

**TIME SERIES MODELLING AND FORECASTING
COMMUTING ACCIDENT AND ASSOCIATION WITH
METEOROLOGICAL PARAMETERS IN JOHOR BAHRU AND
KUALA LUMPUR, MALAYSIA (2015-2019)**

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KUALA LUMPUR, MALAYSIA (2015-2019)**

By

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DECLARATION

I declare that this thesis was done by myself and follows traditional writing format approved by the School of Medical Sciences, Universiti Sains Malaysia. This work has not been submitted for any other degree or professional qualification. I ensured that all references to the works of others have been appropriately credited within this thesis.

Dr Nur Sujaihah Binti Hanafi

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LIST OF SYMBOLS

%	:	Percentage
°C	:	Degree Celsius
°	:	Degree
>	:	More than
<	:	Less than
km	:	Kilometres
km ²	:	Squares kilometres
mm	:	Milimetres
mm/h	:	Millimetre per hour
p	:	p-value

LIST OF ABBREVIATION

ACF	:	Autocorrelation function
AIC	:	Akaike Information Criterion
AICc	:	Corrected Akaike Information Criterion
API	:	Air pollutant index
AQI	:	Air quality index
ARIMA	:	Autoregressive Integrated Moving Average
ARIMAX	:	ARIMA model with explanatory variables
CAQMS	:	Continuous Air Quality Monitoring Stations
CARS	:	Computerized Accident Reporting System
CI	:	Confidence interval
CO	:	Carbon monoxide
COVID-19	:	Coronavirus 19
DALYs	:	Disability-adjusted life years
df	:	Degree of freedom
DID	:	Department of Irrigation and Drainage
DLNM	:	Distributed lag non-linear model
DOE	:	Department of Environment
DOSH	:	Department of Occupational Safety and Health
DOSM	:	Department of Statistic Malaysia
DOW	:	Day of week
ESSA	:	Employment Social Security Act
EIS	:	Employment injury scheme
GHG(s)	:	Greenhouse gas(es)

HIC	:	Higher income country
HNB	:	Hurdle negative binomial
HOD	:	Hour of day
HQ	:	Headquarter
ILO	:	International Labour Organization
IRR	:	Incidence risk ratio
JKKP	:	<i>Jabatan Keselamatan dan Kesihatan Pekerja</i>
GDP	:	Gross domestic product
LMIC	:	Lower middle-income country
MAPE	:	Mean Absolute Percentage Error
MLE	:	Maximum likelihood estimation
MOF	:	Ministry of Finance
MOH	:	Ministry of Health
MP-HRP	:	Malaysia Plan for Health Research Priorities
NADOPOD	:	Notification of Accident, Dangerous Occurrence, Occupational Poisoning and Occupational Disease
NE	:	Northeast
NO	:	Nitrogen oxides
ns	:	Natural cubic spline
OR	:	Odds ratio
OSH	:	Occupational safety and health
OSHA	:	Occupational Safety and Health Act
OSHMP 25	:	Occupational Safety and Health Malaysian Plan 2021-2025
PACF	:	Partial autocorrelation
PH	:	Public holiday

PM	:	Particulate matter
Q-AIC	:	Quasi-Akaike Information Criterion
RMP	:	Royal Malaysia Police
RMSE	:	Root Mean Square Error (RMSE)
RR	:	Relative risk
RTAs	:	Road traffic accidents
SARIMA	:	Seasonal Autoregressive Integrated Moving Average
SDG	:	Sustainable Developmental Goal
SOCSSO	:	Social Security Organization
SO ₂	:	Sulphur dioxide
STS	:	Structural Time Series
SW	:	Southwest
TOD	:	Type of day
UHI	:	Urban heat island
WEHU	:	Worker Environmental Health Unit
WHO	:	World Health Organization
WMO	:	World Meteorology Organization
3D	:	Three dimensional

**PEMODELAN SIRI MASA DAN RAMALAN KEMALANGAN DALAM
PERJALANAN (COMMUTING ACCIDENT) DAN PERKAITAN DENGAN
PARAMETERS METEOROLOGI DI JOHOR BAHRU DAN KUALA
LUMPUR, MALAYSIA (2015-2019)**

ABSTRAK

Pengenalan: Di negara tropika seperti Malaysia, hujan dan suhu berfungsi sebagai parameter meteorologi utama yang berpotensi meningkatkan risiko kemalangan jalan raya. Penduduk yang bekerja di bandar-bandar utama sangat berisiko, terutamanya sewaktu berulang-alik ke tempat kerja, mengakibatkan lonjakan kemalangan dalam perjalanan (*commuting accidents*). Walau bagaimanapun, bukti penyelidikan menggunakan kaedah pengukuran objektif, seperti data siri masa dalam memodelkan perkaitan antara meteorologi dan kemalangan dalam perjalanan atau kemalangan jalan raya secara amnya, dalam konteks di Malaysia khususnya, adalah sangat terhad. Oleh itu, kajian ini bertujuan untuk memodelkan perkaitan antara suhu, hujan dan kemalangan dalam perjalanan serta meramalkan kejadian ini pada masa akan datang.

Kaedah: Kajian ini menggunakan data sekunder retrospektif kemalangan jalan raya, hujan, dan suhu di bandar Kuala Lumpur dan Johor Bahru, dari 1 Januari 2015 hingga 31 Disember 2019. Dalam fasa pertama, pembolehubah tindak balas adalah bilangan kemalangan jalan raya dalam kalangan penduduk yang bekerja. Model regresi kuasi-*Poisson* telah digunakan untuk menyiasat kesan faktor temporal terhadap pembolehubah tindakbalas. Perkaitan antara suhu, hujan dan kemalangan jalan raya dalam kalangan pekerja kemudiannya diperiksa menggunakan gabungan pemodelan regresi Terpangkas Binomial Negatif (HNB) dan model bukan linear *lag* teragih (DLNM). Fasa kedua kajian ini memfokuskan kepada bilangan kemalangan dalam

perjalanan sebagai pembolehubah tindakbalas, ditakrifkan sebagai kemalangan jalan raya dalam kalangan penduduk yang bekerja sewaktu berulang-alik dari atau ke tempat kerja (7:00 pagi hingga 8:00 malam). Gabungan reka bentuk kajian Silang Kes Berstrata Masa dan DLNM telah digunapakai untuk menyiasat perkaitan antara suhu, hujan dan kemalangan dalam perjalanan, seterusnya, model ARIMA telah digunakan untuk meramalkan kejadian kemalangan ini pada masa akan datang.

