INTEGRATED DISASTER RISK INDEX MODEL FOR THE MALAYSIAN LOCAL ASSESSMENT

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Malaysia is considered a high-risk country on a global level due to the increasing number of natural disasters in recent years. Considering the increasing impact of natural disasters, implementing a local disaster risk assessment would improve the understanding and identification of potential disaster risks that could affect social system, the economy, and numerous institutions. Understanding and evaluating integrated disaster risk must consider multi-hazard and multidimensional vulnerability at the local level, particularly in developing nations like Malaysia. This primary gap has never been recorded in earlier research, and the purpose of this work is to close the gap. Therefore, this study developed an integrated disaster risk assessment index (IDRI) model to measure disaster risk within local administrative boundaries in Malaysia. The emphasis of this thesis is to assist decision makers in identifying high-risk areas that are exposed to natural disasters by considering local vulnerability factors. The proposed index model could enhance government disaster risk reduction measures by implementing an (IDRI) model and guiding decision maker on how to properly evaluate and analyse risk for mitigation, preparedness, and planning. The index was developed by expanding on the multi-hazard spatial overlapping and Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) theoretical framework. In this study, the multi-hazard spatial overlapping combined two common hazards in Malaysia which are floods and landslides. This study used a quantitatively structured questionnaire survey to choose relevant IDRI model indicators based on expert opinion. The multidimensional vulnerability index (MDVI) model was developed using a combination of expert opinion and Principal Component Analysis (PCA). The IDRI map was created using Catastrophe Theory and Geographical Information Analysis (GIS) analysis. Based on the expert interviews, the study revealed that multidimensional vulnerability encompasses six dimensions, which in turn comprise 16 subdimensions and 54 indicators. This approach was applied in three urban districts of Selangor, Malaysia: Sepang, Kuala Langat, and Hulu Langat, which are located within the Langat River catchment and consist of 17 subdistricts. The spatial vulnerability assessment was conducted to classify vulnerability and risk in the study areas. The map produced five vulnerability categories (very low, low, medium, high and very high). The findings indicate that of the total vulnerability areas in the study, 7% were in the very high class, 12.6% were in the high class, 25.7% were in the medium class, 34.7% were in the low class and 20% were in the very low class. Overall, 32.9% of the total study area was found to be at risk, with 4.3% in the very high-risk area. Based on the Receiving Operating Characteristics (ROC) validation, the integrated disaster risk index model accuracy was 0.888, suggesting that the proposed model is good for evaluating risk. In comparison with the latest flood events in 2021, the IDRI components were highly correlated with disaster impact. In conclusion, the contribution of this study provides a novel perspective on disaster risk assessment by addressing several types of hazards and multidimensional vulnerability, as compared to the previous study focusing on a single hazard and a physical vulnerability factor. The model produced in this study will help governments at local levels to develop better strategies for disaster risk reduction practices and policies.

