Pengairan Saliran dan Jabatan Meteorologi Malaysia dinilai untuk perbezaan statistik, yang merupakan kaedah yang dapat didekati dengan membatasi kriteria untuk setiap sumber data. Penyelidikan ini bertujuan untuk menyiasat hubungan antara jumlah kejadian kilat dengan jumlah hujan dalam 24 jam dengan menerapkan pekali korelasi pearson (r) dan menentukan kekuatan hubungan antara kilat dan parameter intensiti hujan dengan menerapkan nisbah hujan-kilat perubahan pada kadar hujan-kilat, yang biasanya digunakan untuk menilai hubungan antara hujan dan kilat. Kajian ini mendapati bahawa nilai r antara kilat dan hujan berkisar antara 0.4 hingga 0.9, yang berkorelasi dengan baik dengan curah hujan dan dianggap sebagai korelasi yang dapat diterima. Nilai yang berbeza kerana jumlah kejadian kilat dan hujan tidak konsisten untuk setiap kes bebas. Penemuan penting lain dari kajian ini menunjukkan bahawa 2 jam sebelum kejadian, peningkatan jumlah kilat berkaitan dengan intensiti hujan. Untuk meneliti lebih jauh korelasi ini, beberapa parameter seperti radar dan kilat dikumpulkan kerana stesen pengukur mungkin kehilangan intensiti hujan yang sangat besar yang berkaitan dengan kejadian banjir yang agak tempatan. Menurut penemuan, data kilat dapat digunakan sehubungan dengan hujan. Oleh itu, ketepatan sistem ramalan banjir yang ada dapat ditingkatkan.

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LIST OF ABBREVIATIONS

CAPPI	-	Constant Altitude Plan Position Indicator
CG-	-	Negative Cloud-To-Ground
CG+	-	Positive Cloud-To-Ground
DID	-	Department of Irrigation and Drainage
dBZ	-	Signal strength in decibels
IC	-	Intra-Cloud
IVAT	-	Institute of High Voltage and High Current
LF	-	Low-Frequency
LDN	-	Lightning Detection Network
MetMalaysia	-	Malaysia Meteorological Department
UTM	-	Universiti Teknologi Malaysia
NaFFWS	-	National Flood Forecasting and Warning System
PPI	-	Plan Position Indicator
R	-	Rain intensity in (mm/hr)
SPRHiN	-	Sistem Permohonan Data Rangkaian Stesen Hidrologi
TNBR	-	Tenaga Nasional Berhad Research Sdn. Bhd.
TITEDA	-	Time-Dependent Data
UTC+8	-	Universal Time Coordinated (+ 8 hours)
Z	-	Radar reflectivity factor

LIST OF SYMBOLS

dBZ	-	Decibels
*k*m	-	Kilometer
p-value	-	Probability value
r	-	Pearson Correlation coefficient

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The rapid and robust rainfall during thunderstorms, which frequently causes flash floods, may be disastrous. Most of the country worldwide is not covered by weather radar measurements, despite many advanced nations having networks to detect storms and precipitation. Furthermore, radar coverage is typically poor and insufficient in hilly areas [1]. The development, maturation, and dissipation of thunderstorms usually take 1–2 hours, making it necessary to establish methodologies to constantly monitor severe thunderstorms, particularly in areas not covered by radar systems. Besides, due to the dispersion of the low-frequency electromagnetic signals released by lightning discharges, lightning monitoring may be made from a great distance, in contrast to radar studies of thunderstorms [1].

Throughout history, severe and intense weather events such as severe thunderstorms, hail, wind storms, tornadoes, hurricanes, floods, and others have posed risks and challenges to human life while wreaking havoc and creating harm throughout their way. Flash floods are a big concern in Malaysia, and particular regions see severe occurrences. Figure 1.1 shows that flood is the most common catastrophe in Malaysia, accounting for 62.5% of total disaster events, according to the Emergency Events Database (EM-DAT), a global database on natural and technological disasters [2].