Keputusan: Dalam fasa pertama kajian, sebanyak 11,877 dan 8833 pekerja terlibat dalam 11,531 dan 8632 kemalangan jalan raya dalam tempoh lima tahun, masing-masing di Kuala Lumpur dan Johor Bahru. Majoriti pekerja adalah lelaki (> 75%) dan berumur 15-44 tahun (> 70%). Tempoh masa dalam sehari, yang dibahagikan kepada dua zon, mempunyai perkaitan yang signifikan dengan kemalangan jalan raya dalam kalangan pekerja. Di kedua-dua bandar utama, nisbah risiko insiden (IRR) adalah tertinggi semasa T3 (12:00 pm - 5:59 pm) berbanding T1 (12:00 am – 5:59 am) dan semasa *PEAK 2* (4:30 pm-7:30 pm) berbanding *OTHER* (12:00 pagi – 7:29 pagi, 7:31 malam – 11:59 malam). Di Kuala Lumpur, pekerja mempunyai risiko kemalangan jalan raya yang lebih tinggi pada hari bekerja berbanding hujung minggu (IRR 1.18, 95% CI: 1.10, 1.27). Minggu yang mempunyai tiga hari atau lebih cuti sekolah menunjukkan pengurangan risiko kemalangan jalan raya di kedua-dua bandar utama (Kuala Lumpur: IRR 0.78, 95% CI: 0.69-0.88; Johor Bahru: IRR 0.83, 95% CI: 0.72-0.95). Suhu yang lebih rendah mempunyai perkaitan yang signifikan dengan kemalangan jalan raya, memuncak pada 22°C di Kuala Lumpur (OR 1.46, 95% CI 1.10-1.94) dan 26°C di Johor Bahru (OR 1.36, 95% CI 1.04-1.78). Kesan lag tertinggi bagi suhu rendah ekstrim (23°C) adalah pada lag 0, dan untuk suhu tinggi ekstrim, kesannya tertangguh sehingga 16 jam di Kuala Lumpur (36°C) dan 24 jam untuk Johor

Bahru (34°C). Intensiti hujan meningkatkan kemungkinan kejadian kemalangan jalan raya, dengan kesan paling ketara pada lag 9 jam dan 12 jam masing-masing di Kuala Lumpur dan Johor Bahru. Dalam fasa kedua kajian, sebanyak 8941 dan 6548 kemalangan dalam perjalanan direkodkan di Kuala Lumpur dan Johor Bahru dari 1 Januari 2015 hingga 31 Disember 2019. Kuala Lumpur menunjukkan perkaitan linear songsang yang signifikan antara suhu maksimum harian dan kemalangan dalam perjalanan, dengan kemungkinan tertinggi pada suhu 28°C (OR 1.76, 95% CI 1.14-2.72), manakala Johor Bahru mempunyai perkaitan linear yang tidak signifikan, memuncak pada suhu 35°C (OR 1.21, 95% CI 0.63-2.32). Tiada perkaitan yang signifikan antara hujan dan kemalangan dalam perjalanan di kedua-dua bandar utama. Model ramalan terbaik untuk Kuala Lumpur adalah regresi ARIMA (1,1,1) ralat, dengan suhu minimum mingguan digunakan sebagai faktor regresi (*regressor*). Di Johor Bahru, ARIMA (1,1,1) dikenalpasti sebagai model yang paling sesuai. Kedua-dua model menunjukkan tiada sebarang perubahan pada unjuran kemalangan dalam perjalanan mingguan pada tahun 2020.

Kesimpulan: Penemuan kajian menunjukkan perkaitan antara suhu, hujan, dan kesan lag masing-masing terhadap kemalangan jalan raya dalam kalangan penduduk bandar utama yang bekerja, dan seterusnya ke atas kemalangan dalam perjalanan, menggariskan kepentingan memasukkan parameter meteorologi dalam dasar kesihatan awam seperti keselamatan dan kesihatan pekerjaan, perancangan bandar, dan keselamatan jalan raya. Penemuan ini juga boleh memandu intervensi bersasar dan meningkatkan kesediaan pekerja di bandar-bandar utama untuk menghadapi kesan cuaca ekstrem akibat perubahan iklim.

**TIME SERIES MODELLING AND FORECASTING COMMUTING
ACCIDENT AND ASSOCIATION WITH METEOROLOGICAL
PARAMETERS IN JOHOR BAHRU AND KUALA LUMPUR,
MALAYSIA (2015-2019)**

ABSTRACT

Introduction: In tropical countries such as Malaysia, rainfall and temperature serve as primary meteorological parameters that potentially increase the risk of road traffic accidents (RTAs). The working population in major cities is particularly vulnerable, especially during commuting hours, resulting in a surge of commuting accidents. However, research evidence utilizing objective measures, such as time series data, to model the association between meteorological factors and commuting accidents or even the RTAs in general, particularly within the Malaysian context are substantially limited. Therefore, this study aims to model the association between rainfall and temperature with commuting accidents and forecast their future occurrence.

Methods: This study employed retrospective secondary data on RTAs, rainfall, and temperature from Kuala Lumpur and Johor Bahru from 1 January 2015 to 31 December 2019. In the first phase, the outcome variable was the number of RTAs among the working population. A quasi-Poisson regression model was utilized to investigate the influence of different temporal factors on the outcome variable. Its association with temperature and rainfall was then examined using a combination of Hurdle Negative Binomial (HNB) regression and Distributed lag non-linear models (DLNM). The second phase focused on the number of commuting accidents as an outcome variable, defined as RTAs involving the working population during commuting hours (7:00 am to 8:00 pm). A combined approach using time-stratified

case-crossover design and DLNM was implemented to investigate the association between temperature and rainfall with commuting accidents and subsequently, an ARIMA model was employed to forecast their future incidence.

Results: In phase one, 11,877 and 8833 workers were involved in 11,531 and 8632 RTAs over five years in Kuala Lumpur and Johor Bahru, respectively. The majority of workers were male (> 75%) and aged 15-44 years (> 70%). The time of day, divided into two time zones, was significantly associated with RTAs among workers. The incidence risk ratio (IRR) was highest during T3 (12:00 pm - 5:59 pm) compared to T1 (12:00 am – 5:59 am) and during PEAK 2 (4:30 pm-7:30 pm) compared to OTHER (12:00 am – 7:29 am, 7:31 pm – 11:59 pm) in both cities. In Kuala Lumpur, workers had higher RTA risk during weekdays compared to weekend (IRR of 1.18, 95% CI: 1.10, 1.27). Weeks comprising of three or more school holiday showed a reduced RTA risk in both cities (Kuala Lumpur: IRR 0.78, 95% CI: 0.69-0.88; Johor Bahru: IRR 0.83, 95% CI: 0.72-0.95). Lower temperatures significantly affected RTA occurrence, peaking at 22°C in Kuala Lumpur (OR 1.46, 95% CI 1.10-1.94) and 26°C in Johor Bahru (OR 1.36, 95% CI 1.04-1.78). The strongest lag effect of extremely low temperature (23°C) was at lag 0, and for extremely high temperature, it was delayed up to 16 hours in Kuala Lumpur (36°C) and 24 hours for Johor Bahru (34°C). Rainfall intensity increased RTA odds, with the most pronounced effects at lag 9-hour and 12-hour in Kuala Lumpur and Johor Bahru, respectively. In phase two, 8941 and 6548 commuting accidents were recorded in Kuala Lumpur and Johor Bahru from 1 January 2015 to 31 December 2019. Kuala Lumpur showed a significant inverse linear association between daily maximum temperature and commuting accidents, with the highest odds at 28°C (OR 1.76, 95% CI 1.14-2.72), while Johor Bahru had a non-