ABSTRAK

Malaysia dianggap sebagai negara berisiko tinggi di peringkat global berikutan peningkatan jumlah bencana alam dalam beberapa tahun kebelakangan ini. Memandangkan peningkatan kesan bencana alam, melaksanakan penilaian risiko bencana tempatan akan meningkatkan pemahaman dan pengenalpastian potensi risiko bencana yang boleh menjejaskan sistem sosial, ekonomi dan banyak institusi. Memahami dan menilai risiko bencana bersepadu mesti mempertimbangkan pelbagai bahaya dan kerentanan pelbagai dimensi di peringkat tempatan, terutamanya di negara membangun seperti Malaysia. Jurang utama ini tidak pernah direkodkan dalam penyelidikan terdahulu, dan tujuan kerja ini adalah untuk menutup jurang tersebut. Oleh itu, kajian ini membangunkan model indeks penilaian risiko bencana bersepadu (IDRI) untuk mengukur risiko bencana dalam sempadan pentadbiran tempatan di Malaysia. Tesis ini menekankan untuk membantu pembuat keputusan dalam mengenal pasti kawasan berisiko tinggi yang terdedah kepada bencana alam dengan mengambil kira faktor kelemahan setempat. Indeks ini dibangunkan dengan mengembangkan rangka kerja teoritis bertindih spatial berbilang bahaya dan Kaedah untuk Penambahbaikan Penilaian Kerentanan di Eropah (MOVE). Dalam kajian ini, pertindihan ruang berbilang bahaya menggabungkan dua bahaya biasa di Malaysia iaitu banjir dan tanah runtuh. Kajian ini menggunakan tinjauan soal selidik berstruktur kuantitatif untuk memilih penunjuk model IDRI yang berkaitan berdasarkan pendapat pakar. Model indeks kerentanan pelbagai dimensi (MDVI) dibangunkan menggunakan gabungan pendapat pakar dan analisis komponen utama (PCA). Peta IDRI telah dibuat menggunakan teori *Catastrophe* dan analisis Sistem Maklumat Geografi (GIS). Berdasarkan temubual pakar, kajian ini mengemukakan bahawa kerentanan multidimensi meliputi enam dimensi, yang pada seterusnya terdiri daripada 16 subdimensi dan 54 petunjuk. Pendekatan ini telah digunakan di tiga daerah bandar di Selangor, Malaysia: Sepang, Kuala Langat, dan Hulu Langat, yang terletak di dalam tadahan Sungai Langat dan terdiri daripada 17 mukim. Penilaian kerentanan kawasan telah dijalankan bagi mengelaskan kerentanan dan risiko di kawasan kajian. Peta menghasilkan lima kategori kerentanan (sangat rendah, rendah, sederhana, tinggi dan sangat tinggi). Penemuan menunjukkan bahawa daripada jumlah keseluruhan kawasan rentan dalam kajian, 7% berada dalam kelas yang sangat tinggi, 12.6% dalam kelas tinggi, 25.7% dalam kelas sederhana, 34.7% dalam kelas rendah dan 20% dalam kelas yang sangat rendah. Pada keseluruhannya, 32.9% daripada jumlah kawasan kajian didapati berisiko, dengan 4.3% berada di kawasan yang sangat berisiko tinggi. Berdasarkan pengesahihan ciri operasi penerima (ROC), ketepatan model indeks risiko bencana bersepadu ialah 0.888, menunjukkan bahawa model yang dicadangkan adalah baik untuk penilaian risiko. Perbandingan dengan kejadian banjir terkini pada tahun 2021, komponen IDRI sangat berkorelasi dengan kesan bencana. Kesimpulannya, sumbangan kajian ini memberikan perspektif baru tentang penilaian risiko bencana dengan menangani beberapa jenis bahaya dan kerentanan berbilang dimensi, berbanding dengan kajian terdahulu yang memfokuskan pada bahaya tunggal dan faktor kerentanan fizikal. Model yang dihasilkan dalam kajian ini akan membantu kerajaan di peringkat tempatan untuk membangunkan strategi yang lebih baik untuk amalan dan dasar pengurangan risiko bencana.

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LIST OF ABBREVIATIONS

AAD	-	Average Annual Damage
AJMC	-	Ampang Jaya Municipal Council
ANN	-	Artificial Neural Network
ARMONIA	-	Applied Multi-Risk Mapping of Natural Hazards for Impact Assessment
ASEAN	-	The Association of Southeast Asian Nations
AUC	-	Area Under Curve
CCA	-	Climate Change Adaptation
CEDMHA	-	Centre for Excellence in Disaster Management and Humanitarian Assistance
CREAM	-	Construction of Research Institute of Malaysia
CVI	-	Cultural Vulnerability Index
DID	-	Department of Irrigation and Drainage
DMGM	-	Department of Mineral and Geoscience Malaysia
DMRC	-	Disaster Management and Relief Committee
DOSM	-	Department of Statistics Malaysia
DRA	-	Disaster Risk Assessment
DRI	-	Disaster Risk Index
DRM	-	Disaster Risk Management
DRR	-	Disaster Risk Reduction
EM – DAT	-	Emergency Database
EnVI	-	Environmental Vulnerability Index
EVI	-	Economic Vulnerability Index
EWS	-	Early Warning System
FN	-	False Negative
FP	-	False Positive
FRDM	-	Fire Rescue Department Malaysia
GIS	-	Geographical Information System
HFA	-	Hyogo Framework Action
HLDO	-	Hulu Langat District Office

