Department of Civil Engineering

Assessment of Effect of Climate Change on Integrated Social-Environmental Vulnerability (SENVIINT) of Sarawak, Malaysia

Ismallianto Isia
0000-0001-9071-8718

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To the best of my knowledge and belief, this report contains no material previously published by any other person except where due acknowledgement has been made. This report contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature : ……………………………………………………………………………………

Name : ISMALLIANTO ISIA

Date : 14 MAY 2024

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List of Abbreviations

OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNDRO	Office of the United Nations Disaster Relief Coordinator
GIS	Geographical Information Systems
NE	Northeast Monsoon
INT	Inter-Monsoon
SW	Southwest Monsoon
Int-April	Inter-Monsoon April
Int-Oct	Inter-Monsoon October
LNG	Liquefied Natural Gas
SENVIINT	Socio-Environmental Vulnerability Index
DOSM	Department Of Statistics, Malaysia
LAK	Kuching Water Board
LAS	Sibu Water Board
LAKU	Northern Region Water Board
JNALB	Rural Water Supply Department
MCMC	Malaysian Communications and Multimedia Commission
PWD	Public Works Department
DID	Department of Irrigation and Drainage
NADMA	Government of Malaysia and National Disaster Management Agency
NREB	Natural Resources and Environment Board
METMalaysia	Meteorology Malaysia
AHP	Analytic Hierarchy Process
KMO	Kaiser-Meyer-Olkin

Abstract

The country of Malaysia, located in the tropical region, is confronted with significant challenges, and impacts due to climate change. The study aims to evaluate climate change's effects on socio-environmental vulnerability indices in Sarawak's major districts and propose adaptation strategies, with three main objectives. Objective one assesses climate change's impact on exposure, sensitivity, and coping capacity within Sarawak's vulnerability index, emphasizing three indicators for exposure, eleven for sensitivity, and inversely related coping capabilities. Objective two adapts an existing vulnerability model, calculating indices for exposure, sensitivity, and coping capacity to create the SENVIINT index. Objective three integrates socio-environmental factors to map vulnerability in Sarawak, combining social and environmental indicators, normalizing data, assigning weights, and visualizing results using ArcMap software. The mapping obtained from this study has revealed that vulnerability in Sarawak is closely related to exposure, sensitivity, and ability to cope with the effects of climate change, highlighting inequalities across regions and underlining the urgency of addressing socio-economic inequalities and promoting ecosystem preservation to increase resilience at the community level. nor the region. The adaptation of the SENVIINT model for vulnerability indexing in Sarawak unveils a nuanced understanding of the region's susceptibility to various stressors, integrating social and environmental factors to guide policymakers in crafting targeted resilience strategies for sustainable development, thereby fostering inclusive growth and environmental preservation for future generations. The last findings of this study has reveal that the districts of Sarawak, namely Kuching, Sibu, Bintulu, and Miri, have a most vulnerable to climate change compared to other districts. Specifically, these districts exhibit a higher SENVIINT index value, surpassing the threshold of 0.8. Conversely, the districts of Sebauh, Tatau, and Subis demonstrate a lower level of vulnerability with a value below 0.4. This study presents a contribution to the social and environmental approach in evaluating the vulnerability to risks of climate change and the likely adaptation options for Sarawak. The assessment provides empirical evidence that the inhabitants of four districts in Sarawak are exposed to climate change risks and hazards. If nothing is done to improve management, policies, laws, and regulations in Malaysia to cope with climate change impacts, these risks and hazards will continue to pose a threat.

CHAPTER 1

INTRODUCTION

1.1 Overview

Intergovernmental Panel on Climate Change (ICPP) defines climate change as the changes in climate over an extended period, whether due to natural variability or anthropogenic activity (*AR6 Climate Change 2022: Mitigation of Climate Change — IPCC*; Das et al., 2020). In addition, the United Nation Framework Convention on Climate Change (UNFCCC) defines climate change as a change of climate that attributes directly or indirectly by human activity, which alters the global composition of the atmosphere. The UNFCCC definition focuses exclusively on the effect by human activities. IPCC reports that significant changes in intensity, areas and frequency of occurrence of extreme weather and climate events including heavy precipitation, droughts, heat waves, and sea-level rise (Shukla *et al.*, 2019). Observation on climate change hot days, hot nights, heat waves, and heavy precipitation will persist more frequent, and future typical cyclones will become more severe as documented by the IPCC Fourth Assessment Report. Therefore, increase in area affected by droughts and extent of rising sea-level is expected.

Impacts of climate change/variability had affected and will continue to affect human and ecological systems at multiple scales encompassing people, institutions, and places. This in turn affects human's well-being and livelihoods (Nguyen *et al.*, 2019; Ebi *et al.*, 2020). Agro-ecosystems might be exposed to a range of natural, introduced, and anthropogenic stressors including climate change/variability, which in turn affects their ecosystem services (Mekonnen et al., 2019). In the context of climate change, many landscapes and households making their livelihoods within them are becoming vulnerable from time to time (Gupta *et al.*, 2020a). Since the mid-20th century, increase of anthropogenic greenhouse gas concentration and composition in the atmosphere associated to global averaged temperature has increased significantly (>90% probability). IPCC Third Assessment Report (TAR) concluded that most of the observed warming over the last 50 year probably (>66% probability) with an increase in GHG emissions are interrelated. IPCC TAR indicated that an average of 0.6°C increased in global average surface temperature over the last century (Shukla *et al.*, 2019). However, the recent IPCC Fourth Assessment Report (AR4) updated from the figure 0.6°C to about 0.74°C since the beginning of 20th century, with 1998 recorded as the warmest year between 1860 and 2007 (Das *et al.*, 2020).

Large variability in climate has been witness around the world over the past few years. In 2005/2006, Asia, Russia and part of Eastern Europe experienced an extremely cold winter condition and warmer winter condition in late 2006/2007. Malaysia has also seen an increase in the number of extreme weather episodes over the past few years, some on a scale not experienced before (Tang, 2019). It saw devastating monsoon floods affecting the States of Perlis and Kedah in December 2005, 2010, 2014 and 2015 (Alhoot *et al.*, 2016). Monsoonal rain with Typhoon Utor, resulted in unprecedented floods in Johor, Melaka, and Southern Pahang in December 2006 and January 2007 (Hamzah *et al.*, 2017). Wilayah Persekutuan Kuala Lumpur, the capital of Malaysia was badly flooded in March 2009 and December 2014 to January 2015 (Muzamil *et al.*, 2022). Changes in rainfall patterns have caused rivers and canals in northern Peninsular Malaysia prolong dry spell from March till May 2010. Perlis and Kedah once again experienced a serious flood event which breaks the record of once a 100-year flood in November 2010 (Hanif *et al.*, 2022). In Sarawak, impacts of climate change/variability are persistent as indicated by observed and projected trends of climate parameters. Reports indicated that the irregular trend of weather in Sarawak had shown an increasing trend since the 19th century (Bong and Richard, 2020). The country will face significant climate change/vulnerability in 2050 for the scenario of continued vulnerability with a static representation of current adaptive capacity.

1.2 Background

1.2.1 Climate Change and Weather

Climate change and weather are two related concepts that have a significant impact on the planet Earth and life upon it. Climate change refers to long-term changes including changes in temperature, precipitation, and weather patterns worldwide (Raihan, 2023). It is a natural phenomenon that has occurred over a period of time, usually decades or centuries. Natural factors such as volcanic activity, variations in solar activity, and changes in natural cycles have caused fluctuations in temperature and different weather patterns in the past (Hussain *et al.*, 2020). For example, volcanic eruptions can release large amounts of gases and particles into the atmosphere, which can block sunlight and cause cooling. Weather, on the other hand, refers to the current and short-term atmospheric conditions in a specific region. It is a temporary phenomenon that can change rapidly and unpredictably. However, in recent decades, human activity has become the primary driver behind significant climate change. Human activities such as burning fossil fuels, deforestation, and industrial processes have released large amounts of greenhouse gases into the atmosphere, which trap heat and rising global temperatures, melting glaciers, changes in precipitation patterns, and shifts in the distribution of plant and animal species (Peduzzi, 2019; Ebi et al., 2020; Sekaranom et al., 2021) . This human-induced climate change is happening at a much faster rate than natural climate change, and it is causing significant impacts on ecosystems and human societies. Weather patterns are also affected by climate change, as changes in the global climate can lead to more extreme weather events such as heatwaves, droughts, and hurricanes. Therefore, it is important to understand the relationship between climate change and weather is important for predicting and mitigating the impacts of climate change on the planet and its inhabitants.

One of the primary causes of climate change is the increased concentration of greenhouse gases in the atmosphere as illustrated in Figure 1.1. Greenhouse gases are gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that trap heat from the sun in the atmosphere and contribute to global warming (Shukla *et al.*, 2019). The increased concentration of greenhouse gases in the atmosphere, primarily due to human activities such as burning fossil fuels and deforestation, has caused climate change. Burning fossil fuels such as coal, oil, and gas releases large amounts of CO_2 into the atmosphere, contributing to the greenhouse effect. Deforestation, which involves cutting down trees, also contributes to climate change by reducing the number of trees that absorb CO_2 from the atmosphere (Sa'adi *et al.*, 2023). Intensive agricultural practices, such as using fertilizers and raising livestock, also release significant amounts of greenhouse gases into the atmosphere. The increased concentration of greenhouse gases in the atmosphere leads to a warming effect, which can cause a range of negative impacts, including rising sea levels, more frequent and severe weather events, and changes in ecosystems and wildlife habitats.

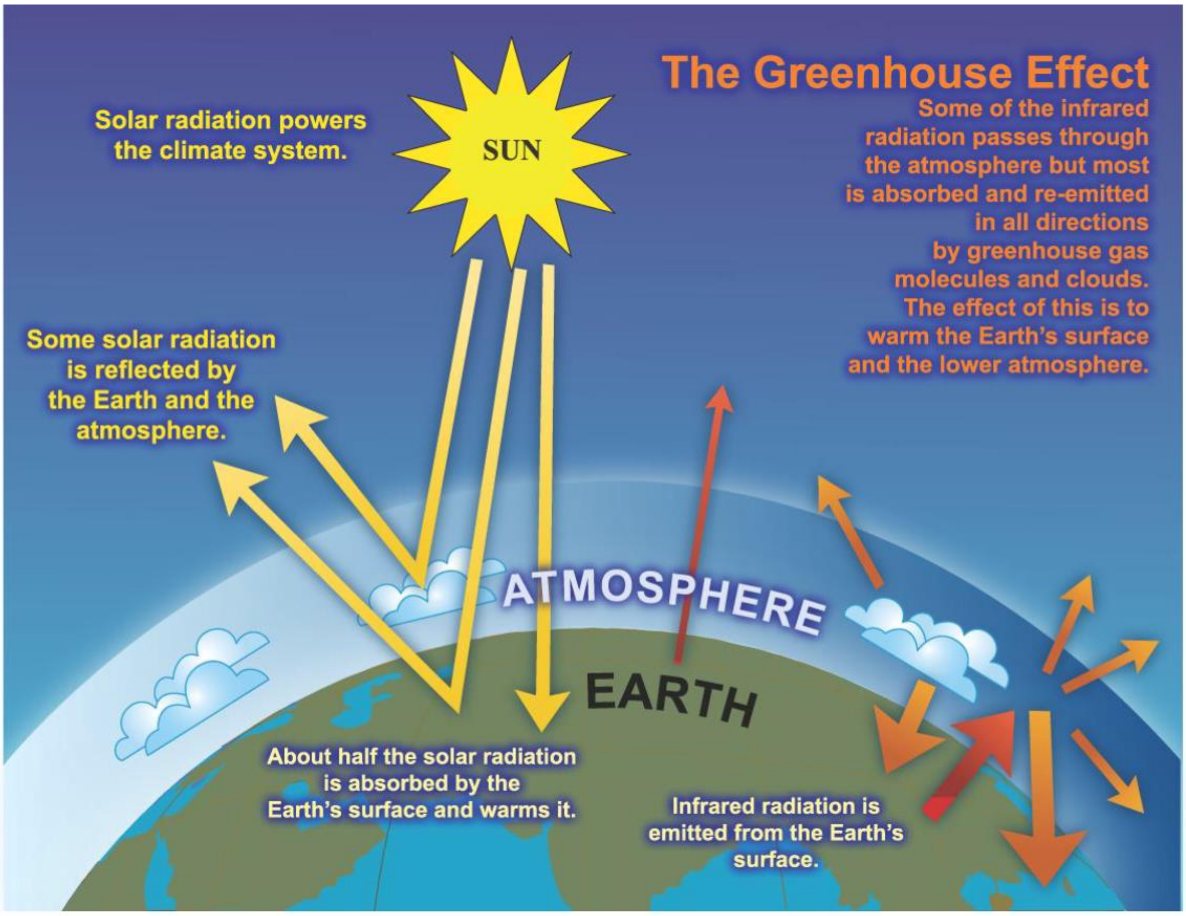

Figure 1.1 The greenhouse effect (Shukla *et al.*, 2019)