significant positive association, peaking at 35°C (OR 1.21, 95% CI 0.63-2.32). No significant association between rainfall and commuting accidents was observed in both cities. The best forecasting model for Kuala Lumpur was a regression with ARIMA (1,1,1) error, with a weekly daily minimum temperature utilized as regressor. In Johor Bahru, ARIMA (1,1,1) was identified as the best fitted model. Both models indicated no substantial changes in the projected trajectory of weekly commuting accidents during 2020.

Conclusion: The study findings elucidate the association between temperature, rainfall, and their lag effect with RTAs among the working population, and subsequently on commuting accidents, underscoring the significance of incorporating meteorological parameters in public health policy related to occupational safety and health, urban planning, and road safety. These insights can also inform targeted intervention and enhance the preparedness of urban workers for extreme weather events resulting from climate change.

CHAPTER 1 INTRODUCTION

1.1 Background of Study

The increase in average global temperature has initiated a series of events leading to climate change. This phenomenon has resulted in the emergence of new weather patterns that are more extreme and intense. Consequently, the meteorological parameters, which are crucial components of atmospheric systems and are used to describe weather or climate conditions, have become more unpredictable and are expected to potentially cause a costly and disruptive impact on human life and livelihood including road traffic accidents (RTAs). In Malaysia, RTA was defined as an accident or incident that causes any persons, property, vehicle, structure or animal damage or injury, as stipulated in Malaysia Road Transport Act 1987 (Syukri *et al.*, 2021). According to Malaysia Institute of Road Safety (MIROS), 20 % of RTAs in Malaysia recorded from 1997 to 2007 were attributed to inclement weather, primarily due to rainfall (Mohd Hafzi *et al.*, 2010). Similarly, the Federal Highway Administration (FHWA) had concluded that, on average, more than 6.3 million road crashes were reported yearly in the United States where 21 % (1.5 million) were weather-related (Xing *et al.*, 2019).

Recognizing the significant impact of meteorological parameters on RTAs, researchers worldwide have begun to explore and further investigate this relationship. Research findings by Bergel-Hayat *et al.*, (2013) and Zou, Zhang & Cheng, (2021) demonstrated that weather was a significant factor contributing to the frequency and severity of road crashes and injuries. Another study conducted in the Seoul City had indicated that heavy rain was more likely to be associated with an increased level of accident severity (Lee *et al.*, 2018). Similarly, in China, a study conducted in Shenzhen

revealed 6.44 % and 0.68 % of registered RTAs from 2010 to 2016 were attributed to high temperature ($> 17\text{ }^{\circ}\text{C}$) and rainfall respectively (Zhan *et al.*, 2020). Adverse weather conditions can influence individual's decision to travel as well as their choice of travel modalities. Several studies had demonstrated that daily commuters were more likely to travel using private vehicle rather than public transport during inclement weather, exacerbating traffic congestion and increasing the risk of RTAs (Böcker, Dijst & Prillwitz, 2013; Wu & Liao, 2020). Exposure to air pollutants and rainfall could interfere with driver's visibility. Heavy rain in particular, reduces the friction between tires and road surface, whereas high temperatures influence drivers' cognitive function and mood, which may affect their driving or riding behaviour and performance (Mohd Jawi *et al.*, 2010; Jaroszweski, Chapman & Petts, 2013; Basagaña *et al.*, 2015; Zhai *et al.*, 2019).

Of particular concern, two-thirds of RTAs occurred among individuals in their most productive age, with men being three times more likely to be affected than women (Toroyan, 2009). This statistic is particularly alarming given that, even in contemporary society, it remains prevalent for male family members to serve as primary financial providers. The impact of RTAs extends beyond the immediate emotional and physical toll on families; it also places a significant strain on organizations due to costly management, absenteeism, and productivity loss (Abdul Kareem, 2003). Furthermore, RTAs have also emerged as a leading cause of death and disability-adjusted life years (DALYs) among the working population, with a significant proportion occurring during work commuting (WHO, 2018; Vos *et al.*, 2020). This is attributed to the fact that the majority of workers commute by road on a daily basis, either to or from work, as well as travelling during working hours (Rusli, 2014; Gariazzo *et al.*, 2021). Compared to the general population, the working

population has less flexibility in their work schedules and must commute regardless of weather conditions. Workers whose driving is an integral part of their occupation are particularly vulnerable to RTAs, as their time spent on the road also increases. In Malaysia, the total number of commuting accidents reported to Social Security Organization (SOCSO) has demonstrated a consistent increase over the past decades. The annual accident rate increased from 45 to 53 cases per 10,000 employees between 2015 and 2019, where 85 % of these incidents occurring during peaks hours when people typically travel to and from work while the remaining 15 % of accidents taking place during working hours (SOCSO, 2019).

Furthermore, in a global comparison of health burden related to RTAs across continents, it was found that over 75 % of associated fatalities and injuries occurred in major cities of upper and lower middle-income, the same region which undergoing the most rapid pace of urbanization (Toroyan, 2009). The emergence of major urban centres, a consequence of urbanization, has witnessed rapid growth of urban populations, concurrent with the expansion of road networks, motorization and employment opportunities (Cabrera-Arnau, Prieto Curiel & Bishop, 2020). Urban employment offers financial stability, enabling increased urban residents' spending, including the purchase of vehicles. In Malaysia, one of the most urbanized nations in Southeast Asia, vehicle ownership and registration have seen a steady rise over the past decade, with an annual average of one million new vehicles (Sadali, 2020). A 2021 announcement by Malaysia's Minister of Transportation revealed a 3.8 % increase in registered vehicles and a 2.86 % rise in registered drivers between 2019 and 2020 (Majid, 2021). The number of motor vehicles globally increased from 0.85 billion in 2000 to 2.1 billion in 2016 leading to increased exposure to traffic accidents, particularly during work commuting (Majid, 2021). In Malaysia, prior to COVID-19

pandemic, the number of RTAs were steadily increased over the past two decades, as reported by Department of Statistic (DOSM), where Kuala Lumpur, Johor, Selangor, and Penang, the most urbanized states in Malaysia, leading in accident rates (DOSM, 2023). Consistently, the number of occupational accidents reported to Department of Occupational Safety and Health (DOSH) and the number of benefit recipients of SOCSO employment injury scheme (EIS) due to commuting accident were highest among employees working in these major cities (SOCSO, 2019; DOSH, 2021).