IDRA	-	Integrated Disaster Risk Assessment
IDRI	-	Integrated Disaster Risk Index
IEC	-	International Electrotechnical Committee
INFORM	-	Index of Risk Management
InVI	-	Institutional Vulnerability Index
IPCC	-	Intergovernmental Panel on Climate Change
ISO	-	International Organisation of Standardisation
KeTSA	-	Ministry of Energy and Natural Resources
KLDO	-	Kuala Langat District Office
KLMC	-	Kuala Langat Municipal Council
KMC	-	Kajang Municipal Council
KMO	-	Kaiser Mayer Olkin
MCDF	-	Malaysia Civil Defence Force
MCDM	-	Multi Criteria Decision Making
MDVA	-	Multidimensional Vulnerability Assessment
MDVI	-	Multidimensional Vulnerability Index
MHI	-	Multi-Hazard Index
MOBIDIC	-	Modello di Bilancio Idrologico Distribuito e Continuo
MOVE	-	Methods for the Improvement of Vulnerability Assessment in Europe
NADMA	-	National Disaster Management Agency
NGO	-	Non-Governmental Organisation
NSC	-	National Security Council
PCA	-	Principal Component Analysis
PLAN Malaysia	-	Department of Urban and Town Planning
PVI	-	Physical Vulnerability Index
PWD	-	Public Work Department
RMA	-	Royal Malaysia Army
RMP	-	Royal Malaysia Police
ROC	-	Receiving Operating Characteristics
RVA	-	Regional Risk and Vulnerability Assessment
SDMU	-	Selangor Disaster Management Unit

SDO	-	Sepang District Office
SMC	-	Sepang Municipal Office
SPSS	-	Statistical Products and Service Solution
SVI	-	Social Vulnerability Index
SWD	-	Social Welfare Department
TN	-	True Negative
TNR	-	True Negative Rate
TP	-	True Positive
TPR	-	True Positive Rate
UNDRO	-	United Nations Disaster Relief Organisation
UNDRR	-	United Nation Office for Disaster Risk Reduction
UNISDR	-	United Nation International Strategy for Disaster Reduction
USD	-	United States Dolar
WHO	-	World Health Organisation
WRI	-	World Risk Index

LIST OF SYMBOLS

%	-	Percentage
∑	-	Sum
m	-	Meter
RM	-	Ringgit Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Background of The Study

The term disaster is always integrated with the term natural hazard. A natural hazard is a natural phenomenon with a propensity to cause negative impacts on people and the environment (UNISDR, 2017). Based on a 2018 International Federation of the Red Cross report, two billion people have been affected by disasters over the last ten years, while the damage costs have been estimated at USD 1,658 billion (IFRC, 2018). Most of the natural hazards that occur in Malaysia are weather-related and they are generally flood events. Although Malaysia is considered less prone to disasters, it remains vulnerable to flooding, landslides and mudslides. After the major flood event on the East Coast of Peninsular Malaysia, the National Disaster Management Agency (NADMA) was established as a specialised focal point agency to conduct disaster risk management (DRM) and coordinate disaster risk reduction (DRR). The management of disaster risk in Malaysia is regulated under Directive No. 20 (Omar Chong & Kamarudin, 2018). As reported by the Department of Irrigation and Drainage (DID) in 2009, rapid urbanisation has caused 4.82 million people in Malaysia to be exposed to disaster risk (Zainol et al., 2018).

Disaster risk refers to the potential for and probability of the loss of life, assets, health and livelihoods that could occur in a society in the future (UNISDR, 2016). DRR, a main agenda in the Sendai Framework (2015-2030), has been encouraged at all levels, global, regional, national and local (Birkmann, 2005; Torres et al., 2021). One priority in the Sendai Framework is to gain a better understanding of all the components of risk, such as hazard characteristics, vulnerability, capacity and the environment at the local level (UNISDR, 2015). Therefore, to better understand all the components at a local level, the development of risk is often assessed. Effective risk assessment helps to have better knowledge and understanding of disaster management

(Aitkenhead et al., 2021). According to Muzamil et al. (2022), disaster management involves four phases: mitigation, preparedness, response and recovery. Risk assessment play a major role in all phase involves analysing the possibility of hazards and the potential impacts on exposed elements (people, buildings, the environment, society and the economy). Therefore, risk assessment is progressively considered as a practical tool for assessing natural hazards.

Disaster risk assessment consists of two components: hazard and vulnerability. However, the two important components of an integrated risk assessment are multi-hazard and multidimensional vulnerability, which consider more than one type of hazard, the exposure of sensitive targets and the time, depending on the vulnerability of the study area (De Angeli et al., 2022; Gallina et al., 2016). In recent decades, the global use of the integrated risk approach has been increasing, especially in the European region (IPCC, 2012). The multidimensional vulnerability indicators consider six dimensions: social, economic, cultural, institutional, physical and environmental (Kienberger et al., 2014). An integrated vulnerability approach can also be described as a hybrid approach that includes exposure to climate change as an internal component of vulnerability (Kim et al., 2021).