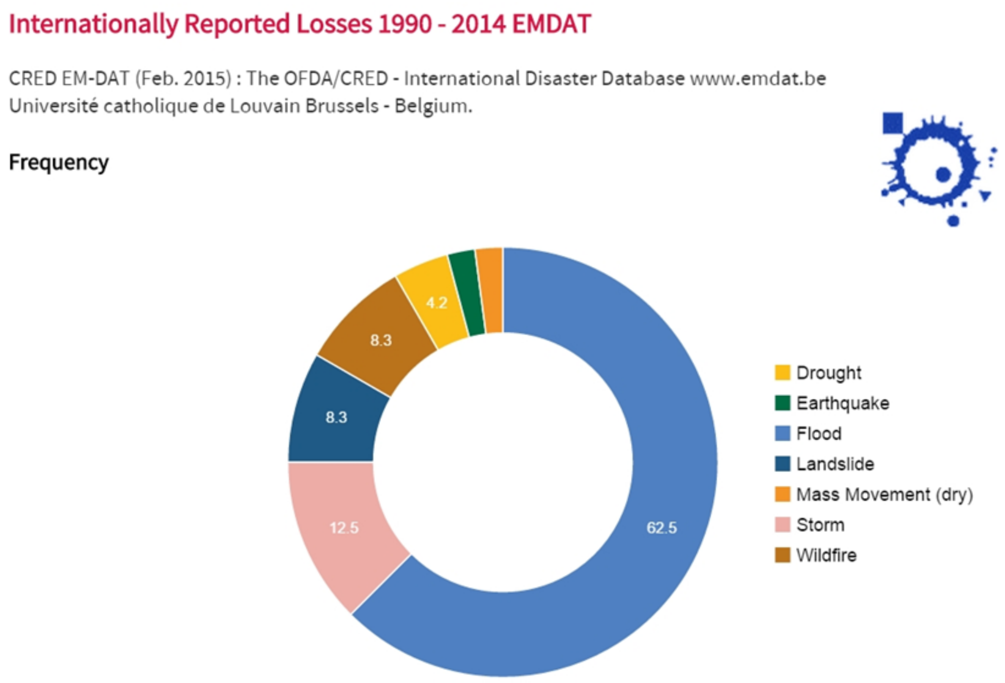

Figure 1.1 Percentage of occurrences of disasters (Adapted from [2])

Flooding is the build-up of water around a water body and the discharge of surplus water onto the surrounding floodplain area. A floodplain is a flat area adjacent to a river, stream, or body of water prone to flooding [3]. Flash floods are a type of flooding that occurs suddenly. Flash floods are typically caused by the pouring of severe rainfall, mainly when riverbanks are breakable and cannot contain adequate water. This flood is commonly characterized as a flood that happens within 6 hours of the onset of heavy rains. It is usually linked to the number of cumulus clouds in the sky, lightning, tropical storms, and cold temperatures [4].

Generally, floods are a common natural calamity that causes severe damage to people and property worldwide. Flooding contributes to 40% of overall economic damage generated by all catastrophes [5]. DID reports that floods harm 9 % of the country's geographical area (29,800 km²), as shown in Figure 1.2, 22 % of residents (4.82 million), and the average yearly flood loss is around USD 0.3 billion [6].

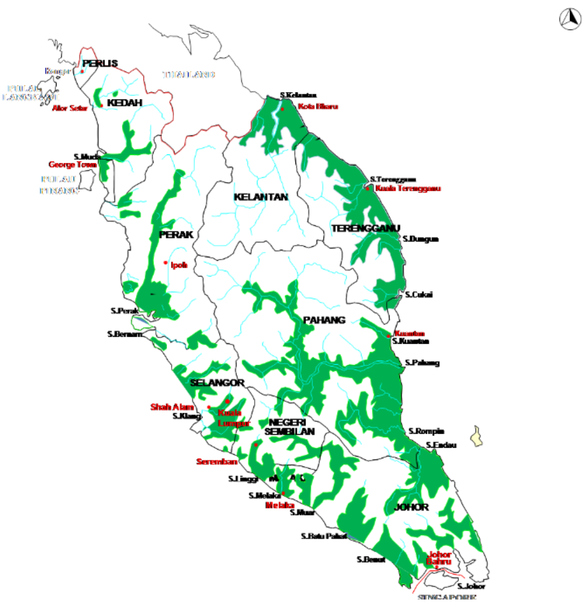

Figure 1.2 Flood-prone area in Malaysia (Adapted from [7]