Interesting, major cities were also identified as key contributors to climate change, as urban activities such as transportation and industrialization are primary sources of greenhouse gas (GHG) emissions. Estimates suggested that cities were responsible for 75 % of global carbon dioxide emissions, which lead to rising global temperatures, causing sea levels to rise and increased in the number of extreme weather events such as heavy rainfall, heatwaves, floods, droughts and storms (J.Young, 2015; Seneviratne *et al.*, 2021)

1.2 Problem Statement

In recent years, it has become increasingly evident that the meteorological parameters, particularly, temperature and rainfall, may have a significant impact on RTAs, with the urban workers being particularly vulnerable and disproportionately affected. Accelerated urbanization produces substantial emissions of GHG, a precursor of climate change, leading to unpredictable and extreme weathers such as heavy rainfall, storm, and flood. It is also closely linked to the phenomenon of urban heat island (UHI), causing major cities to be warmer compared to the surrounding suburban and rural areas. Urbanization also provides more job opportunities, which contributes to population growth, leading to a rapid rise in traffic volumes as people need to commute from one location to another, particularly during work commuting.

The combination of these factors is therefore increasing their exposure to RTAs. Furthermore, the disruptive economy, which is predominantly concentrated in major cities, causes a new paradigm shift to gig economy, contributing up to 31 % growth of e-hailing and delivery services in Malaysia, surpassing the growth of conventional workforce (DOSM, 2020). This phenomenon has consequently augmented the current statistics on commuting accident, warranting significant public health concern. Considering the steady increased in the number of commuting accidents reported to SOCSO despite an improvement in occupational safety and health (OSH) and gradual decrease of industrial accident in Malaysia, commuting accident was therefore included not only in the 12th Malaysia Plan for Health Research Priorities (MP-HRP) but also in Occupational Safety and Health Malaysian Plan 2021-2025 (OSHMP 25).

1.3 Rationale of Study

A review of the existing literatures on commuting accident, particularly in a local context, revealed a significant gap in research evidence, which justifies the need for further exploration on the potential impact of meteorological parameters. Majority of previous local studies were conducted primarily in domains related to human factors, vehicle characteristics, road conditions and post-crash management, reflecting the currently available interventions that were formulated mostly to address issues within these four domains. For instance, Malaysian guidelines on road safety and safe commuting did not adequately emphasize the importance of weather or meteorological parameters and their relevant preventative measures, despite their significant influence on driving performance, vehicle function, road conditions, which may ultimately magnify the risk of commuting accidents (Sukor *et al.*, 2018; Zou, Zhang & Cheng, 2021).

Conversely, the limited available studies investigating the impact of meteorological parameters predominantly utilized subjective measures such as police report or self-reported questionnaires, which are susceptible to recall biases. Therefore, a more objective measure based on temporally aggregated data such as time-series data is required to provide a better understanding of the relationship between meteorological parameters and commuting accident which is crucial for facilitating more realistic, quantitative, and evidence-based policies. For instance, in OSH, policies such as teleworking which had been imposed during COVID-19 pandemic to reduce the spread of the SARS-CoV-2 virus, were also demonstrated to decrease the occurrence of commuting accident (Giovanis, 2018; ILO & WHO, 2021). Therefore, similar approaches should be considered and adopted more extensively by organizations or employers to mitigate the impact of meteorological parameters on commuting accident among their employees especially during adverse weather conditions. For transportation and urban planning sector, findings from this study could provide a foundation for improving public transport services and accessibility during inclement weather. Most importantly, incorporating meteorological factors in national policy is essential for strengthening preparedness and adaptability of urban workers toward the impact of extreme weather resulting from climate change. Concurrently, this approach allows for the evaluation of risks and vulnerabilities, which aligns with the 12th MP-HRP on climate change. This study also echoes with the International Labour Organization (ILO) agenda of “Decent work for all” and sustainable developmental goal (SDG), target 3.6 to reduce RTA by half in 2030.

1.4 Research Question

This study was conducted in two parts:

For part 1, the study outcome was the number of RTAs among the working population.

1. What are the trends and characteristics of meteorological parameters and RTAs in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019?
2. How different temporal factors influence the number of RTAs among the working population in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019?
3. What is the association between hourly meteorological parameters and RTAs among the working population in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019?

For part 2, the study outcome was the number of commuting accidents.

1. What is the association between daily meteorological parameters and commuting accident in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019?
2. What will be the projected incidence of commuting accidents in Johor Bahru and Kuala Lumpur for the next five years (2020-2024)?

1.5 Research Hypothesis

PART 1

1. There is a significant influence of different temporal factors on RTAs among the working population in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019.
2. There is a significant association between hourly meteorological parameters and RTAs among the working population in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019.

PART 2

1. There is a significant association between daily meteorological parameters and commuting accident in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019.
2. The incidence of commuting accident in Johor Bahru and Kuala Lumpur is projected to increase over the next five years (2020-2024).

1.6 Research Objectives

1.6.1 General Objective

To model the association between meteorological parameters on commuting accidents and to forecast its future incidence.

1.6.2 Specific Objectives

PART 1

1. To describe the trends and characteristics of meteorological parameters and RTAs among the working population in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019.
2. To examine the influence of different temporal factors on RTAs among the working population in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019.
3. To model the association between hourly meteorological parameters and RTAs among the working population in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019.

PART 2

1. To model the association between daily meteorological parameters and commuting accident in Johor Bahru and Kuala Lumpur from 1 January 2015 until 31 December 2019.
2. To forecast the incidence of commuting accident in Johor Bahru and Kuala Lumpur for the next five years (2020-2024).

CHAPTER 2 LITERATURE REVIEW

A review of existing literatures and knowledges on the impact of meteorological parameters on commuting accidents or road traffic accidents (RTAs) in general in both global and local context was conducted using search engine such as PubMed, Scopus, Science Direct, Taylor & Francis and Google Scholar. The search utilized the combination of key terms and appropriate truncation and wildcards parameter such as Boolean connector (AND or OR). The keywords used were road accident, commuting accident, work-related road accident, meteorological parameter, weather, rainfall, temperature, air pollutants, major city, and their respective medical subject heading (MeSH) terms. At the end of this section, the conceptual framework for this study is presented.