Measuring risk is an important aspect of disaster risk assessment. Identifying multidimensional indicators is an early step in measuring and quantifying risk in a specific location, and it concerns the ability to withstand and experience natural hazards (González et al., 2018). All approaches to measuring risk should be simple, understandable and relevant for DRR and emergency planning (Sadeghi-Pouya et al., 2017). Various models for assessing risk and vulnerability have been developed among the DRR and Climate Change Adaptation (CCA) communities (Birkmann & Welle, 2015). The most widely used method is a disaster risk index (DRI) approach.

The DRI approach is a semi - quantitative method that compares the area exposed to the hazard and its vulnerability to the natural hazard (Mengal et al., 2021; Peduzzi et al., 2009). The development of a DRI enables the monitoring of risk evolution. The evolution of the risk model describes vulnerability and the reasons why people facing the same exposure are at different levels of risk (Healey et al., 2022;

Peduzzi, 2006). Establishing a local-level DRI model can provide a helpful tool for identifying different levels of risk, hazard and vulnerability.

Establishing an integrated DRI model on a local scale may reference a standardised methodology to produce an integrated risk map suitable for a specific area. Integrated disaster risk maps that use DRIs for risk assessment are already widely employed at different levels (global, regional and local). Producing risk maps at a local scale provides a detailed risk assessment for local governments so they can understand the degrees of risk in their administrative regions (Peng, 2018).

A disaster risk map provides valuable information for disaster risk management. The main goal in mapping disaster risk is to provide information for decision makers. A spatial disaster risk assessment is a useful tool for specifying risk levels and important when devising a disaster management plan (Luu & von Meding, 2018). Thus, developing an integrated DRI model at the local level in Malaysia will help to measure and quantify risk. The risk measurement efficiency of a DRI would improve disaster management at the local level in Malaysia. On the other hand, the development of the model should also follow the priorities outlined in the Sendai Framework for increasing the local-level practice and understanding of DRR.

1.2 Statement of Research Problem

Malaysia is located in South-east Asia, geographically outside the Pacific Rim of Fire. Therefore, it is not exposed to the ravages and devastation caused by severe natural disasters. However, the country is vulnerable to natural hazards such as floods, tsunamis, landslides, storms, forest fires, seismic activity and haze. According to the World Risk Report 2021, Malaysia is considered a high-risk country and ranked 71st among 180 countries in terms of the risks it faces (Aleksandrova et al., 2022). In comparison, a previous report from 2012 regarded Malaysia as a medium-risk country, ranking it 91st (Alliance Development Works, 2012). The change in Malaysia's global risk classification is due to the increased hazard exposure in Malaysia, especially over the last decade. In the previous 20 years (1998 – 2018), Malaysia has experienced 37

major disaster hazard events (EM-DAT, 2021), that have affected three million people and caused damage worth USD 2 billion (CEDMHA, 2019). Given the increasing impact of natural disaster events, developing a national disaster risk assessment would enhance the understanding and identification of the potential hazard threats that may affect vulnerable elements of the social system, the economy and many institutions.

The disaster events that occurred in Malaysia in 2021 demonstrate the need for disaster risk assessments to gain a better understanding at the local level. The impact of climate change caused several extreme events that increased the exposure of the community, many organisations and the social system. Based on the 2021 disaster events, the impact of disasters increases when an area never previously exposed to disaster is hit by such an event. Therefore, the impact of disasters has increased over the years, causing more areas to become vulnerable. Rapid urbanisation and the increase in the impact of climate change have exposed vulnerable groups, the health system and institutions to the threat of potential hazards in the future (CEDMHA, 2019; A. A. Shah et al., 2020).

Understanding and formulating the risk of a natural hazard at the local level requires a wide range of aspects to be considered. Previous research has predominantly focused on models at the global level, leaving a gap in local-level models. Thus, utilizing global models for local applications is inadequate in terms of precision.This may be achieved by developing an integrated approach, through which an interdisciplinary view should be incorporated into risk assessment. Analysing, quantifying and visualising multidimensional vulnerabilities, authorities, decision makers and other stakeholders should enable the management and mitigation of existing and new risks. Only then may a complete and more holistic impression of the actual situation be obtained. Many countries have established their own national or local forms of risk assessment to analyse the hazards affecting the country and assess the possibility and impact of such events at the national or local levels (Lin, 2018).