As reported by DID [6], Malaysia has witnessed large floods in recent decades, notably in December 2006 and January 2007, which badly impacted Johor state. Indeed, throughout the recent Johor floods during 2006 and 2007, a few severe rainfall episodes resulted in significant flooding. The entire cost of these flood catastrophes regarding property loss was estimated to be USD 0.5 billion, making it one of the most expensive flood occurrences in the Malaysian experience. Around 110,000 residents were relocated and transported to relief camps, with 18 killed [6]. Since the flood was arriving so abruptly, residents needed to be notified of the danger immediately. Thus, rescue operations could begin, and plans could be made to lessen the impacts. [8] stated that although flood occurrences are inevitable, governments and residents should be aware of the specific time and location of the next flood and what regions will be flooded due to such events to avoid future catastrophes, and an effective flood forecasting system must be established. Therefore, flood forecasting is implemented to enhance the floor monitoring system's reliability.

Research shows the possible correlation between lightning events and heavy precipitation associated with flash floods [1], [9], [10]. Malaysia often faces the problem of thunderstorms, especially during the two major seasonal monsoons known as the Northeast and Southwest monsoons [3], [11]. The east and west areas of

Peninsular Malaysia would have a high possibility of heavy floods during these two seasons [11]. Moreover, most occurrences are accompanied by slow-moving thunderstorms, thunderstorms continuously moving through the same region or downpours from the tropical storm. Thunderstorms are frequently responsible for catastrophic and life-threatening flash floods [12]. Lightning activity among these storms may be observed and monitored thousands of kilometers apart, significantly improving extreme thunderstorm forecasts and nowcast [12]. Therefore, studying lightning activity during flash floods contributes to a better insight into complicated hydro-meteorological situations [10]. Numerous studies have found a strong association between lightning and excessive rainfall, and lightning data has been demonstrated to give extra insight for decision-making when faced with the risk of a flash flood [13]–[15].

Lightning and rainfall are two distinct phenomena that commonly occur in thunderstorms, and the correlation between the two has been studied for a long time. According to research, the highest lightning intensity comes before the highest rainfall. However, others claim no set temporal association exists between the highest cloud-to-ground lightning rate and rainfall. [16] stated that heavy rainfall might be classified into two types: continuous lightning and the other with little or no lightning. Hence, this research examines the relationship between lightning and rainfall activity in flash flood prediction possibilities, focusing on the reported areas that had experienced flash flood events.

1.2 Problem Statement

Flooding is a common hydrological phenomenon caused by heavy rainfall. Malaysia is separated by the South China Sea and contains West Malaysia (Peninsular Malaysia) and East Malaysia (Sabah and Sarawak)[3]. Despite not having four seasons as in temperate regions, Malaysia encounters monsoon seasons, resulting in experiencing high rainfall intensity during the seasons. The east and west areas of Peninsular Malaysia would have a high possibility of heavy floods during these seasons. These two seasonal monsoons are referred to as the Northeast and Southwest monsoons. However, the Department of Irrigation and Drainage (DID) has classified floods in Malaysia into two types which are monsoon and flash floods [17], [18]. Floods may be forecast considerably, except for flash floods, the amount and pattern of which are frequently less definite. Malaysia often faces the problem of conventional thunderstorms, especially during flash floods. [19]–[21].

Furthermore, the rapid and unexpected events catch individuals off guard during regular routines. A flash flood is an incident or physical condition involving fatalities, injury, collateral and environmental destruction, business disturbance, or other forms of harm or failure. The National Oceanic and Atmospheric Administration (NOAA) reported that flash floods occur in less than minutes or hours of extreme rainfall [3], [22]. Moreover, due to variations in weather cycles, the frequencies of devastating rainfall events that result in severe flooding are predicted to grow shortly. A rainfall and flood prediction is difficult for an engineer to meet the community's demands.

Radar is one of the various methods and implementations of engineering that have been utilized by the Malaysia Meteorological Department (MetMalaysia). The Department of Irrigation and Drainage (DID) currently provides flood counter-measure by measuring the amount of rainfall using a rain gauge. There is a possible correlation between lightning events and heavy precipitation associated with flash floods. Therefore, flash flood events estimations acquired from lightning and rainfall observations can be utilized as a short-term forecast system. Early warning issues can be provided at an accurate time and location. However, there are several reasons flash flood occurs besides thunderstorms and heavy rainfall, such as the melting of ice debris in the ocean, high wave current at the seashore, broken reservoir, and hurricane inside the sea [23].