2.1 Meteorological parameters and atmospheric system

Meteorological parameters, including temperature, rainfall, humidity, wind, and solar radiation, constitute the components of the troposphere, the lowest layer of atmosphere (METMalaysia, 2024). These parameters interact with each other within high or low air pressure system to define various weather patterns and climate conditions. The Earth's rotation, in conjunction with its uneven distribution of continents and ocean and the presence of mountain ranges, also serves as a significant driver of atmospheric interactions (Seneviratne *et al.*, 2021). Understanding these interactions and the functioning of the atmospheric system is crucial not only for meteorologist and climatologist but also for policymakers in developing strategies to mitigate the impact of extreme weather pattern and climate change. Weather refer to a short-term conditions of meteorological parameters, which are continuously changing and fluctuating, whereas climate is defined as atmospheric changes or average weather

conditions that occur over an extended period, typically every 30-year interval. (National Geographic, 2023).

The atmospheric cycle responsible for diverse weather phenomena encompass multiple processes. It starts with the solar radiation, a primary energy source, a driver for water cycle, heating the Earth's surface causing evaporation of the water surface and transpiration of vegetation, increasing the temperature and facilitating the upward movement of the water vapor through convection (Sung, 2017). As the less dense water vapour ascend from the ground, the air pressure, which varies with altitude decreases, as does the temperature. This phenomenon causes the water vapor to gradually expand and condense into tiny liquid water droplet until it can no longer retain its moisture content, resulting in cloud formation and rainfall (Sung, 2017). Clear skies and stable weather conditions are often associated with high-pressure systems, whereas low-pressure system typically bring cloud cover and rainfall (UCAR Scied, 2024). Conversely, temperature gradient that induce changes in the air pressure also drive air movement from high pressure to low-pressure area, a phenomena refer to as wind (Alketbi, 2023).

Malaysia, a country surrounded by extensive bodies of water and situated at the equator, receives a direct solar radiation at the 90° angle, resulting in a surplus of heat for approximately 12 hours a day, enabling warm air to expand and retain substantial water content for a an extended period (World Bank Group, 2021). However, as previously described, as the air rises and cools, it can no longer maintain this moisture, resulting in a significant rainfall. This phenomenon exemplifies the tropical rainforest climate in Malaysia, which is characterized by hot and humid conditions with abundant rainfall throughout the year. However, due to the sunlight at the equator concentrated in a small area, weather in Malaysia does not vary

significantly. The annual average, maximum and minimum temperature in Malaysia are approximately 26.9°C , 32.0°C and 23.6°C respectively (METMalaysia, 2022). Over the past 40 year, the average daily temperature in Malaysia has demonstrated an increasing trend with 2016 appearing to be the warmest year, showing anomalies of 0.95°C and 0.84°C compared to the national and world average temperatures, respectively (METMalaysia, 2020). This phenomenon results from the impact of El Nino, a climate pattern of unusual warming of the water surface in the eastern equatorial Pacific ocean (METMalaysia, 2024; WMO, 2024). Regarding rainfall, its distribution is primarily influenced by Southwest (SW) and Northeast (NE) monsoons, with the former bringing less rainfall and more drier compared to the latter (Syafriana, Norzaida & Noor Shazwani, 2018; Muhammad, Abdullah & Julien, 2020; World Bank Group, 2021; METMalaysia, 2022; Vincent & Yusoff, 2022). In average, a total annual rainfall in Malaysia is ranging between 1500 mm to 4600 mm, constituted approximately 150 to 200 rainy days per year, with Sarawak and Selangor received the highest rainfall in 2019 (METMalaysia, 2020; Muhammad, Abdullah & Julien, 2020). Although Malaysia typically experiences predictable weather patterns, it has not been immunized to the global phenomenon of climate change which resulted in the rise of frequency and intensity of extreme weather events. For instance, in October 2017, a tropical depression (*Lekukan Tropika*) caused constant rain in Kelantan and Terengganu followed by continuous heavy rain in Penang and Kedah (METMalaysia, 2017).

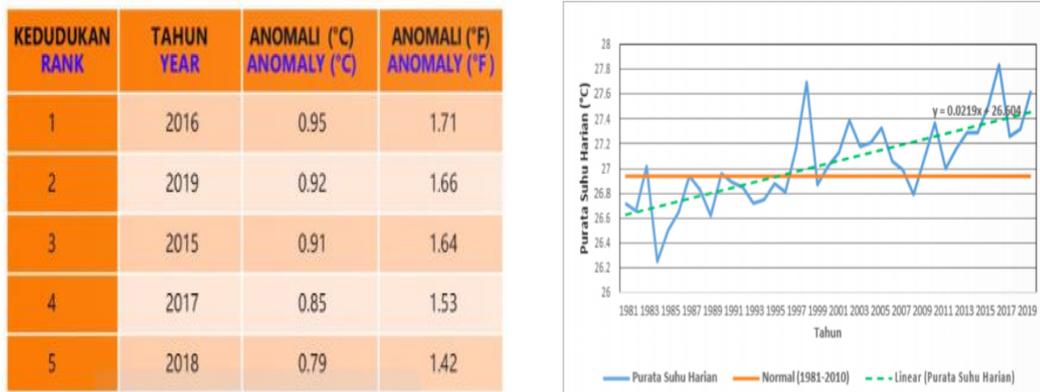


Figure 2.1: Annual rank of temperature anomaly (left) and average daily temperature compared to period of 1980-2010 (right) in Malaysia

(Source: Malaysia Meteorology Department, 2020)

2.2 Meteorological parameters and major city

In addition to understanding how meteorological parameters interact within the atmospheric system to produce various weather conditions, it is essential to identify and analyse factors that can influence the trends and patterns of meteorological parameters or weather conditions, particularly those related to anthropogenic activities. Compared to naturogenic factors, anthropogenic factors are more amenable to management through controls measures such as regulations and voluntary initiatives. Anthropogenic activities are most pronounced in major cities as a consequence of increasing urbanization and rapid industrialization. Urbanization increased populations density as well as their associated activities, leading to increased reliance on fossil fuel needed for energy consumption, such as heightened demand for electricity generation, heating and cooling of buildings, and transportation of goods and people (Mansour *et al.*, 2022; US EPA, 2023). Transportation and industrialization that characterize modern urban centres not only lead to a surge in energy consumption but also serve as a major point and mobile sources for greenhouse gases (GHGs) emissions (Ha, Asada & Arimura, 2019; Kuddus, Tynan & McBryde, 2020). Increases

in GHGs such as carbon dioxide and methane causes the trapping of heat in the atmosphere and inhibit heat escape especially at night, leading to the urban heat island (UHI) phenomenon (Mansour *et al.*, 2022). This phenomenon causes cities or urban centres to experience a distinctive microclimate that is warmer than surrounding environments.