The development of DRI has been encouraging at many different scales, global, regional, national and local. In recent decades, significant focus has been directed to the tools that attempt to measure an area's risk, vulnerability and resilience

to disaster. In Malaysia, disaster risk assessment practices focus on single hazard and damage assessment. Moreover, these models tend to concentrate primarily on the physical vulnerability factors and the associated damage that could result from a disaster event. Although a disaster-prone area may be effectively identified, there remains a lack of the appropriate measures needed to identify its vulnerability (Saharizan et al., 2018). Therefore, developing an integrated approach to DRI at the local level is needed to monitor more accurately the transformation of risk in a specific area.

Countries are not homogeneous, hence the need to consider local attributes when assessing disaster risk. Establishing a specific integrated risk approach can determine elements of vulnerability, such as social, economic, physical, cultural, environmental and institutional. This would also determine the resilience and ability of society or system to cope with and respond to natural hazards. Considering expert opinions and knowledge in the development of an IDRI would help to improve the risk assessment aspect of DRR policy. The development of the IDRI model assists agencies participating in DRM, such as NADMA, DID, and local governments, in enhancing their local disaster risk assessment efforts.

This research seeks to develop a holistic index-based approach model that is suitable for local, area-specific application in Malaysia. To quantify the risk posed by a natural hazard using all six dimensions of vulnerability, an integrated DRI model will be developed to suit the Malaysian conditions. Therefore, evaluating the integrated disaster risk index (IDRI) assessment in terms of people and society is key to reducing their risk of and vulnerability to disaster, as well as building disaster resilience among communities.

1.3 Research Question

The following research questions were expected to achieve the study's research objectives:

1. Based on historical events, which types of hazards occur in Malaysia and how frequently do they occur?
2. Which vulnerability indicators are highly important, based on expert opinion, for conducting risk assessment at the local level in Malaysia?
3. How can the different types of hazards that occur in the same spatial area be combined?
4. How can the integrated disaster risk index in the study area be calculated and determined?
5. Which method can be used to classify the indicators in the multidimensional vulnerability?
6. Is the index model proposed in this study efficient enough to be used to conduct integrated disaster risk assessment?

1.4 Aim and Objectives

This research aims to develop an integrated disaster risk index model toassist decision makers in identifying high-risk areas that are exposed to natural disasters by considering local vulnerability factors. Developing an integrated spatial disaster risk map will help to illustrate which areas have higher or lower levels of risk. A conventional way in Malaysia is to apply the hazard and physical damages scale to differentiate risks in different locations. However, many more factors of vulnerability should be considered. Based on the literature review, six dimensions of vulnerability components were investigated. In addition, a combination of hazards (multi-hazard) was adopted in the risk model. To achieve the above aim, several research objectives were formulated; these are listed as follows:

1. To classify hazard characteristics based on the frequency and spatial interaction for use in the multi-hazard index model as part of an integrated disaster risk assessment index model.

2. To determine and develop indicators for the multidimensional vulnerability index model as part of the integrated disaster risk assessment index model.

3. To formulate an integrated disaster risk index equation model that is suitable for Malaysia by considering multi-hazard and multidimensional vulnerabilities.

4. To produce an integrated disaster risk index mapping, based on the proposed integrated disaster risk index model.

5. To assess the performance of the proposed index model in conducting integrated disaster risk assessment.

1.5 Scope of Study

In brief, this section outlines the scope of the study.

1.5.1 Scale

The main goal of developing the integrated disaster risk index model is its application in local assessments in Malaysia. The local scale or boundaries of the framework development correlate with the Malaysian administrative boundaries. Malaysia comprises Peninsular Malaysia, Sabah and Sarawak. Administration within Malaysia involves four main levels: State, district and municipal (local authority), and mukim (sub-district). There are 13 states in Malaysia and three federal territories (Kuala Lumpur, Putrajaya and Labuan). Each state has a Chief Minister as the head of governance and consists of districts and municipalities, which have their own boundaries and functions. These are led by district officers at the district level, who serve as intermediaries for all government matters and programs.