Climate change has led to changes in weather patterns worldwide, resulting in extreme weather events such as floods, droughts, hurricanes, and heatwaves. These extreme weather events occur more frequently and with greater intensity due to climate change, which can cause significant damage to infrastructure, homes, and businesses. Climate change also affects the timing and distribution of rainfall, which can impact agriculture and food security (Sekaranom *et al.*, 2021). Changes in global temperatures can also have serious consequences for human health, as extreme heat can cause heat exhaustion, dehydration, and other health problems. Climate change also affects biodiversity, as changes in temperature and rainfall patterns can disrupt ecosystems and lead to the extinction of species. Overall, climate change has serious consequences for the environment, economy, and society, and urgent action is needed to mitigate its impacts.

Understanding the background of climate change and its relationship is important for the development of models and long-term weather predictions. By studying the long-term changes in average weather patterns, scientists can develop models that can help predict future weather patterns and their impacts on the environment and human society. These models are crucial in taking necessary mitigation and adaptation measures to create a more sustainable future. Mitigation measures refer to reduce greenhouse gas emissions and slow down the rate of climate change (Shukla *et al.*, 2019). Adaptation measures refer to help communities and ecosystems adapt to the impacts of climate change that are already happening. By understanding how weather patterns are changing over time, scientists can identify areas that are most vulnerable to climate change and prioritize adaptation measures accordingly. For example, if a region is experiencing more frequent and severe droughts, scientists can recommend measures such as water conservation and drought-resistant crops to help communities adapt (Kaur *et al.*, 2020). Similarly, if a region is experiencing more frequent and severe storms, scientists can recommend measures such as building sea walls and improving drainage systems to help communities prepare for and cope with flooding. Overall, studying long-term changes in weather patterns is essential for creating a more sustainable future and protecting the environment and human society from the impacts of climate change.

1.2.2 Weather in Malaysia

Malaysia, consisting of Peninsular Malaysia and East Malaysia (Sabah and Sarawak), is situated in the equatorial zone. It undergoes four distinct seasons: the southwest monsoon (mid-May to September), the northeast monsoon (early November to March), and two shorter inter-monsoon periods. The northeast monsoon brings heavy precipitation to the east coast states of Peninsular Malaysia, Sabah, and western Sarawak. The climate of Peninsular Malaysia is directly influenced by winds from the mainland, while East Malaysia is affected by maritime conditions (Malaysian Meteorological Department, 2009; Saádi *et al.*, 2017). November, December, and January see the highest rainfall in the east coast states of Peninsular Malaysia, whereas June and July are the dry months. Except for the southwest coastal area, the rest of the peninsula experiences the highest rainfall in October-November and April-May. The northwestern region has the least rainfall in June, July, and February. The southwest coastal area receives the highest rainfall in October and November, the lowest rainfall in February, and experiences dry periods from March to May and June to July.

The occurrence of maximum rainfall for the coastal regions of Sarawak and northeastern Sabah is limited to January. In June or July, Sarawak's coastal areas witness the lowest rainfall, while Sabah's northeast coastal area experiences the same in April. The northeast monsoon brings heavy rainfall between December and March. In Sarawak's inland areas, rainfall is evenly distributed throughout the year, with a dry period from June to August due to the influence of south-westerly winds. The northwest coastal areas of Sabah receive the highest rainfall primarily in October, followed by June, and the minimum rainfall is observed in February and August. Maximum rainfall in the central parts of Sabah occurs in May and October, while minimum rainfall is recorded in February and August. Southern Sabah experiences a relatively uniform distribution of rainfall, with a slightly drier period from February to April.

In Malaysia, the temperature range varies within a day with coastal areas having a range of 5°C to 10°C and inland regions having a range of 8°C to 12°C. Temperatures in the lowlands generally range from 26°C to 28°C. During the monsoon seasons, the temperature in the east coast states of Peninsular Malaysia fluctuates significantly. The average temperatures are usually highest in April and May and lowest in December and January across most areas.

The mean monthly relative humidity in Malaysia is between 70% and 90% contingent upon location and month. Notably, Alor Setar exhibits the most extensive range in average monthly relative humidity, with a variance of 15%, whereas Bintulu displays the narrowest difference of merely 3%. Typically, Malaysia savors approximately six hours of diurnal sunshine. However, Alor Setar and Kota Bharu encounter roughly seven hours of sunshine daily, whereas Kuching basks in only five hours of sunlight. Alor Setar receives the maximum number of daily sunshine hours, amounting to an average of 8.7 hours, whereas Kuching boasts the least amount of sunshine, averaging 3.7 hours per day in January.

1.2.3 Climate Change Landscape in Malaysia

Climate change is a significant global environmental concern and is increasingly manifesting in Malaysia through intensified and unpredictable weather patterns and more severe weather events over time. The factors contributing to climate change are ascribed to both natural and anthropogenic causes, namely long-term interactions between the ocean and atmosphere and human activities, respectively. Consequently, climate change results in an increase in sea levels, greater precipitation leading to heightened risks of flooding, and prolonged periods of drought. In Malaysia, the El Niño-Southern Oscillation (ENSO) phenomenon reduces rainfall and substantially raises regional temperatures during the dry season. Dry seasons have become more frequent in Peninsular Malaysia and have been prolonged in East Malaysia since 1970.

Based on climatological data in Malaysia, it was observed that the utmost surface temperatures were recorded in the years 1972, 1982, and 1997, which were concomitant with the occurrence of El-Niño phenomena in 1972, 1982, 1987, 1991, and 1997 (Tan *et al.*, 2021). Throughout these intervals, the maximum annual temperatures were notably recorded in western Peninsular Malaysia and Sabah. In recent times, the temperatures in East Malaysia have been persistently higher than those in Peninsular Malaysia, with the most notable temperature elevation of 3.8°C documented in Sarawak. Predictions suggest that the temperature increase in the eastern region of Sarawak is expected to double from 1.4°C to 3.8°C between the years 2029 and 2050 (Kemarau and Eboy, 2021).

The climate projections furnished by the Malaysian Meteorological Department provided significant insights into future climate scenarios from 2001 to 2099. The Atmosphere-Ocean General Circulation Models (AOGCMs) indicate that surface temperature discrepancies are expected to increase and deviate in the next 50 years. As per Table 1.1 the annual mean temperature changes (°C) observed for the period 1990 to 1999 are highlighted. The simulations forecast that East Malaysia will witness temperature increases ranging from 1.0°C to 3.5°C, while Peninsular Malaysia is expected to experience temperature rises ranging from 1.1°C to 3.6°C (Malaysian Meteorological Department, 2009). Furthermore, the projections underscore a substantial increase in rainfall, particularly in western Sarawak, as the northeast monsoon circulation from December to February brings intense rainfall and the threat of flooding.

Table 1.1 Predicted shifts in annual average temperature levels (°C) for the period 2020-2099 (Malaysian Meteorological Department, 2009)

Area	2020 - 2029	2050 - 2059	2090 - 2099
Northwest Peninsular Malaysia (PM)	1.3	1.9	3.1
Northwest Peninsular Malaysia (NPM)	1.1	1.7	2.9
Central Peninsular Malaysia (CPM)	1.5	2.0	3.2
Southern Peninsular Malaysia (SPM)	1.4	1.9	3.2
Eastern Sabah	1.0	1.7	2.8
Western Sabah	1.2	1.9	3.0
Eastern Sarawak	1.4	2.0	3.8
Western Sarawak	1.2	2.0	3.4

The General Circulation Model (GCM) projections indicate that surface temperatures in Peninsular Malaysia, Sabah, and Sarawak will remain steady or decrease by 0.4°C to 0.5°C in all months, except for March, April, and May, over the period from 2080 to 2089. The GCM simulations for various regions in 2028, 2048, 2061, and 2079 forecast an average surface temperature increase of 2.3°C to 3.6°C in Peninsular Malaysia and an increase of 2.4°C to 3.7°C in East Malaysia (Khan et al., 2020; Kemarau & Eboy, 2021). By the end of the century, the highest temperature increase is predicted to occur in eastern Sarawak, reaching 3.8°C, while the lowest increase is expected in northeastern Peninsular Malaysia.

The substantial rainfall events that have recently occurred in both Peninsular and East Malaysia can be attributed to the amplification of weather patterns by tropical storms in the South China Sea. The rainfall patterns in Malaysia are influenced by El-Niño and La-Niña events. The driest years for both Peninsular Malaysia and East Malaysia were recorded during El-Niño events in 1963, 1970, 1997, and 2002, resulting in a significant decrease in rainfall. Conversely, La-Niña events bring wetter years to Malaysia, and the wettest years were recorded in 1984, 1988, and 1999, particularly in East Malaysia (Chenoli *et al.*, 2022; Ng *et al.*, 2022) . An analysis of the period from 1961 to 2007 indicates an upward trend in rainfall for Sarawak, with the maximum rainfall occurring in September, October, and

November in western Sarawak, and lower rainfall in northern Sarawak during March, April, and May. During the northeast monsoons of 2006/2007 and 2007/2008, Malaysia experienced heavy rainfall and floods. These changes in temperature and rainfall patterns have rendered northern Peninsular Malaysia, as well as the coasts of Sarawak and Sabah, more vulnerable. The vulnerability is attributed to the impacts of climate change (Kemarau and Eboy, 2021; Payus et al., 2020). Figure 1.2 displays the forecasted patterns of annual rainfall variations from 2001 to 2099 compared to the reference period of 1990 to 1999.