The migration of human populations from rural to urban areas also results in deforestation, which can decrease vegetation shading, evapotranspiration and carbon sequestration. The construction and concentration of buildings and other infrastructures required for housing, business and services activities, serves as impermeable surfaces that absorb and retain heat and block the wind (Mughal *et al.*, 2019; Qian *et al.*, 2022). The utilization of materials with high heat capacity, such as asphalt and concrete, for road construction, contribute to the accumulation of thermal energy during the day and its gradual release at night, leading to prolonged period of elevated temperature in major cities (Shafaghat *et al.*, 2016). In addition to UHI, the urban rain island phenomena has also garnered interest among researchers to investigate its relationship with urbanization. A study conducted in China demonstrated that the urban rain island, measured by monthly rainfall or precipitation was more pronounced during accelerated urbanization (2010-2019) compared to the period of slow urbanization (1960-1969) (Luo *et al.*, 2022). The study also highlighted the difference between urban and suburban area when comparisons were made during the same period. More urbanized areas, such as region in the southeast coast of China, received approximately 800 mm to 2000 mm precipitation annually, compared to less urbanized areas such as Xinjiang and Qinghai, which receive annual rainfall between 0 mm to 400 mm annually. The increased precipitation in urbanized regions was attributed to the urban heat island effect and increased artificial water dissipation

despite reduction in vegetation secondary to deforestation. Examples of artificial water dissipation include building water dissipation, artificial irrigation, and road sprinkling (Luo *et al.*, 2022). A similar study conducted in Yangtze River Delta Region in China also demonstrated consistent findings regarding the impact of UHI and pollutant aerosol in increasing the frequency and intensity of rainfall by altering air circulation and serving as condensation nuclei, facilitating the cloud formation in major cities especially during summer (Zhong *et al.*, 2017). Of greater concern, the changes in rainfall pattern, coupled with impervious surfaces that overwhelm the drainage system, lead to frequent urban flooding as stormwater management is implicated, heightening road congestion and increasing the risk of RTAs further (Zhang *et al.*, 2014; Liu & Niyogi, 2019).

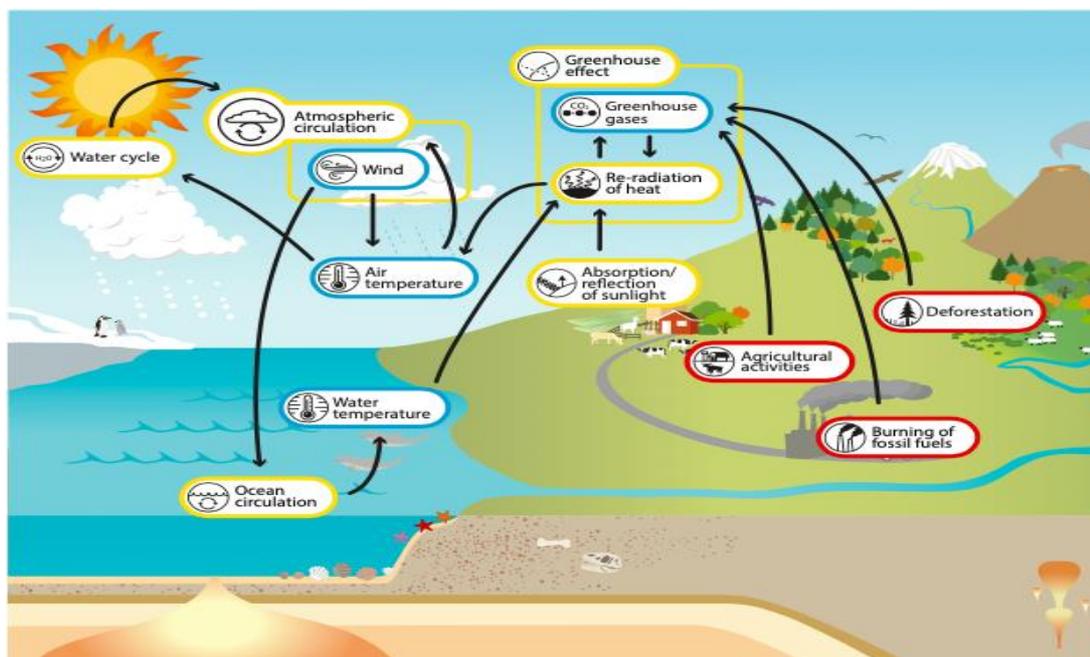


Figure 2.2: Atmospheric system and circulation

Source: <https://ugc.berkeley.edu/background-content/atmospheric-circulation/>

2.3 Commuting and road traffic accidents

Commuting, in general, is defined as a regular activity of travelling back and forth from one place to another whereas accident is an unplanned or unforeseen event

or circumstances (Merriam-Webster, 2022). Commuting accidents which constitutes a subset of RTAs, currently receive insufficient attention. This oversight is concerning as it indicates a gap in transportation safety and occupational safety and health research, as it specifically involving vulnerable group of working population. According to ILO, commuting accident is defined as an accident resulting in death or personal injury occurring on the direct way between the place of work and: i) the worker's principal or secondary residence; or ii) the place where the worker usually takes a meal; or iii) the place where the worker usually receives his or her remuneration (ILO & WHO, 2021). This definition has served as a standard definition and basis for reporting, which was subsequently adopted by state members and adapted according to their local suitability. Consequently, there appeared to be some degree of variation between and within countries on how commuting accident are defined. For instance, for the legal purpose of notification and reporting of occupational injuries, in many countries, commuting accidents are only subjected to incidents that occur during or related to work activities, unlike the definition used for the purpose of work compensation claims, which is more comprehensive and includes all elements proposed by ILO.

In Malaysia, under Section 24 (1) Employee's Social Security Act (ESSA) 1969 or Act 4, which is administered by Social Security Organization (SOCSO), commuting accident or 'accident while travelling' is defined in a manner similar to scenarios outlined by ILO, with additional scope encompassing journeys made for any reasons directly connected to employment. This definition has also been adopted by Ex-Gratia scheme for work disaster, another worker's compensation scheme in Malaysia offered exclusively to government workers (MOF, 2024). In addition to that, all employers in Malaysia are legally obligated to notify any occupational accidents

involving their workers to the Department of Occupational, Safety and Health (DOSH) using a specific form known as *Jabatan Keselamatan dan Kesihatan Pekerja (JKKP)* 6, as stipulated in Notification of Accident, Dangerous Occurrence, Occupational Poisoning and Occupational Disease (NADOPOD) Regulation 2004, which is part of Occupational Safety and Health Act (OSHA) 1994. However, this regulatory structure lacks a precise definition or description of commuting accidents. This absence of clarity explains the stance taken by DOSH in the Occupational Safety and Health Malaysian Plan 2025 (OSHMP 25), which explicitly emphasizes that commuting accident occurring during journeys from worker's place of residence to or from their workplace do not fall within their jurisdiction. Consequently, corresponding data were not captured or monitored by their department (DOSH, 2021).