Regarding disaster risk management at the district level, the district officer acts as the committee's chief at this level, with the assistance of other government agencies, including the local authorities. However, at the municipal level, the local authorities are responsible for management services, the treasury, development and landscape planning, as well as community and municipal services. In disaster risk management, the local authorities are involved in the post-disaster preparedness and response process. The mukim is the minor administrative boundary, consisting of several villages or residential areas and led by the 'Penghulu' (the sub-district chief). The Penghulu is responsible for a mukim's administrative matters, development, security, unity, religion and welfare. They perform any duties as directed by the district officer and assistants.

1.5.2 Study Area

The study area covered three districts in Selangor that is Hulu Langat, Sepang and Kuala Langat. These three districts were generally located in the Langat River Catchment. Each of these districts has mukims (subdistricts). As shown in Figure 1.1, this study area consisted of 17 mukims. Both Hulu Langat and Kuala Langat have seven mukims. In Hulu Langat are the mukims of Ampang, Kajang, Hulu Langat, Cheras, Beranang, Hulu Semenyih and Semenyih. Kuala Langat consists of the mukims of Bandar, Batu, Jugra, Kelanang, Morib, Tanjung Dua Belas and Telok Panglima Garang. Meanwhile, Sepang consists of three mukims: Dengkil, Labu and Sepang.

Historically, this study area has been affected by several types of disasters, such as floods, landslides, storms and forest fires. From 2014 to 2019, there were 176 flood events, mainly experienced by Hulu Langat (98 occasions), Sepang (51) and Kuala Langat (27) (Izumi et al., 2019). In 2011, a major landslide in Mukim Hulu Langat caused 16 deaths (CEDMHA, 2016; Izumi et al., 2019). Meanwhile, several areas are susceptible to landslides, such as Ampang, Cheras, Kajang, Dengkil, Labu and Sepang (Lee and Pradhan 2007; Muhamad, Reza, and Pereira 2017; Othman et al., 2014). Several development projects have been undertaken in this area, such as the

Cyberjaya Multimedia Super Corridor, Kuala Lumpur International Airport, industrial areas and an increasing number of residences, further accelerating the process of urbanisation in this area (Atiqah et al., 2017).

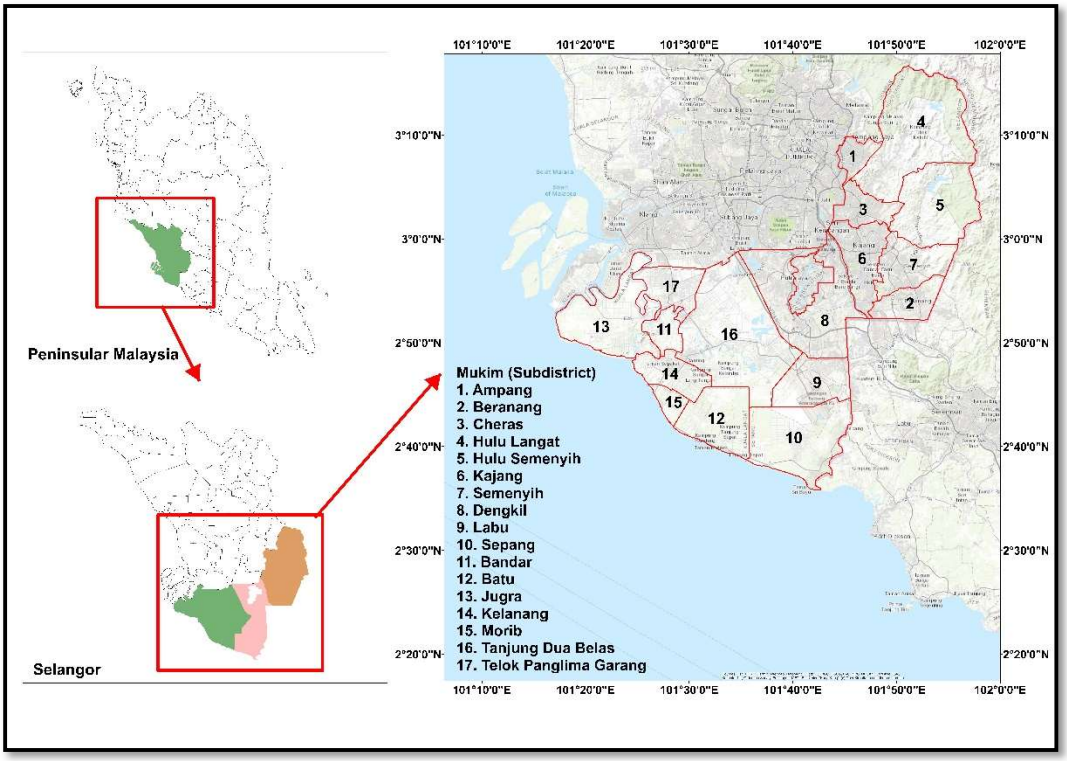

Figure 1.1 Location map of the study area.