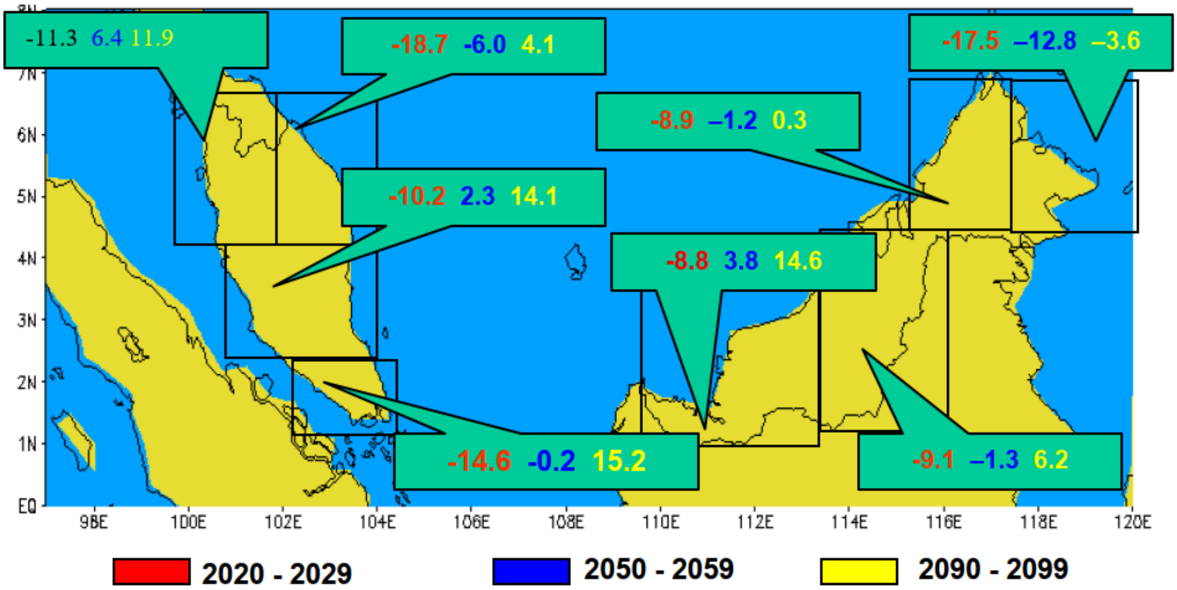

Figure 1.2 Forecasted variations in annual average rainfall percentages (%) from 2001 to 2099 in relation to 1990 to 1999 (Malaysian Meteorological Department, 2009)

The simulations pertaining to seasonal rainfall patterns have revealed that the most noteworthy fluctuations (-60% to 40%) manifest themselves during the months of December, January, and February. Conversely, the least amount of variation (15% to 25%) takes place in September, October, and November. Projections put forth have indicated that Sabah, Sarawak, and Peninsular Malaysia will be impacted by El-Niño in the years 2028, 2048, 2061, and 2079, leading to a decrease in rainfall across all regions. It has been predicted that there will be a substantial drop in average annual rainfall for Sabah and Sarawak from 2079 to 2099, while Peninsular Malaysia is expected to experience an increase in rainfall from 2090 to 2099.

1.3 Problem Statement

Hasty urbanized development, industrialization, and expectation of a better quality of life have caused Malaysia to move towards environmental degradation along with the social vulnerability of the society (Abid *et al.*, 2021; Nor Diana *et al.*, 2021). Harmful waste secretions, climate change, change in land-use patterns, environmental pollution, deforestation, and ecosystem interruption are few major threating alarms to the country especially in Sarawak (Alhoot *et al.*, 2016; Abdul Rahman, 2018; Qureshi *et al.*, 2019). Irregular rainfalls, shifting of monsoon, more variation in temperature is the major effect of climate change. In the last two decades, Malaysia has experienced warming and rainfall irregularities particularly which gave garnering much attention in the study of climate trends and the implications (*AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability — IPCC*; *AR6 Climate Change 2022: Mitigation of Climate Change — IPCC*; Shukla et al., 2019; Din et al., 2017; Saádi et al., 2017; Tang, 2019). Most of the research on climate change in Malaysia is correlated to the effects of climate change rather than examining the historical and future trends, and a large proportion of the studies is related to agriculture. Many studies have examined the immediate and underlying drivers of climate (Zanetti *et al.*, 2016; Nagy *et al.*, 2019); however, studies on socio-environmental vulnerability in Sarawak are limited.

Other study examined the vulnerability and conservation of species, focusing on biodiversity loss without accounting for other climate-sensitive and vulnerable sectors. Most adaptation assessments have been limited to impacts sensitivity, exposure, and vulnerability, with limited studies examining the effects of adaptation actions (Bukvic *et al.*, 2020; Gupta *et al.*, 2020b; Membele *et al.*, 2022). Another lack of information in Sarawak state is the effect of climate change on social factors like age (children or elderly), gender discrimination, mortality rate, housing characteristics, employment, disability, the economic gap in the society and the immigration/outmigration, which makes any state socially vulnerable (Birkmann et al., 2022; Cao et al., 2023; Nájera-González, A., and Carrillo-González, 2022). All these socio-environmental factors need to be quantified and find the best optimize solution against the social and environmental vulnerability profile of Sarawak. The proposed index will be able to provide guidelines to policymakers at the district level regarding vulnerability assessment of the region in view of social and environmental aspects and provide a link to the sustainable development of different regions of the state.

1.4 Aims & Objectives

Climate change is the biggest challenge faced by the entire world today. As a result of climate change, the water, flora, fauna, and the local community of the earth will undergo various specials and temporal redistribution. This redistribution of different resources will influence the magnitude of hazards such as floods and drought. Change in the magnitude of hazards will change the level of vulnerability of the impacted region. As such, there is a need to study the impact of climate change on the vulnerability of an area. Further, vulnerability is also related to other factors, such as social, economic, hydrological, and environmental factors. As a result, it is necessary to incorporate these factors in deriving the vulnerability index of an area. Considering the factors stated above, the primary objective of the study can be summarized as below.

1) To study the impact of climate change on the exposure, sensitivity and coping capacity and its impact on the proposed vulnerability index for Sarawak.
2) To adapt the available model for vulnerability index for Sarawak case
3) To integrate socio-environmental factors for vulnerability index mapping in Sarawak.

1.5 Research Significance

In the last two decades, the whole world and Malaysia particularly has experienced warming and rainfall irregularities which gave garnering much attention in the study of climate trends and the implications. In Malaysia, especially in the Sarawak, lack of environmental awareness to major environmental problems, rapid urbanizations, and industrialization which causing deforestation, rising mean temperature differences and degradation of biodiversity (Alamgir *et al.*, 2020). Most of the research towards climate change in Malaysia is correlated to the effects of climate change where a large proportion of the studies is related to agriculture. Garnering has become most of research attention in the variations brought by climate change on water resources. Various studies have predicted the changes of water resources in Malaysia based on future projections of climate change and how climate variations affected hydrological components in the river basin, in conjunction with land uses (Tan *et al.*, 2019; Tang, 2019; Hanif *et al.*, 2022). However, since the Malaysian government signed the Paris Agreement in 2016, the gap between science and politics has widened. The attention of policymakers should not be for today only but should be concentrated on the future as well.

The proposed integrated social and environmental vulnerability index can provide guidelines to policymakers at the districts level regarding vulnerability assessment of the region in view of social aspects and provide a link of the sustainable development of the targeted area. The cross-scale interactions between them require a portfolio of integrated approaches to mitigate its impacts on social and environment. The proposed study tries to find out the black spot region in the state based on socio-environmental vulnerability index mapping and tries to forecast the extent of the black spot in near future due to climate change under different scenarios, for example, areas with less health facilities are more vulnerable to climate change than areas with sufficient health facilities. The outcome of the proposed study may be used as a tool for policymakers to initiate the environmental protection program at the grass-root level and to support real-world decision making through nexus approaches within the coupled human-natural system.

In a time of severe climate change, the normative elements of disaster harm in disaster risk management have become more important. So, this study also suggests a disaster management framework in Sarawak, Malaysia, to improve the disaster management system and practices in case of floods and drought. Figure 1.3 shows the proposed structure for the cycle of managing disasters caused by climate change.

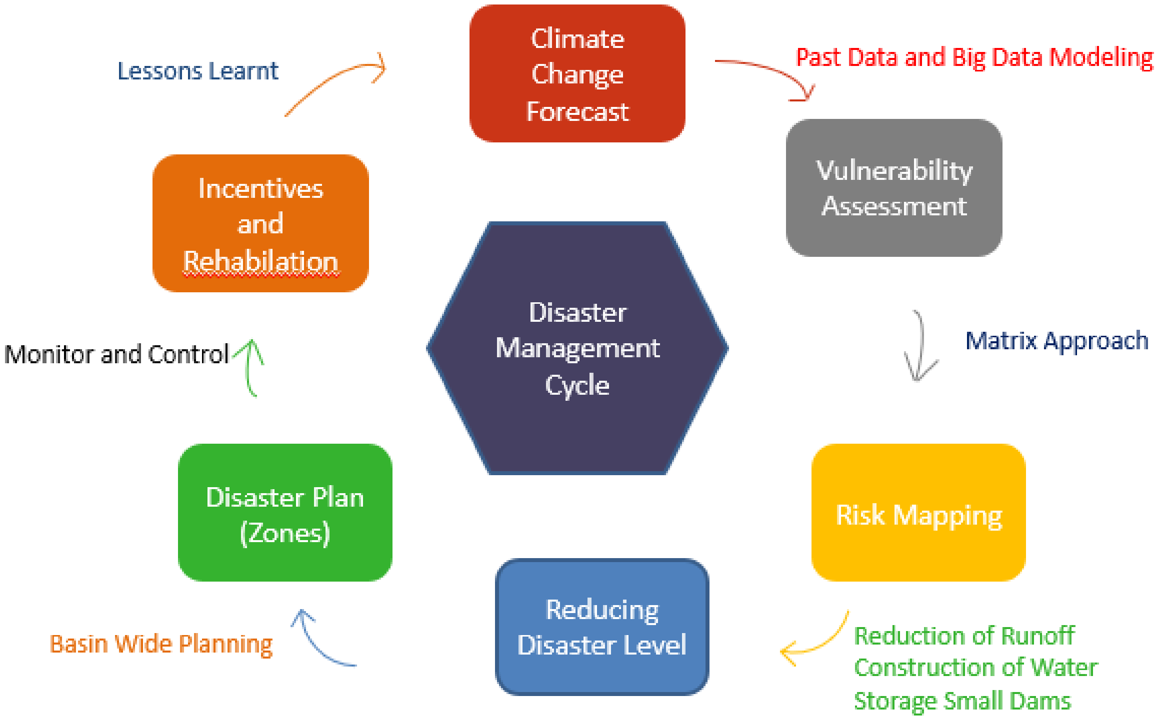

Figure 1.3 Framework for disaster management cycle (Muzamil *et al.*, 2022)