The paucity of existing literatures exploring evidence related to commuting accidents may be attributed to data availability and accessibility, as well as the diverse definitions adopted by different countries as previously mentioned. This scarcity presents challenges for comparative analysis, resulting in a substantial reliance on studies conducted on RTAs. On a global scale, RTAs have emerged as a leading cause of mortality and disability-adjusted life years (DALYs) among the working population, where substantial proportion of the accident happened while travelling to and from work or during work activities (Concha-Barrientos *et al.*, 2005; WHO, 2018; Gariazzo *et al.*, 2021). Regarding work-related road traffic accidents, despite a steady decrease in the fatality rate from 1990 to 2016, significant disparities between higher income (HI) and lower-middle income countries (LMIC) persist, necessitating multifaceted interventions to address this incongruity (WHO, 2018). As of 2016, the estimated fatality rate among workers aged 15 to 49 years in HIC was 2.1 per 100 000 workers compared to 4.2 per 100 000 for LMIC (Wu, Schwebel & Hu, 2018). In

Malaysia, commuting accident reported to SOCSO have demonstrated a gradual increase in the annual rate from 45 per 10, 000 workers in 2015 to 55 per 10, 000 in 2019 (SOCSO, 2019). Notably, more than 85 % of these accidents occurred during travel to or from the workplace, with the majority taking place within 10-12 km from the workplace, during peak hours, among male workers, and working in a morning shift (Nurulhuda Jamaluddin *et al.*, 2015; Harun Bakar, 2018; Yaacob *et al.*, 2018). From an economic perspective, the ILO in 2005 estimated that the total cost attributed to occupational injuries and diseases may reach up to 4 % of countries' gross domestic product (GDP), especially in LMIC (ILO, 2015).

2.4 Temporality of commuting and road traffic accidents

As data on RTAs become increasingly digitized, their accessibility has improved. One of the primary aspects of RTAs data that is routinely captured is a temporal component. This facilitated the analysis of the temporal aspect of RTAs, a domain that is closely interconnected with other aspects of RTAs including human behaviour, environmental conditions and societal pattern. Despite the scarcity of evidence related to commuting accidents compared to existing literature in RTAs, findings from the latter are, in fact consistent and support the common temporal pattern that characterize commuting accidents. The available evidence on the relationship between RTAs and temporal factors, however, was inconclusive. When looking specifically into the link between time or hour of the day and RTAs, many past studies concurred with the significant association established between these variables (Sukhai *et al.*, 2011; Jamaluddin, Jen Sim & Shabadin, 2013; Junus *et al.*, 2017; Selamat & Surlenty, 2017; Odusola *et al.*, 2023).

Morning and evening peak hours on weekdays, which typically coincides with work commuting activities, are often associated with significant crash rates due to

combination of heightened traffic volume, pressure to arrive at work or return home promptly, work-related fatigue leading to aggressive driving behaviour and violation of traffic regulations (Sukhai *et al.*, 2011; Morris & Hirsch, 2016; Emmanuel Munch, 2023; Eriksson, Winslott Hiselius & Lidestam, 2023). Late-night incidents were also posited to increase the risk of RTAs, attributed to leisure and post-work social activities involving alcohol consumption (Nistal-Nuño, 2018; Weast, 2018; Tang *et al.*, 2020; Macioszek & Kurek, 2021). This is most pronounced during weekend and on Friday as individuals commence their weekend activities earlier. Moreover, according to J.Pahukula *et al.*, (2015), workers who work outside standard or normal shift were also found to exhibit a higher risk of RTAs particularly those who completed their shift late at night or early in the morning. Fatigue, sleepiness, and darkness due to inadequate lighting were hypothesized to contribute to the increased risk of RTAs during these hours (Pahukula, Hernandez & Unnikrishnan, 2015; Camden *et al.*, 2020).

Public holidays or special event such as religious celebration often involved long distance travel which can cause spikes in RTAs especially at the highway and rural or suburban area due to unfamiliar road and fatigue from long journey. However, Wiratama *et al.*, (2021) and Tang *et al.*, (2020) contend that similar risk can be observed in urban area due to high-risk behaviour among drivers and heavy traffic. On the other hand, for countries that experience extreme weather patterns, seasonal variation also play a role in contributing to hazardous driving condition. For instance, during winter, road traction reduced due to icy road and visibility was compromised especially during snowstorm (Kim, Jung & Yoon, 2021; Tobin *et al.*, 2022).

2.5 Commuting accident (road traffic accidents) and meteorological parameters

Numerous studies worldwide have observed a significant impact of exposure to meteorological parameters on the incidence of frequency of RTAs. However, it is challenging to find studies specifically investigating its impact on commuting accidents. Consequently, studies on RTAs were predominantly presented in this section. Furthermore, although meteorological parameters comprise of at least five components (i.e., temperature, rainfall, humidity, wind, and solar radiation) as described earlier, the subsequent review will focus only on temperature and rainfall which emerges repeatedly throughout the literatures and constituted meteorological factors of interest for this study.

2.5.1 Rainfall

Review of existing literatures that explored the impact or relationship between rainfall and RTAs predominantly utilised data gathered either from nearest meteorological stations or using radar or any type of gridded rainfall data, with the latter postulated to offer superior representation of the selected study area (Jaroszweski & McNamara, 2014; Silva *et al.*, 2022). The primary concern associated with utilizing data from weather or meteorological station was the issue of missing data and the location of the station, which is typically established at the airport compound, usually far away from the centre where people are mostly concentrated (Black, Villarini & Mote, 2017). Notwithstanding variations in data collection methodologies, the majority of studies exhibited similarities in their analysis of rainfall in relation to its impact on RTAs. Most investigations converted the original continuous rainfall data into categorical data prior to comparing its effect on RTAs to time-intervals of no rain or performing analysis individually for each rainfall category (Bergel-Hayat *et al.*,

2013; Rusli *et al.*, 2017; Lee *et al.*, 2018; Xing *et al.*, 2019; Zhan *et al.*, 2020). This approach was predominantly employed to address the presence of outliers or extreme rainfall values.