1.5.3 Validation Process

Due to a lack of data in this study, the model validation focused solely on overall risk. The validation of the risk index map is based on historical data and a previous flood report. The risk area data are based on disaster hotspot locations that occur in the study area. However, the disaster hotspot location does not differentiate levels of risk. So the validation of index model produced are soley based on point based using Receiving Operating Characteristics (ROC) Validation approach. The point-based data was classified into risk and non-risk points, as well as whether or not an area was located in a disaster-prone area. So, the validation point does not consider

vulnerability level of the area but vulnerability index conducted based on comparison with disaster report for flood event in December 2021.

1.6 Significance of the Study

This study's main contribution is to provide a model for the assessment of integrated disaster risk based on the index-based approach. The proposed model considers two main components: the multi-hazard and multidimensional components. Given the anticipation of further natural disaster events, the proposed IDRI model can be used to enhance the mitigation and preparedness elements of the DRR process.

Some studies of risk, hazard and vulnerability assessments tend to separate the process into single-hazard assessments or single dimensions when conducting a risk assessment. However, in this study, the proposed model integrated the multiple hazard types with six dimensions of vulnerability. The proposed model is beneficial because it has been designed to support local governments in the decision-making aspect of land-use planning for risk management, especially in developing countries. Due to the uncertainty factors caused by climate change and extreme events, it is an advantage to be better prepared for multiple types of hazards.

Eliminating hazard occurrence is impossible, so it is an advantage to be prepared for incoming disaster events. Therefore, the proposed IDRI model considers the adaptation and capacity aspects with which a community copes in social, economic, physical, institutional, environmental, and cultural terms. This study also includes vulnerability aspects, as well as institutional and cultural features. Institutional features could be used to evaluate the preparedness of local governments for future disaster events. Cultural aspects could be used to evaluate community perceptions of attitudes to and awareness of disasters. This could provide information to agencies responsible for disaster awareness campaigns and the disaster-related information received by a community.

A multidimensional vulnerability index can assist local institutions to develop emergency and recovery plans, public awareness campaigns and disaster risk reduction

measures that are suitable for each dimension of vulnerability. The development of the IDRI model and IDRI mapping in this study should also contribute by providing a methodological approach to conducting local-level disaster risk assessment. The index-based approach used in this study could provide risk results through mapping, charts and rankings so that areas with higher or lower potential risk can be compared. The key specific and significant contributions of this study to the body of knowledge and local-scale assessments are listed as follows:

i. The development of a new approach to disaster risk index model by integrating multi-hazard and multidimensional vulnerability dimensions (physical, social, economic, cultural, institutional, and environmental).

ii. Integrating the expert knowledge and statistical approach in selection of multidimensional vulnerability indicators rather than author selection. At the same time provide a list of vulnerability indicators based on different dimension contributing to disaster risk assessment.

iii. At present, no clear methodology or multi-hazard risk map exist for Malaysia. This kind of map is needed by agencies such as NADMA, the DID and the Public Works Department (PWD) to identify risk areas so that they can prioritise and perform DRM.

iv. The development of an Integrated Disaster Risk Index (IDRI) model for local-level risk assessment in Malaysia.

v. The integrated disaster risk map can be used as a reference by decision makers when determining which areas are at critical risk of disasters and disaster-induced climate change.

vi. Improving the methodologies for disaster risk management, risk assessment and risk identification at the local level.

vii. Mapping the social and cultural dimension of communities within the risk assessment area as part of social capacity programs.

Lastly, the proposed IDRI model contributes by facilitating decision making in relation to disaster management, disaster mitigation and preparedness plans, public awareness campaigns, government policies, standard operating procedures for disasters and local authority planning strategies. This research will be instrumental for responsible agencies such as NADMA, the Department of Town and Country Planning (PLAN Malaysia), District Offices, Local Councils, Social Welfare Department (SWD), the National Security Council (NSC) and the National Disaster Management and Relief Committee.