Disaster management plans are different because there are different ways to handle each type of disaster. In the same way, it is important to use the new ways to manage big data. Many countries also have data from the past, so big data analysis methods should be able to predict climate trends and how bad they might be. Using the forecast as a guide, the framework suggests using a matrix to rank the areas that are most likely to harm. Higher-risk areas should get more attention, and state resources can also be used in this way. Based on the flood vulnerability matrix, suitable actions to be taken include maintenance of the existing reservoirs and construction of new water storage dams ranging from small- to large-scale dams. Possible suitable actions should be taken to reduce the runoff or divert the flood into various reservoirs. These should be at a certain safe distance from the populated areas and special attention should be given to the city drainage system. Runoff water should be diverted to possible flood pocket zones to save the cities and human lives. In case of possible resettlements, incentives should be given to people for rehabilitation if any damage occurred due to floods. All possible data needs for the framework should be considered when managing relevant data. It is necessary to establish specialized data centres at the state and national levels to preserve accurate records of precipitation and the potential for flooding. In the final phase, a lesson learned session should be held and the outcomes implemented into the framework to improve future crisis management. The framework proposed can also be used in other countries with similar flood disasters. There may be some small changes that can be made to the framework to fit the needs of each country. The main parts of how to deal with a flood disaster will stay the same.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Climate change presents as one of a major obstacle that society must overcome in the 21st century. It worsens pre-existing inequalities while rise to new disparities (Tang, 2019; Giri *et al.*, 2021). The socio-environmental milieu experiences continual transformation influenced by a multitude of factors that exert influence on both human societies and the natural world. Within this ever-evolving scenario, the heightened vulnerability of communities and ecosystems to the adverse ramifications of climate change and socio-economic changes emerges as a crucial apprehension in contemporary times. In the present scenario, the emergence of the Socio-Environmental Vulnerability Index (SEVI) has been a priceless asset for evaluating and comprehending the correlation between human well-being and environmental ecosystem. There is widespread recognition that the effects of climate change are likely to be highly uneven, with some individuals, households, communities, or regions experiencing significant negative effects, such as the loss of life and property due to climate extremes, the loss of agricultural productivity, increase water stress and damage to infrastructure from the melting of permafrost (Berrouet et al., 2018; Bong and Richard, 2020). Disasters or catastrophic events can cause extreme impacts to human and ecosystems. Disaster result from the combination of both exposure to the climate event and susceptibility to harm by the communities affected inequities (Tang, 2019; Giri *et al.*, 2021). The impacts of disasters include major destruction of assets and the economic, loss and adverse impacts on living organisms and ecosystem.

Current research endeavours are heavily invested in assessment of climate change impacts (Beilfuss and Nhemachena, 2019; Handayani et al., 2017; Monterroso et al., 2014; Preston et al., 2011; Xu et al., 2020; Zikra et al., 2015). However, most of the investigation did not focus on socio-environmental vulnerability assessment, while this is very essential not only provides the basic information data for proposing mitigation and adaptation measures but also is a foundation for establishing polices, strategies, and plans for a specific sector, community, region, or nation. This literature review endeavours to investigate the utilization and importance of the Socio-Environmental Vulnerability Index in the specific context of Sarawak, a Malaysian state well-known for its varied cultural legacy, abundant biodiversity, and swift progress. Sarawak's susceptibility to ecological alterations, combined with the exceptional socio-economic status of its societies, renders it an alluring subject of study to scrutinize the efficiency of SENVIINT as a comprehensive appraisal framework. Over time, Sarawak has experienced notable changes in its economic framework and land usage patterns caused by the extensive exploitation of resources and development projects. These modifications can significantly affect the area's ecosystems, climate, and local communities, ultimately influencing their social, economic, and cultural welfare. Hence, it is of utmost importance to assess and understand the level of vulnerability that the people and ecosystem of Sarawak are encountering.

The focus on this research is specifically on the three crucial components of SENVIINT, namely exposure, sensitivity, and coping capacity. Exposure denotes the level of exposure of Sarawak's communities and ecosystems to different environmental stressors like land use changes, resource scarcity, and extreme weather events. Sensitivity evaluates the susceptibility of both human and natural systems to these stressors, taking into consideration socio-economic factors, demographic characteristics, and ecosystem fragility. On the contrary, coping capacity investigates the potential of both communities and institutions to adapt, respond, and rebound from the adverse impacts of environmental transformations. Finally, the present section extensively delves into the integration of the cardinal constituents of vulnerability, namely exposure, sensitivity, and coping capacity, into the vulnerability mapping processes. It meticulously scrutinizes the individual contributions of each indicator to the all-encompassing vulnerability index and explicates how spatial analysis facilitates the visual representation of the interdependence among these components. Drawing on diverse case studies across various regions, the review accentuates the criticality of factoring in these elements in socio-environmental vulnerability mapping.

2.2 Climate Change: A Global Environment Challenge

Climate change poses a formidable and pressing worldwide dilemma that stems from human interventions, primarily the combustion of fossil fuels, deforestation, industrial processes, and agriculture. Human activities such as fossil fuel burning , deforestation (Isia et al., 2023; Jones et al., 2016), industrialization (Seeboonruang 2016; Taiye 2014), transportation (Rufat et al., 2022), and agriculture emit greenhouse gases (Tang 2019; Leal Filho et al., 2021), particularly methane, carbon dioxide, and nitrous oxide, into the atmosphere. This leads to an intensified greenhouse effect, thereby exacerbating the phenomenon of global warming (Tan et al., 2021; Ng et al., 2022).

The impacts of climate change are extensive and impact diverse facets of our planet. The escalation in temperatures has resulted in the thawing of ice sheets and glaciers in polar regions, contributing to the escalation of ocean levels and jeopardizing coastal societies. The frequency and intensity of extreme weather occurrences, such as hurricanes and heatwaves, have notably amplified, resulting in severe ramifications for both communities and economies. Climate change has the capability to disturb biodiversity and ecosystems, ultimately causing habitat loss, alterations in the distribution of species, and even placing them at risk of extinction (Hussain et al., 2020; Grigorescu et al., 2021a; Nájera-González & Carrillo-González, 2022). Marine life, coral reefs, and marine ecosystems are threatened by ocean acidification caused by excess CO_2 absorption.

Furthermore, the phenomenon of climate change exerts an influence on the dissemination of ailments, afflictions related to elevated temperatures, and exacerbates the condition of air purity, thus impacting the welfare and physical condition of humanity. Furthermore, certain communities that are more susceptible to harm are even further disadvantaged, thereby exacerbating social disparities. The mitigation of climate change necessitates prompt and collaborative actions on a global scale. The Paris Agreement, established in 2015, endeavors to curtail the escalation of global temperature by maintaining it at a level significantly lower than 2 degrees Celsius and strives to restrict it to a mere 1.5 degrees Celsius above pre-industrial stages (Fekete, 2019). This agreement accentuates the shift towards renewable energy, the reduction of greenhouse gas discharges, and the enforcement of measures to adapt to the changing climate.

Individual and collective efforts are indispensable in the fight against climate change. Progressing towards the usage of clean energy, incorporating sustainable practices, cutting down on waste, and backing climate policies are all significant strides towards a sustainable future. As a worldwide society, it is imperative that we collaborate to face this challenge, alleviate its effects, and uphold a livable planet for the generations to come. The only way to construct a sustainable and robust future capable of tackling the climate crisis is through a collective commitment.

2.2.1 Climate Change in Malaysia

Climate change poses a critical environmental concern for Malaysia, a Southeast Asian nation that boasts of a tropical climate and an expansive coastline. As a country that is susceptible to this phenomenon, Malaysia faces different challenges that emanate from the effects of climate change. The challenges that Malaysia faces have extensive implications for its inhabitants, economy, and ecological systems. One of the primary climate change-induced predicaments in Malaysia is the escalation of temperatures (Isia et al., 2023). The upsurge in heatwaves could adversely affect human health, agriculture, and general well-being. Extreme weather events, such as heavy rainfall, floods, landslides, and tropical storms have been on the rise. Consequently, there has been considerable infrastructural damage and disruptions to livelihoods. The nation's extensive coastal boundary renders it vulnerable to escalating sea levels, which in turn endangers low-lying coastal regions, infrastructure, and potable water sources. Moreover, global warming adversely affects the availability of water (Seeboonruang, 2016; Haque *et al.*, 2023), instigating water stress and scarcities in specific regions (Bera *et al.*, 2021; Youssef *et al.*, 2021), impinging upon agriculture (Sekaranom *et al.*, 2021), industry (Ebrahimi *et al.*, 2022), and everyday life (Khalid *et al.*, 2017).

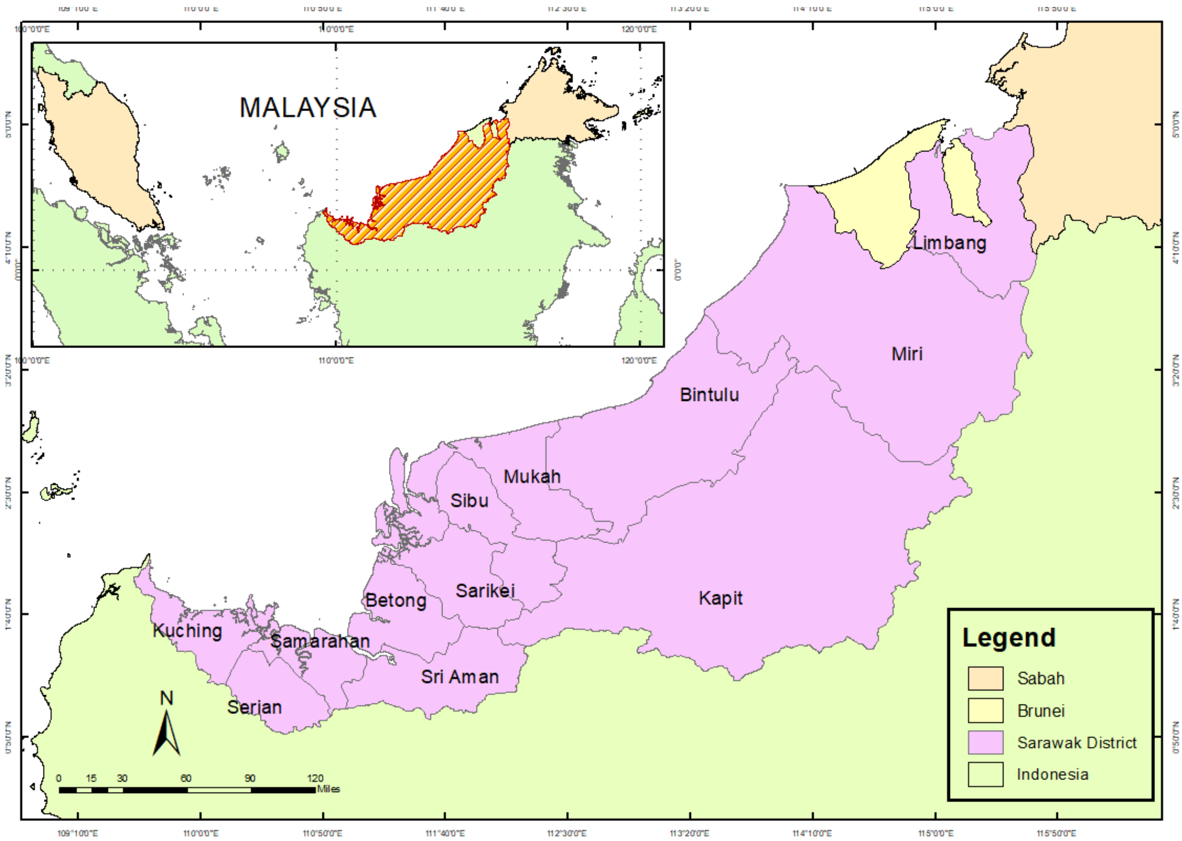

Figure 2.1 Geographical of Malaysia encompassing Peninsular, Sabah, and Sarawak - Insert map (Isia et al., 2023)

Malaysia is renowned for its rich biodiversity, but climate change endangers various species and ecosystems (Figure 2.1). Potential consequences of altering climatic conditions include biodiversity depletion and habitat deterioration, which disturb ecological equilibrium and environmental well-being. The agricultural sector experiences acute effects of climate change, wherein modifications in weather patterns detrimentally impact crop yields and food security (Ehsan et al., 2019). The disruptions in livelihoods and food supply that result from these changes disproportionately affect rural communities, thus rendering them particularly vulnerable. Moreover, the phenomenon of climate change plays a role in the dissemination of diseases transmitted by vectors and afflictions associated with high temperatures, thereby presenting a health hazard to the populace. Consequently, the public health sector encounters amplified challenges in managing these emerging health threats.