Researchers have identified two primary mechanisms hypothesized to contribute to the detrimental effect of rainfall on RTAs. These mechanisms comprise the reduction in drivers' visibility and the decreased in vehicle traction and tyre grip (Keay & Simmonds, 2006; Spitzhüttl *et al.*, 2020; Sangkharat *et al.*, 2021). Heavy rainfall, in particular, can significantly impair visibility, thereby limiting driver's capacity to detect lights and signal or to react and anticipate changes in traffic pattern or road condition such as obscuring road markings, presence of manhole or potholes (Mohd Hafzi *et al.*, 2010; Rusli *et al.*, 2017). Rainfall can also make it more challenging for drivers to judge a distance and creating reflections that diminish a driver's sense of orientation. The loss of vehicle traction is attributed to hydroplaning, a phenomenon that occurs when a layer of rainwater accumulates between vehicle's tires and the road surface, thus compromising the driver's ability to control their vehicle (Bergel-Hayat *et al.*, 2013; Jaroszweski, Chapman & Petts, 2013; Xing *et al.*, 2019).

This was evident in study conducted in six states of United States of America that reported a significant positive linear association between rainfall and RTAs (Black, Villarini & Mote, 2017). There were also, however, studies that partially consistent with this finding. A study conducted in Thailand which employed a six-year time series analysis comparing the daily impact of different levels of rainfall on ambulance dispatch due to RTAs between two regions, the Northern and Southern province, found that the rain group of 10-20mm/day have the highest pooled estimated relative risk (RR) of 1.052, (95% CI: 1.026–1.079) and 1.062 (95% CI: 1.043–1.082)

respectively, while unexpectedly, heavy rain with more than 20 mm/day reported an opposite impact (Sangkharat *et al.*, 2021). It was hypothesized that drivers were more likely to adopt a more cautious behaviour as the rain intensity increased. This was supported by Xing *et al.* (2019) who conducted a study in Hong Kong, investigating an hourly non-linear and lag impact of several meteorological parameters on different outcome of RTAs which showed the immediate effect of rainfall (lag 0) on the road crash incidence is significant for all levels of rainfall intensity, except for 0–0.5 mm/h. Specifically, the maximum RR of rainfall (lag 0) was 1.19 (95% CI: 1.04–1.35), 1.36 (95% CI: 1.20–1.55), 1.34 (95% CI: 1.16, 1.55) respectively for rainfall of 0.5–2.0 mm/h, 2.0–5.0 mm/h and over 5.0 mm/h. However, the cumulative effect peaked at 2.5 mm/h, and then decreased when rainfall intensity further increased (Xing *et al.*, 2019). Despite all studies experiencing quite similar climate of tropical and subtropical regions, the inconsistencies in findings could be attributed to the difference in study timelines. The two latter studies involved data collection for the entire years, while the duration of study by Black *et al.* (2017) was restricted to period of winter precipitation. Studies that incorporating the lag effect of rainfall on RTAs generally observed a decreased in effect as the lag increased (Lobo *et al.*, 2019; Xing *et al.*, 2019; Zhan *et al.*, 2020). This trend may be attributed not only by drivers modifying their behaviour to exercise greater caution but also to changes in road conditions, which become clean and less hazardous after accumulation of oil and debris during rainfall (Lobo *et al.*, 2019). Zhan *et al.* (2020) provide additional support for this findings, demonstrating that the delayed effect of rainfall persisted longer in colder seasons compared to warmer ones. This differences is attributable to the accelerated evaporation in warmer weather, which reduces road surface slipperiness and rapidly restored the essential friction between tires and road surfaces (Zhan *et al.*, 2020).

Locally published studies identified a mixed effect of rainfall on RTAs. A structural time series (STS) modelling utilized the national data of 13 years (2001-2013) obtained from Royal Malaysia Police (RMP) Computerized Accident Reporting System (CARS) found that monthly rainfall had a significant impact on the number of RTAs; however, when analysis was stratified into three different regions (Southern, Central and East Coast), the association was found to be significant only for the Central region. A study focusing on single-vehicle crash along four rural mountainous highway in Sabah revealed that for every 1% increase in average hourly rainfall will increase the risk of crash by 0.06% (Rusli *et al.*, 2017). Another study specifically examining the impact of rainfall on motorcycle fatal crash for three years (2010-2012) has found no association between these two parameters (Abdul Manan *et al.*, 2018).

2.5.2 Temperature

Studies investigating the relationship between exposure to temperature and RTAs or commuting accident, frequently employ measures such as mean, maximum or minimum temperature or combination of two or more of those parameters. Some studies however, further added categorical variables comparing heatwave and non-heatwaves day to illustrated the impact of temperature on RTAs (Basagaña *et al.*, 2015). Utilizing 12-years RTAs data during warm season in Catalonia Spain, Basagana *et al.*, (2015) found that the estimated crashes risk was increased significantly by 2.9% (95% CI 0.7%, 5.1%) during heat wave days. Further analysis demonstrated a stronger association (7.7%, 95% CI: 1.2%, 14.6%) between temperature and RTAs when the crashes were limited to driver performance-associated factors where for each 1°C increase in maximum temperature, the estimated RR of crashes increased significantly by 1.1% (95% CI: 0.1%, 2.1%).

Over time, building upon existing literatures, recent studies have expanded the investigation to include the lag effect and potential non-linear association between temperature and RTAs. A study utilizing a combination of time-stratified case-cross over design and distributed lag non-linear model conducted in Hong Kong demonstrated that the maximum RR of extreme hot weather (33 °C) was at lag 0 with RR of 1.11 (95% CI: 0.96–1.30) and for extreme cold weather (12°C) was at lag 5 is 1.14 (95% CI: 1.03–1.26) respectively (Xing *et al.*, 2019). Employing the same statistical analysis and high resolution of hourly data, Zhan et al. (2020) revealed a J-shaped curve of association between hourly temperature and RTAs in Shenzhen, China. The study further elucidated the findings using a threshold of temperature above 17°C, in which for 1°C increase in temperature, hourly RTAs casualties were increased by 0.87% (95% CI: 0.52%-1.22%). When stratifying into different factors, peak hours (8.30%, 95% CI: 4.26–12.66%) and warm season (10.64%, 95% CI: 4.33–15.96%) demonstrated higher attribution to RTAs.

When a similar study was conducted in the same country (China) but with different climatic conditions characterized by a much wider temperature range, using less disaggregated data (daily interval), a U-shaped curve of association between daily temperature and RTAs was observed, reflecting the strongest effect identified at both low and high temperature, while the lowest effect was at median or mean temperature (Li *et al.*, 2024). Examining another study conducted in a more distant region comparing the impact of temperature on RTAs in two different groups in Italy; general indistinct population and work-related victims revealed that the former group demonstrated a positive association with high temperature (RR=1.12, 95 % CI: 1.09–1.16) and a protective effect was observed for cold temperature (RR = 0.93, 95 % CI: 0.91–0.96). For work-related crashes, a positive association was found for both hot