1.7 Structure of Thesis

This thesis consists of six chapters. A summary of each chapter is provided below.

Chapter 1, as the introduction to this thesis, illustrates the general idea and direction of this research. This chapter consists of several sections such as the background of the study, the statement of the research problem, the research questions, the aims and objectives, as well as the scope and significance of the study.

Chapter 2 explores the disaster risk assessment literature, which covers aspects including the concept, terms and definitions. This chapter also discusses in detail the theoretical framework used to develop the integrated disaster risk index for local assessment. Moreover, this chapter discusses the previous concepts, theories and methods that have been used to conduct disaster risk assessment.

Chapter 3 discusses the research design approach and the methodology framework for this study. The chapter presents the research material, questionnaire design and data analysis used to fulfil each of the study objectives.

Chapter 4 presents the results of the integrated risk index model. The integrated disaster risk index model focuses on two main components: the multi-hazard and multidimensional vulnerability components. Finally, this chapter discusses the overall

integrated disaster risk assessment model used in the development of the integrated disaster risk index.

Chapter 5 presents and discusses the results from the development of the integrated disaster risk index in the study area. These findings also include a performance assessment of the index model developed in this study.

Chapter 6 presents the key findings of the study and recommendations for future studies in this field. This chapter also discusses the recommendation of the research so that future models could incorporate improvements.

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LIST OF PUBLICATIONS

Journal with Impact Factor

1) Alias, N. E., Salim, N. A., Taib, S. M., Mohd Yusof, M. B., Saari, R., **Adli Ramli, M. W**., Othman, I. K., Annammala, K. V., Yusof, H. M., Ismail, N., Yuzir, A., & Blenkinsop, S. (2020). Community responses on effective flood dissemination warnings—A case study of the December 2014 Kelantan Flood, Malaysia. Journal of Flood Risk Management, 13(S1). https://doi.org/10.1111/jfr3.12552. (Q1, IF: 4.005)

2) **Ramli, M. W. A**., Alias, N. E., Yusof, H. M., Yusop, Z., & Taib, S. M. (2021). Development of a local, integrated disaster risk assessment framework for Malaysia. Sustainability (Switzerland), 13(19). https://doi.org/10.3390/su131910792. (Q2, IF: 3.889)

Index Journal

1) Wahab, Y., Hamid, Z., Ahmad, F., Jusoh, R., Ghani, K., Anuar, A., & **Ramli, M. W. A**. (2021). A new approach on landslide vulnerability assessment and landslide risk index for critical infrastructures in Malaysia. Malaysian Construction Research Journal, 33(1), 23–45. (Indexed by Scopus)

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1) **Ramli, M. W. A, Alias**, N. E, Yusop, Z., Talib M.S., (2020), Disaster Risk Index: A Review of Local Scale Concept and Methodologies. IOP Conf. Series: Earth and Environmental Science. doi:10.1088/1755-1315/479/1/012023. (Indexed by Scopus)

2) Bahar, A. F., Yusop, Z., Alias N. E., & **Ramli, M.W.A** (2021), Influence of Dam to Rainfall-Runoff Response in a Tropical Climate – A Case Study of Selangor River Basin, Malaysia. IOP Conf. Series: Materials Science

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Index Book Chapter

1) **Muhammad Wafiy Adli Ramli**, Nor Eliza Alias, Shazwin Mat Taib, (2018). Evaluating Transportation Modes and Routes for Disaster Relief in Kelantan Using Geographical Information System, in Zulkifli Yusop , Azmi Aris , Nor Eliza Alias , Kogila Vani Annammala , William L. Waugh, Jr (ed.) Improving Flood Management, Prediction and Monitoring (Community, Environment and Disaster Risk Management, Volume 20) Emerald Publishing Limited, pp.63 – 71, ISBN 978-1-78756-552-4. (Indexed by Scopus)

2) **Ramli, M. W. A**., Alias, N. E. B., Yusop, Z. bin, & Taib, S. M. (2022). Disaster Risk Management: An Overview of Disaster Risk Assessment in Asean Countries. In Sustainability Management Strategies and Impact in Developing Countries, Community, Environment and Disaster Risk Management (Vol. 26, pp. 15–27). https://doi.org/10.1108/s2040-726220220000026002. (Indexed by Scopus)