Malaysia committed in an active participates in international climate agreements, indicating its unwavering dedication towards global climate action. Besides, collaborative endeavors among governmental entities, private industries, non-governmental organizations, and global associates are actively being pursued to construct resilience and adapt to the exigencies presented by climate change. The implementation of climate-intelligent policies and sustainable practices are being embraced to preserve the environment and cultivate a tenacious economy.

Despite the endeavors, persistent attentiveness and unceasing endeavors are demanded to confront the multifarious predicaments presented by climate change in Malaysia. Through an exhaustive and concerted strategy, Malaysia can effectively grapple with the intricacies of climate change, thereby securing a sustainable and resilient future for its populace and natural endowments.

2.3 Definition of Vulnerability

Vulnerability may be defined as an inherent risk present in an individual or system when faced with a hazard, highlighting its inherent tendency to be susceptible or impacted by harm. The concept of vulnerability is a fundamental notion that resides at the core of comprehending and tackling obstacles in diverse contexts such as ecology, sociology, catastrophe research, and climate transformation. Vulnerability may be defined as an inherent risk present in an individual or system when faced with a hazard, highlighting its inherent tendency to be susceptible or impacted by harm. The concept of vulnerability is a fundamental notion that resides at the core of comprehending and tackling obstacles in diverse contexts such as ecology, sociology, catastrophe research, and climate transformation.

The community's susceptibility to threatening circumstances from natural or human-induced sources is encompassed by physical, economic, and social factors. Vulnerability, whether due to natural disasters, socio-economic disparities, or environmental changes, highlights weaknesses and emphasizes the need for resilience (Rolfe *et al.*, 2020; Thong *et al.*, 2022). Policymakers, researchers, and communities can develop specific strategies to mitigate risks, build adaptable capacities, and promote sustainable solutions for a more resilient and equitable future by recognizing and quantifying vulnerability. Generally, vulnerability pertains to a system's inadequacy in dealing with external challenges or disruptions. It is a notion employed in diverse research disciplines, although there is no unanimously accepted meaning and definition (Beilfuss and Nhemachena, 2019). According to the research interest, the application of the term has been used to either the, ecological, environmental, or biophysical subsystem, or alternatively, to the socio-ecological system (di Girasole and Cannatella, 2017; Jha, R. K., and Gundimeda, 2019; Porio and See, 2015).

Therefore, professionals from various fields utilize distinct interpretations and understandings of vulnerability, resulting in a multitude of approaches to defining and assessing it. The diversity in the perspectives of vulnerability across different fields can be attributed to their emphasis towards emphasizing varied elements of risk, household responses to it, and the resulting welfare implications. The subjects encompassed within this field of study are diverse, not limited to sociology, anthropology, geography, economics, food security, sustainability, environmental science, disaster management, and health and nutrition (Paul 2014). However, most of most use is observed in natural hazards research fields. The term vulnerability entered officially in the natural hazards research field in 1979 with a report issued by the UNDRO (Peduzzi 2019). According to UNDRO (Office of the United Nations Disaster Relief), there is a combined relation among “Risk, Hazard, and Vulnerability” and the relation is formulized as (Figure 2.2):

$$Risk = (Hazard \times Vulnerability) \quad (1)$$

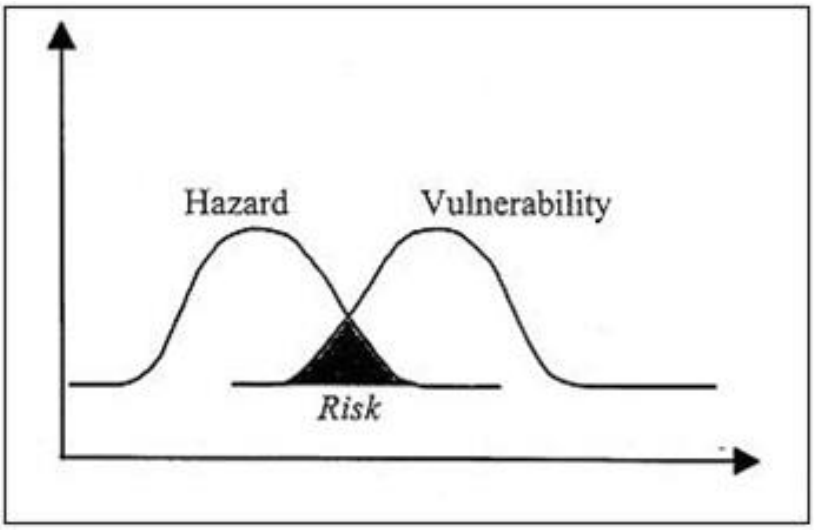

Figure 2.2 The interpretation of risk by UNDRO (Peduzzi 2019)

Meanwhile, the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) acknowledges that vulnerability refers to the exposure of individuals, communities, or systems to the adverse effects of hazards or shocks. On the other hand, risk pertains to the possibility of those negative impacts occurring, considering the likelihood and potential consequences of a hazard event. Recognizing vulnerability and risk is vital to ensure efficient disaster preparedness, response, and resilience-building initiatives globally.

However, the term vulnerability is gaining more traction within the field of geography following Timmerman's conceptualization. He argued that "vulnerability is a term of such broad use as to be almost useless for careful description at the present, except as a rhetorical indicator of areas of greatest concern" (Timmerman 1981). On the contrary, Gupta (2020) posited that vulnerability has been associated or compared with various concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk (Liverman 1990). Currently, vulnerability is being utilized in the realm of global change, environment, and development studies. Recently, the discussion of urban vulnerability and the susceptibility has gained significant attention in the field of urban geography (Ziegler *et al.*, 2012). Vulnerability can manifest on both personal and individual levels, whether in spatial or non-spatial contexts. Meanwhile, social vulnerability pertains to the susceptibility of social groups or society towards potential losses brought by extreme events and their capacity to absorb and endure the impacts (Beilfuss and Nhemachena, 2019). Moreover, vulnerability can exist in various domains such as a residence, an electrical network, or transportation infrastructure from a technical standpoint. Finally, the interaction between society and biophysical conditions presents a potential for loss that can impact the resilience of the environment to respond to hazards or disasters, while also influencing society's ability to adapt to changing conditions.

Hence, the differences in vulnerability definitions arise from a range of epistemological perspectives and resulting methodological approaches. Furthermore, there exist significant discrepancies in the assortment of threats, encompassing natural, chemical, technological, biological, man-made, and instrumental hazards, as well as the magnitude of their impact on a global versus local scale. Additionally, the geographical areas examined, whether developed or developing regions, also display substantial variations.

2.3.1 Evolution of the Vulnerability Concept

The comprehension of vulnerability has undergone evolution across diverse contexts and scenarios. The term vulnerability denotes the degree to which a socio-ecological framework is susceptible to unfavorable consequences arising from the exposure to a hazard (Berrouet *et al.*, 2018). While the definition seems to be widely accepted, the means of implementing it to measure vulnerability is still unresolved and remains an open question. To begin with the term's "harm", "exposure", and "hazard" are all subject to broad interpretation, with the interconnections among them similarly so. Furthermore, the assignment is rendered considerably more arduous by the multidisciplinary nature of the literature pertaining to susceptibility, given that the notion has been utilized in the fields of geography, sociology, economics, health, and environmental science. Through an analysis of its origins in diverse fields and the evolving emphasis from species and ecosystems to human populations and societal structures, valuable insights can be gleaned regarding the vital role that vulnerability plays in comprehending and confronting the obstacles of an interrelated global community.

The origins of susceptibility can be retraced to the ecological writings of the late 19th and early 20th centuries. During this time, naturalists and ecologists keenly observed the susceptibility of certain species and ecosystems to environmental changes and disturbances. At first, vulnerability was employed to describe the probability of certain species facing extinction or ecological disruptions because of environmental pressures. During the middle of the 20th century, the concept of vulnerability spread to the realm of human geography. The emphasis moved from ecological vulnerability to comprehending how communities were susceptible to hazards, managed their repercussions, and recuperated from catastrophes. Human vulnerability emerged as a crucial element in disaster research and aided in the creation of resilience plans.

The latter portion of the 20th century witnessed the emergence of the notion of vulnerability as a significant aspect of sociology. Researchers embarked on studying how social collectives and individuals were vulnerable to hazards and disruptions due to a variety of factors, such as societal inequalities, economic discrepancies, and political marginalization. The assessments of vulnerability not only encompassed exposure to hazards but also incorporated social and economic dimensions, thereby emphasizing the interdependence between vulnerability and social contexts. In the 1980s and 1990s, the study of vulnerability experienced a further enhancement with the emergence of disaster studies as a distinctive field. Distinguished researchers such as Timmerman played pivotal roles in advancing the comprehension of vulnerability in the context of disasters (Timmerman, 1981). Vulnerability assessments became more comprehensive by integrating elements such as socio-economic status, access to resources, and infrastructure. This approach facilitated a more nuanced understanding of vulnerability that extended beyond mere exposure to hazards.

As sustainable development gained traction as a global objective, vulnerability became a central concern. Policymakers and international organizations acknowledged the significance of addressing vulnerability to attain sustainability objectives. The concept of vulnerability was perceived as a dynamic interaction between social, economic, and environmental factors, necessitating holistic approaches to evaluation and mitigation. In the present day, as climate change takes center stage as a critical worldwide issue, evaluations of vulnerability have gained importance in both the realms of climate science and policy. The IPCC has underscored the importance of understanding the susceptibility to climate change, recognizing that it is influenced by exposure, sensitivity, and adaptability. Accordingly, vulnerability assessments have evolved into pivotal instruments for comprehending the hazards posed by climate change and for formulating adaptive measures.

In contemporary era, vulnerability has acquired a broader meaning, ultimately leading to the concept of socio-environmental vulnerability. This comprehensive approach recognizes the complex interconnectedness between human societies and the environment. Evaluations of socio-environmental vulnerability examine not just the vulnerability of communities but also the vulnerability of ecosystems and their interrelatedness. This inclusive outlook requires concerted efforts to address social and environmental vulnerabilities simultaneously. In summary, the concept of vulnerability has undergone a multifaceted evolution, encompassing ecological, social, and environmental dimensions. Starting in ecological literature, vulnerability extended its reach to human geography, sociology, and disaster studies, becoming a vital perspective in comprehending the interactions between societies and their surroundings. Today's understanding of socio-environmental vulnerability highlights the inseparable link between human well-being and ecological balance. Embracing vulnerability comprehensively offers valuable perspectives on the complexities of an interconnected world, enabling the development of focused approaches to enhance resilience and promote sustainability for generations to come. Table 2.1 shows the chronological evolution of the vulnerability concept from its early origins to its contemporary understanding.