1.3 Research Objective

The objectives of the research are:

(a) To investigate the existence of flash flood events associated with the lightning occurrence

(b) To analyze the flash flood data recorded from the National Flood Forecasting and Warning System (NaFFWS) with rainfall data from the Department of Irrigation and Drainage (DID), radar data from Malaysia Meteorological Department (MetMalaysia), and lightning data from Tenaga Nasional Berhad Research Sdn. Bhd. (TNBR)

(c) To assess the correlation between flash floods events and rainfall associated with the lightning occurrence

1.4 Research Scope and Limitation

This research identifies flash flood events by obtaining the report from National Flood Forecasting and Warning System (NaFFWS). There are 7 cases chosen between the January-April 2022. Meanwhile, the adopted hourly rainfall data is acquired from the Department of Irrigation and Drainage (DID), Sistem Permohonan Data Rangkaian Stesen Hidrologi (SPRHiN), and the Malaysia Meteorological Department (MetMalaysia).

In this research, lightning data is provided by Tenaga Nasional Berhad Research Sdn. Bhd. (TNBR) and MetMalaysia. While radar data is also obtained from MetMalaysia, the raw data is in NETCDF format. The collected data will be analyzed and determined if their correlation makes the most accurate flash flood events estimate.

This research only focuses on the flash flood events within a 100 km distance of the Institute of High Voltage and High Current (IVAT), Universiti Teknologi Malaysia (UTM), Johor. This data will be validated by finding the possible correlation between flash flood events and rainfall associated with lightning occurrence. Therefore, an attempt using lightning can be applied as an early warning of flash floods.

1.4.1 Limitation of lightning data

This research has a specific limitation of data as follows:

(a) Lightning data is obtained from TNBR and MetMalaysia by locating the coordinate of latitude and longitude lightning

(b) Different types of lightning (Cloud to ground and 10% Intracloud) are provided by TNBR

(c) MetMalaysia data is supplied based on the Senai and Kluang station

(d) The lightning data is given based on the selected date of the case

1.4.2 Limitation of rainfall data

This research has a specific limitation of data such as:

(a) Rainfall data is provided by NaFFWS, DID, SPRHiN and MetMalaysia

(b) There are 15 active rainfall stations supplied by NaFFWS, DID and SPRHiN

(c) Time-Dependent Data (TIDEDA®) software is used to acquire the data in 10 minutes interval

(d) Hourly rainfall data is supplied based on the Senai station

(e) Millimeters (mm) is the unit for rainfall

(f) Data is acquired based on the selected date of the case

(g) Data provided is only at a particular duration

1.4.3 Limitation of radar data

This research has the specific limitation of data which are as follows:

(a) Raw radar data is retrieved in the rainbow format in 10 minutes interval

(b) Radar data for Senai and Kluang stations supplied by MetMalaysia

(c) dBZ is the unit for reflectivity

1.5 Thesis Outline

This research comprises five chapters: introduction, literature review, methodology, results and discussion, and finally, the conclusion and recommendations for future research. Chapter 1 outlines the introduction of the whole research study consisting of the problem statement, objectives, research scope, and limitations. A general overview of this research is also included. Chapter 2 is dedicated to the various past literature available, derived from papers, books, and journals. All previous studies are summarized to verify the possible correlation between lightning events and heavy precipitation associated with flash floods. Next, the theoretical parts relevant to the research are also explained.

Meanwhile, Chapter 3 details the method and calculation used to analyze all the data collection. The rainfall, lightning, and radar data correlate to find a good correlation. This is to help improve the quality and accuracy of the comparative results. Chapter 4 presents the final results for the correlation between rainfall, lightning, and radar data. It also discusses the data analysis presented in table and graph forms. Finally, Chapter 5 summarizes the study and concludes the research by providing recommendations for future research on flood forecasting systems.

Nomenclature: The term ‘flash flood events’ and ‘events’ describe the flash flood associated with lightning and rainfall occurrences. For short-duration rainfall, the occurrence time is 15 minutes or 30 minutes, or 1-hour intervals

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LIST OF PUBLICATIONS

Razman, A. A., **Bahari, N.,** & Esa, M. R. M. (2021). Temporal and Wavelet Analysis on Narrow Bipolar Pulse and First Return Stroke Recorded in Malaysia Thunderstorm. **AIP Conference Proceedings Indexed by Scopus**.

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