Table 2.1 Chronological evolution of the vulnerability concept (Cao et al., 2023; Courteille et al., 2022; Paul 2014)

Time Period	Field/Context	Evolution, Impact and Contributions
Late 19th to Early 20th Century	Ecological Literature	First observed in ecological literature, describing susceptibility of species and ecosystems to environmental changes.
Mid-20th Century	Human Geography and Vulnerability	Expanded to human geography, focusing on communities' exposure, coping, and recovery from natural hazards.
Late 20th Century	Sociology and Vulnerability	Gained traction in sociology, exploring social groups' susceptibility to risks due to social inequalities and economic disparities.
1980s-1990s	Disaster Studies and Vulnerability	Became prominent in disaster studies, assessing vulnerability beyond exposure to hazards, including socio-economic factors.
Late 20th Century	Sustainable Development and Vulnerability	Recognized as a concern in sustainable development, requiring holistic approaches to address social, economic, and environmental factors.

Table 2.1 Presents the chronological evolution of the vulnerability concept (Cao et al., 2023; Courteille et al., 2022; Paul 2014) (cont.)

Time Period	Field/Context	Evolution, Impact and Contributions
21st Century	Climate Change and Vulnerability	Gained prominence in climate science and policy, emphasized by the IPCC, focusing on exposure, sensitivity, and adaptive capacity to climate change.
Contemporary Era	Socio-Environmental Vulnerability	Evolved into a broader concept, considering the intricate relationship between human societies and the environment, calling for integrated approaches to address social and environmental vulnerabilities.

2.3.2 Type of Vulnerability

The concept of vulnerability is complex and multifarious, comprising diverse dimensions that affect the proneness of individuals, communities, and ecosystems to negative consequences. This area investigates a plethora of vulnerability types, spanning from socio-economic and environmental vulnerability to health and climate vulnerability, elucidating the intricacies of each category.

The category of urban vulnerability pertains to the proneness of cities and their inhabitants to diverse hazards and strains, which frequently emanate from socio-economic, environmental, and infrastructural elements (Gandini, 2020) . It encompasses the potential for adverse impacts and challenges in dealing with shocks such as natural disasters, climate change, insufficient public services, poverty, and inequality. The factors that contribute to urban vulnerability comprise population density, fragile governance, scarceness of resources, and restricted access to vital services (Diaz-Sarachaga and Jato-Espino, 2020; Gandini, 2020). Mitigating urban vulnerability necessitates the implementation of comprehensive strategies that encompass a multitude of resilience-building measures, equitable urban planning, social safety nets, and sustainable development practices. These strategies are indispensable in fortifying the ability of cities to endure and recuperate from unforeseen shocks, while also enhancing the well-being of their inhabitants.

The term "health vulnerability" pertains to the susceptibility of certain individuals or populations to encounter unfavorable health outcomes due to a combination of biological, social, economic, and environmental factors (Fatemi et al., 2017; Otto et al., 2017; Grigorescu, et al., 2021). It encompasses a heightened risk of illness, restricted healthcare access, and reduced capacity to manage health-related challenges. Contributing factors to health vulnerability may comprise age, pre-existing health conditions, poverty, limited access to healthcare facilities, and discrimination (Kumar, et al 2016; Ebi, et al. (2020). To tackle health vulnerability, targeted interventions such as enhanced healthcare access, public health campaigns, social support programs, and efforts to decrease disparities are necessary. By resolving these factors, we can augment the comprehensive health and well-being of vulnerable populations and foster health equity.

In the meantime, climate vulnerability pertains to the susceptibility of regions, communities, or ecosystems to the unfavorable impacts of climate change. The emergence of this issue stems from their expose with climate-related risks such as extreme weather events and the escalation of sea levels, as well as their sensitivity and ability to adapt to these alterations (Tang, 2019; Thong *et al.*, 2022). Regions that are vulnerable often experience disruptions in ecology, society, and economics, which affect livelihoods, infrastructure, and ecosystems (Abdul Rahman, 2018; El-Zein *et al.*, 2021; Faruk and Maharjan, 2022). Various elements that influence climate vulnerability encompass the geographical position, socio-economic standing, inadequate governance, and restricted accessibility to resources. Addressing the vulnerability of the climate requires the implementation of proactive measures not limited to climate adaptation strategies, sustainable development planning, disaster preparedness, and international cooperation (Hardiansyah *et al.*, 2020). These measures are imperative in building resilience and mitigating the risks associated with the detrimental effects of climate change.

Moreover, environmental susceptibility pertains to the proneness of ecosystems and natural resources towards disturbances and pressures, oftentimes caused by human activities and natural phenomena. It encompasses the possibility of ecological decay, depletion of biodiversity, and disruption of ecosystem services that promote life and human welfare. Contributing factors to environmental vulnerability comprise deforestation, pollution, habitat destruction, overexploitation of resources, and the impacts of climate change. This susceptibility can result in dire repercussions, such as water scarcity, soil erosion, and perils to biodiversity (Payus *et al.*, 2020; Rosly *et al.*, 2022; Raihan, 2023). Environmental susceptibility is influenced by diverse elements such as deforestation, environmental contamination, impairment of ecosystems, resource exploitation, and the consequences of climate change.

The combination of vulnerability that is favorable comprises socio-economic and socio-environmental factors. Socio-economic vulnerability is denoted by the susceptibility of individuals or communities to economic and societal risks, brought about by elements such as poverty, inadequate education, and limited healthcare access (Deguen *et al.*, 2022; Van *et al.*, 2022). These factors can lead to restricted resources, rendering it challenging to cope with economic downturns, disasters, and health crises, perpetuating cycles of poverty. Addressing the issue necessitates the implementation of all-encompassing policies that promote economic expansion, establish robust social safety nets, and provide equitable opportunities to enhance the welfare and capacity for adaptation of susceptible cohorts (Furlan et al., 2021; Leal Filho et al., 2021; Raihan, 2023).

Conversely, socio-environmental vulnerability pertains to those areas that confront unfavorable repercussions due to the interplay of social and environmental determinants. Poverty, lack of resources, and inadequate infrastructure exacerbate their exposure to hazards such as pollution and climate change. To minimize these risks, a comprehensive approach considering both social and environmental aspects, with sustainable development practices, community engagement, and climate adaptation measures, is crucial to safeguard vulnerable communities and enhance resilience against environmental challenges. Table 2.2 shows the summary of the various types of vulnerability.

Table 2.2 Summary of various types of vulnerability (Tang, 2019; Uddin et al., 2019; Wu, 2021; Mourato et al., 2023)

Type of Vulnerability	Definition
Urban Vulnerability	Vulnerabilities specific to cities, including infrastructure and socio-economic aspects.
Health Vulnerability	Susceptibility to health risks and impacts, influenced by various factors.
Climate Vulnerability	Exposure and sensitivity to the impacts of climate change.
Environmental Vulnerability	Sensitivity of ecosystems to environmental changes and disruptions.
Socio-Economic Vulnerability	Susceptibility due to socio-economic factors and resource disparities.

2.4 Understanding Vulnerability: The Role of Exposure, Sensitivity, and Coping Capacity

The future climatic hazards have a great potential to impact populations around the world, especially in cities which has become the centre of economic expansion, resulting in an exponential growth in urban populations (Tascon-Gonzalez *et al.*, 2020). Therefore, cities, including coastal ones, are becoming denser in terms of built environment and infrastructure to sustain such a population growth. The term-built environment refers to the man-made surroundings that provide the setting for human activity, ranging in scale from buildings and parks or green space, to neighbourhoods and cities, and includes supporting infrastructure such as the energy networks, waste water collection, water supply or telecom (Page, 2018; Gupta *et al.*, 2020b).Possible future climate change and its associated impacts will have significant implications for urban populations as well as the built environment and infrastructure that serve them. The built environment exerts a considerable influence over local climate and ecology and moderates the way climate hazards are experienced by urban dwellers. Urban populations are already facing a range of weather-related risks such as summer heat waves, air pollution episodes and vector borne diseases, and global warming is likely to add to the existing risks.

Due to this factor, vulnerability is a paramount critical when it comes to evaluating the proneness of individuals, communities, or regions to assorted risks and challenges. It is a product of various factors that govern the extent to which a system is determined to undergo negative ramifications upon encountering hazards or stressors. To conduct a comprehensive assessment of vulnerability, three indispensable dimensions that merit consideration are exposure, sensitivity, and coping capacity. Assessing the vulnerability factor through the evaluation of exposure, sensitivity, and coping capacity enables policymakers and researchers to acquire a holistic perception of plausible hazards. This comprehension plays a pivotal role in devising precise interventions and tactics to elevate fortitude and diminish vulnerability.

2.4.1 Exposure

Exposure pertains to the degree to which a system is physically or geographically exposed to potential hazards or stressors. In the context of climate change, exposure considers factors like proximity to coastlines, geographical location, and dependence on specific ecosystems. For instance, communities situated along the coast encounter elevated susceptibility to the effects of rising sea levels and severe weather phenomena, whereas areas with agricultural-based economies may be at risk due to alterations in precipitation patterns and temperature fluctuations. By comprehending exposure, it is possible to pinpoint areas that are at greater risk and prioritize the necessary interventions accordingly.

In Malaysia, exposures are characterized by days of high temperature, high rainfall, dry spell, thunderstorm, and strong winds. The past decades have seen increasing occurrence of extreme weather events. Sarawak meteorology department was analysis and recorded that Sarawak has the most rainfall, surface temperature and precipitation in Malaysia. The month of January shows the maximum rainfall in coastal of Sarawak and northeast Sabah. Most regions in East Malaysia experienced an increase of up to 100 mm in rainfall during the two monsoon seasons. In detail, Sarawak has an increase of 6 – 10 % in rainfall amount and Sabah has an increase of more than 10% (Malaysian Meteorological Department, 2009). This would lead to higher high flows, meaning more severe floods, and lower low flows, meaning longer droughts. Floods occurred spontaneously because of consistent, substantial precipitation, high floods and elevated tides, and human action such as impeding of channels or disturbance of drainage, unlawful development, over-exploitation, and so forth. As Mohamad Yusoff (Yusoff *et al.*, 2018) stated, floods have achieved 40–50% of a wide range of calamities causing deaths globally. Similarly, floods are catastrophic events that have ruled from the 1880s until now and affect different populaces in Malaysia. The flood number periodically rises in every annual occurrence in Malaysia. Figure 2.3 shows the disaster statistics for Malaysia in 2020.

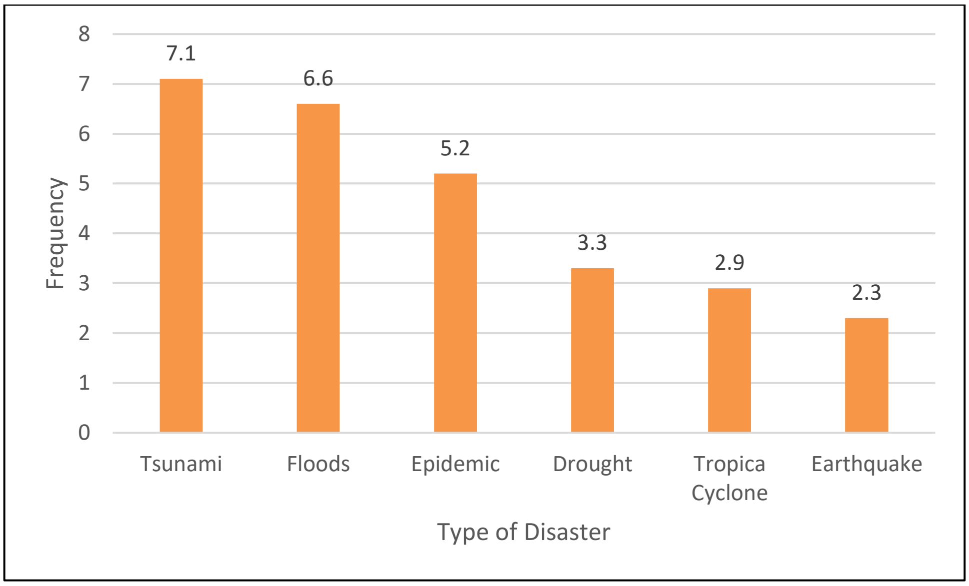

Figure 2.3 Disaster statistics for Malaysia(Muzamil *et al.*, 2022)

It can be analysed that the risk index for a tsunami occurring in 2020 is the highest at 7.1 followed by a flood located in the second-highest natural disasters risk index at 6.6 out of 10. According to the Flood Malaysia Indicator, Malaysia experienced significant floods from December 2014 to January 2015. Pretty much every state was hit by floods during that period, with more than 200,000 individuals affected. In 2016, it was recorded that Selangor, Kedah, and Penang were the states with the most floods. The ongoing floods also occurred in various areas such as Johor, Pahang, Melaka, and Sarawak. Floods can happen anytime, anywhere, unpredictably. Figure 2.4 shows the flood frequency in Sarawak from 2015 until 2019 (Muzamil *et al.*, 2022).

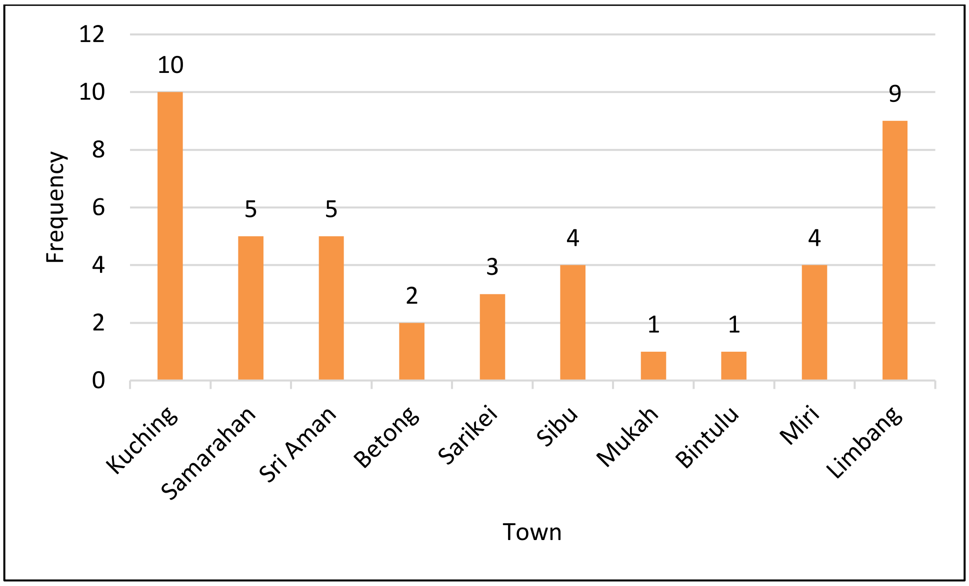

Figure 2.4 Flood frequency data in Sarawak from 2015 until 2019 (Muzamil *et al.*, 2022)

It is observed that Kuching stated the highest frequency of flooding within the previous five years. Next, it was followed by Limbang, Samarahan, Sri Aman, and the lowest one is from Mukah. These data have been summed into the month-to-month, occasional, and yearly sums to figure out the extraordinary rainfall event in Sarawak. According to the Sarawak Government, the winter monsoon, generally between November and February, brings weighty downpour, while the summer monsoon from June to October is typically breezier (Muzamil *et al.*, 2022). For instance, in December 2014 and January 2015, another substantial amount of precipitation occurred practically all through Sarawak, where explicitly a focused energy precipitation over 250 mm of precipitation occurred in Kuching between 18 and 19 January 2015 due to critical flood catastrophes in Sarawak (Tang, 2019). Flood control includes an integrated ecosystem approach, including members of the local community, such as farmers, as well as financial decentralization to local organizations (Saádi *et al.*, 2017). It is also reported that elderly persons are the most affected group during disaster events (Busayo *et al.*, 2022). Sarawak, a state in Borneo in Malaysia, experienced yearly precipitation around 3000 to 4000 mm (Tang, 2019). Meanwhile, Busayo and Kalumba (Busayo, E. T., and Kalumba, 2021) stated that the low-lying landform, notwithstanding the very high yearly precipitation, adds to streak flooding events in Kuching, the capital city of Sarawak. Meanwhile, the hydroelectric dams project located in the woodland regions of southern and north-eastern Sarawak are still ongoing and are estimated to be finished in 2030 (Rosly *et al.*, 2022).

Drought is a natural hazard with large impacts on regular human activities, reduction of crop production and water shortages. Drought is linked to precipitation intensity, amount of precipitation occurrences and time scale between two wet seasons. The severe drought in 1998 was connected to the strong El Nino Southern Oscillation event, which affected millions of residents in Sarawak, Malaysia, caused high global temperatures, disrupted water supply in regional areas, caused forest fires and impacted irrigated agriculture. According to the World Meteorological Organization (WMO), six drought periods in Sarawak were during the periods 1982–1983, 1986–1988, 1991– 1992, 1997–1998, 2009–2010 and 2014–2016 due to the strong El Nino (Bong and Richard, 2020; Din et al., 2017).

2.4.2 Sensitivity

Sensitivity refers to the degree to which a system is susceptible or responsive to the impact of exposure. Systems that are highly sensitive are likely to encounter significant impacts despite relatively low exposure to the associated risk. Contributing factors to sensitivity consist of the presence of populations that are vulnerable, reliance on specific ecosystems or resources, and insufficient infrastructure or services. Vulnerable socio-demographics, including minors, senior citizens, and marginalized societies, may exhibit heightened susceptibility to the unfavorable consequences of environmental shifts or calamities. Understanding of sensitivity enables the identification of the unique requirements of vulnerable groups and the development of tailored adaptation strategies.

This section lists out the sensitivity or vulnerability to extreme events, disasters, hazards, and climate change. Sensitivity is a multi-dimensional and complex component of social, environmental, and economic vulnerability (Bigi *et al.*, 2021). The ability of people in different communities and societies to adapt and cope with changes was known as social vulnerability. Therefore, the social vulnerability comprises basic information on population density, gender distribution, dependency ratio and public health of the group. Population growth has been accepted as the major drive or key component in sensitivity and vulnerability (Bigi *et al.*, 2021). Many aspects of urban areas are vulnerable 26 to natural disasters and climate change. For instance, Bangladesh is a densely populated urban area which has encountered with the impacts of climate change (Busayo, E. T., and Kalumba, 2021; Mohd et al., 2019). The dense concentration of urban populations can increase the vulnerability to the disasters that are expected to become more intense and frequent because of climate change (Andrade and Szlafsztein, 2018; di Girasole and Cannatella, 2017). The study also found the climate change will affect human health through heat stress, increasing diarrheal due to water and food-borne disease, facilitate the growth and development of various vector-borne disease (such as malaria and dengue), loss and fatalities from natural disasters, and malnutrition resulting directly from declining yields and/or indirectly through increasing food prices and chemical used or lower demand for agricultural labour (Alhoot *et al.*, 2016; Grigorescu *et al.*, 2021a; Thong *et al.*, 2022).

Meanwhile, humans and the environment are dependent on one another. Therefore, the environmental vulnerability deals with vulnerability of the people to environmental hazard. Risks to the environment will eventually translate into risks to human because of their dependence upon the natural environment for resources (Nguyen *et al.*, 2019). There are two main sources that contribute to the environmental vulnerability which are air and water pollution. Air pollution is a major health risk that may worsen with increasing industrial activity and consumption of fossil fuel (Das *et al.*, 2020). Ambient air pollution and climate change are placing Malaysian at significant health risks (Wan Hassan, 2007). Hence, the Department of Environment Malaysia has established an ambient air quality monitoring networks located in urban, sub urban and industrial areas throughout the country to detect any significant change in the air quality which may be harmful to human health and the environment.

Climate change has its direct effects to the water cycle in terms of quality and quantity of water resources (Aslam *et al.*, 2018; Sarker *et al.*, 2022). Adverse impacts of climate change on water cycle and weather could mean that some 31 regions will become dryer, while the other is facing excessive or abundant of rainfall episode which could leads to major flooding events. Changing water cycles caused by climate change will affect food production, land use and survival of human being (Alhoot *et al.*, 2016; Otto *et al.*, 2017).

2.4.3 Coping Capacity

Coping capacity pertains to the capability of a system to confront, adapt to, and recuperate from the effects of exposure and sensitivity. It gauges the system's resilience and adaptability when confronted with stressors. The capacity to cope is subject to various factors such as access to resources, which include financial, technological, and human resources, institutional robustness, community organization, and the efficiency of governance structures. Meanwhile, a greater coping capacity allows a system to better handle and recover from unfavorable occurrences, decreasing vulnerability and encouraging sustainable development.

The capacity to cope refers to a system's capability to regulate the effects of climate change. This involves moderating potential damages, capitalizing on opportunities, and dealing with consequences. The focus of coping capacity is on future learning and reinvention. The impact on human health resulting from climate change is contingent upon several factors. Firstly, the impact of climate change and its accompanying ramifications on local communities. Secondly, it relies on the vulnerability of these communities to the effects. Lastly, it hinges on their capacity to cope with these effects (Grigorescu *et al.*, 2021b). Despite the imminent reduction of greenhouse gas emission rates, it is expected that the Earth's climate will undergo persistent transformation. Hence, it is essential to factor in the coping and adaptive capacity to mitigate any possible detrimental outcomes of climate change in the future.

Geography, as well as geographical positioning, is considered to be one of the most crucial physical adaptabilities (Otto et al., 2017; Aslam et al., 2018). Settlements established in low-lying areas are at a higher risk of experiencing climate change-related natural disasters, particularly floods and intense storms. The region is susceptible to extreme rainfall events or prolonged periods of rainfall, which frequently result in coastal and inland flooding (Payus et al., 2020; Isia, Hadibarata, Jusoh, et al., 2023). Other physical coping abilities that assist in responding to humanitarian emergencies include road density, electricity and telecommunication coverage, potable water supply, literacy, and the availability of health facilities. Improving transportation (road density), communications, and accessibility during natural disaster events to counteract geographical positioning may be considered one of the best coping ability methods (Rufat, S., Tate, E., Emrich, C. T., & Antolini, 2019). Currently, various methods and frameworks for assessing vulnerability to climate change have been developed and applied by different climate research organizations, institutes, agencies throughout the world (Table 2.3).

Table 2.3 The diverse methods for various vulnerabilities in different country

Target Area	**Targeted research**	**Targeted research area**	**Methods**	**Indicators**	**References**
Australia	Flood vulnerability	Integrated of flood vulnerability index with geophysical modelling of floods with socioeconomic assessments of vulnerability	Flood Social Vulnerability Index (FSVI)	Exposure	(El-Zein et al., 2021)
China	Household vulnerability	To construct an extended framework of climate change vulnerability assessment at the household level	Principal Component Analysis (PCA)	Exposure, Sensitivity, Adaptive capacity	(Xu et al., 2020)
India	Drought vulnerability	To identify the most drought state	Exposure-Sensitivity Index (ESI)	Exposure, Sensitivity	(S. Kumar et al., 2016)
Malaysia	Coast vulnerability	To assess the coastal vulnerability index (CVI) of the Pahang coast	Coastal Vulnerability Index (CVI)	Exposure	(Mohd et al., 2019)

Table 2.3 The diverse methods for various vulnerabilities in different country (cont.)

Target Area	Targeted research	Targeted research area	Methods	Indicators	References
Malaysia	Drought vulnerability	To use for drought identification and monitoring in Sarawak River Basin.	Standardized Precipitation Index (SPI)	Exposure	(Bong and Richard, 2020)
Mexico	Agricultural vulnerability	To assess vulnerability to climate change in the Mexican agricultural sector	Principal Component Analysis (PCA)	Exposure, Sensitivity, Adaptive capacity	(Monterroso et al., 2014)
South Africa	Drought vulnerability	To determine municipalities that are socially prone to drought disaster impacts	Iyengar-Sudarshan method	Sensitivity	(Birkmann et al., 2022)
Vietnam	Agricultural vulnerability	To assess Climate Change Vulnerability Index for Agriculture Production	Climate vulnerability assessment support software (CVASS)	Exposure, Sensitivity, Adaptive capacity	(Duong et al., 2017)
Malaysia	Socio-Environmental Vulnerability Index	To understanding the relationship between social and environmental vulnerability index (SENVIINT) of the Sarawak, Malaysia	Socio-environmental vulnerability index (SENVIINT)	Exposure, Sensitivity, Adaptive capacity	Current study

Previous research shows only Ethiopia and India implement the integration of socio-environmental vulnerability assessment to analyses the impact of climate change to household and agro-ecosystems (Table 2.3). Compared with Ethiopia and India which are more focus studied socio-factor on high altitudes and crops production, respectively, however, in Malaysia, the vulnerability assessment method is based on a current risk assessment and yet there is no holistic integration of methods for vulnerability index between social and environmental. Moreover, the research on integrated socio-environmental vulnerability index in Malaysia, especially Sarawak, will provide the data of the black spot region mapping and can use to forecast the extent of the black spot in near future due to climate change under different scenarios. Climate adaptation as a theme is listed as a policy under the Ministry of Urban Wellbeing, Housing and Local Government's National Physical Plan 2; and climate change adaptation, specifically determining measures to aid adaptation of water resources to threats and emerging threats is in the country's Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) (Table 2.4). The Department of Irrigation and Drainage (DID) in Sarawak coordinated both the Integrated Coastal Zone Management program and the Integrated Shoreline Management Plan (ISMP), both aimed at addressing the major issues and problems facing the country's shoreline.

Table 2.4 Leading Malaysia Institutions & Policies/Programs reviewed (Sulaiman, N., She, T. W., Fernando, T., WeiChan, S., Roslan, A. F., & Latib, 2019)

Federal	State	Policies and Priorities Climate	Climate Change Objectives
	Forest Department	Sarawak Forestry Corporation Ordinance, 1995 (Chapter 17)	Adaptation & Productivity
	Drainage Irrigation Department	National Coastal Resources Management Policy. (Environmental Impact Assessment) Order 1987 and the Natural Resources and Environment Ordinance (Sarawak) 1949 (As Amended 1994).	Adaptation & Mitigation
		Integrated Coastal Zone Management Program Integrated Shoreline Management Plan (ISMP)	
	Department of Land and Survey	Sarawak Land Code 1958 (Chapter 81), Agricultural suitability maps	
	Department of Land and Survey	Natural Resources and Environmental (Amendment) Ordinances, 2001 (Cap 84) and its relevant regulations	Mitigation
Department of Environment		Environmental Quality Act 1974	Mitigation
Ministry of Natural Resources and Environment (MNRE)		The National policy on Climate Change 2010	Mitigation
		Ministry has jurisdiction over communication with the UNFCCC	Mitigation

Table 2.4 Leading Malaysia Institutions & Policies/Programs reviewed (Sulaiman, N., She, T. W., Fernando, T., WeiChan, S., Roslan, A. F., & Latib, 2019) (cont.)

Federal	State	Policies and Priorities Climate	Climate Change Objectives
Ministry of Natural Resources and Environment (MNRE)		Second National Communication (NC2) Project – greenhouse gas inventory, projections and mitigation options; vulnerability assessment and adaptation	
Economic Planning Unit		11th Malaysian Development Plan, 2016-2020	Adaptation
Malaysian Meteorological Department		Climate change modelling and forest climate interaction studies. Climate pattern of Sarawak: rainfall, temperature, relative humidity, and solar radiation.	Adaptation
	Department of Agriculture	Divisional Agricultural Department project documents -	Adaptation, Mitigation & Productivity
		State fishery ordinances (2003) TAGANG – Ecotourism projects	
		- TKPM Project documents -	
		- Sarawak Good Agricultural Practices (MyGAP)	
		- Divisional Agricultural suitability maps	
		- Agricultural statistic of Sarawak 2018 -	
		- External trade 2017 handbook	

The Sarawak State Planning Unit, SPU led a plan in 2009 to formulate an integrated water resources management (IWRM) in Sarawak state to meet future water demand up to the year 2050 (*The Official Portal of the Sarawak Government*). The SPU is also formulating an agriculture master plan which is currently in the draft stage. The report, according to officials at the SPU, began in 2019 and is undergoing peer review and final appraisals before release. Key objectives of the master plan include strengthening compliance in the agriculture sector, value chain prioritization – from table to marketing access, infrastructure (production to market), and certification. This effort is geared towards the state government vision 2030 to make Sarawak a net food exporter by 2030.

2.5 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a remarkable methodology for decision-making, formulated by Thomas L. Saaty in the 1970s (Saaty, 1990). It systematically tackles complex problems by breaking them down into a hierarchical structure of criteria and alternatives. AHP boasts widespread use in diverse fields such as business, engineering, project management, and resource allocation, enabling informed and rational decisions to be made with ease. The Analytic Hierarchy Process serves as a critical tool in supporting informed and logical decision-making amidst intricate alternatives. Through the fragmentation of a problem into a hierarchical arrangement of criteria and options, AHP empowers decision-makers to grasp the interconnections between diverse aspects implicated in the decision-making process (Szabo *et al.*, 2021). Its usefulness manifests itself particularly in circumstances where there exists a multitude of factors to be assessed, and each factor may possess a varying degree of importance in attaining the final goal.

The Analytic Hierarchy Process (AHP) possesses great importance owing to numerous inherent benefits it provides. To begin with, it facilitates the amalgamation of both subjective and objective components in the decision-making process. This enables decision-makers to blend their expertise and judgment with quantitative data and metrics, thereby leading to a more comprehensive evaluation process. A fundamental element of AHP involves the pairwise comparison of elements in the hierarchy. Decision-makers allocate numerical values to indicate the relative significance of criteria and the performance of alternatives. This pairwise comparison serves as the bedrock for determining priorities and aids in circumventing the pitfalls of more traditional decision-making approaches.

Moreover, AHP incorporates a consistency check to ensure that decision-makers provide coherent and consistent judgments during the pairwise comparisons. This check helps maintain the reliability and integrity of the decision-making process and minimizes potential biases. The utilization of AHP consists of a number of fundamental stages. The initial stage involves decision-makers establishing the problem and identifying the criteria and alternatives that are to be taken into consideration. They then proceed to arrange these elements into a hierarchical structure, culminating in the primary decision objective at the apex. For every tier of the hierarchy, decision-makers engage in a process of pairwise comparisons to ascertain the respective significance of the constituent components. These comparisons yield numerical values that signify the strength of preference for one element over another. Consequent to this, priority weights for criteria and alternatives are computed utilizing the data obtained from the pairwise comparisons.

The utilization of Analytic Hierarchy Process (AHP) aids in establishing an index and evaluating the susceptibility of the Sarawak area to ecological and societal hazards. By incorporating AHP in the development of the index, policymakers and stakeholders in Sarawak acquire valuable insights into the vulnerabilities of the area, empowering them to devise targeted interventions, establish resilience-enhancing strategies, and implement evidence-based policies that foster sustainable growth and address pressing environmental and social issues. The association between AHP, the Socio-Environmental Vulnerability Index, and Sarawak serves as a prime example of the potential of this methodology in guiding impactful measures towards a more robust and sustainable future for the region.

Principal Component Analysis (PCA) is an statistical methodology that is leveraged to streamline and examine intricate data sets by curtailing their dimensionality, while preserving crucial patterns and trends. Its primary objective is to streamline and assess intricate data sets by diminishing their dimensions while preserving crucial patterns and trends. PCA provides the possibility to transmute a group of likely associated variables into a smaller collection of uncorrelated variables that are known as principal components.

2.6 Principal Component Analysis (PCA) in Sarawak

The fundamental notion that underlies PCA is to locate the directions in which the data exhibit the most variability, and these directions are portrayed through the principal components. The first principal component expounds on the maximum variance in the data, and each subsequent component clarifies the highest remaining variance while being orthogonal to the previous ones. By doing so, PCA enables us to depict the data in a more concise and comprehensible structure, which is particularly advantageous when dealing with expansive data sets or intricate associations among variables.

In the context of the Sarawak Socio-Environmental Vulnerability Index (SENVIINT), Principal Component Analysis (PCA) assumes a crucial role in evaluating and comprehending the elements that contribute to vulnerability in the region. SENVIINT is an all-inclusive measure that assesses the susceptibility of a particular area, like Sarawak, to the effects of social and environmental factors. These factors are inclusive of climate change, natural calamities, economic conditions, population density, resource accessibility, and social infrastructure. Through the application of PCA on the SENVIINT data, policymakers and researchers can effectively identify the key catalysts of vulnerability, whilst concurrently comprehending their interdependence. The first principal component can highlight the most dominant aspect that influences vulnerability in the region, whereas the subsequent components can capture other pertinent dimensions. These components can encompass a blend of social and environmental factors, thus illuminating the intricate relationship between human activities and their effect on the environment.

The implementation of PCA leads to a reduction in dimensionality, which proves to be advantageous in simplifying the SENVIINT assessment. This simplification makes the assessment accessible to policymakers, stakeholders, and the general public. It eliminates the need to deal with an abundance of variables and enables them to concentrate on a few essential components that encapsulate the vulnerable characteristics of Sarawak. This newfound knowledge is invaluable in the creation of effective policies and strategies, aimed at tackling the challenges faced by the region. Furthermore, the implementation of PCA enables regional comparisons by generating a standardized vulnerability index that can be applied to different areas. This allows decision-makers to recognize high-risk regions and allocate resources to address their specific needs. Additionally, PCA can aid in detecting potential trade-offs and synergies between various social and environmental factors. For instance, it may reveal that a region with lower economic conditions possesses a higher adaptive capacity due to better access to resources. This information can influence decision-making regarding targeted interventions.

In conclusion, Principal Component Analysis (PCA) is a powerful instrument for scrutinizing and simplifying intricate data sets, encompassing those linked to the Sarawak Socio-Environmental Vulnerability Index (SENVIINT). By reducing the dimensional complexity of the data, PCA enables the identification of the primary catalysts of vulnerability in the region and perceive the interplay between social and environmental factors. This comprehension is fundamental in devising targeted policies to amplify the region's resilience and sustainability. Figure 2.5 illustrates the utilization of indicators for the Sarawak Socio-Environmental Vulnerability Index (SENVIINT) subsequent to the Principal Component Analysis (PCA) process.

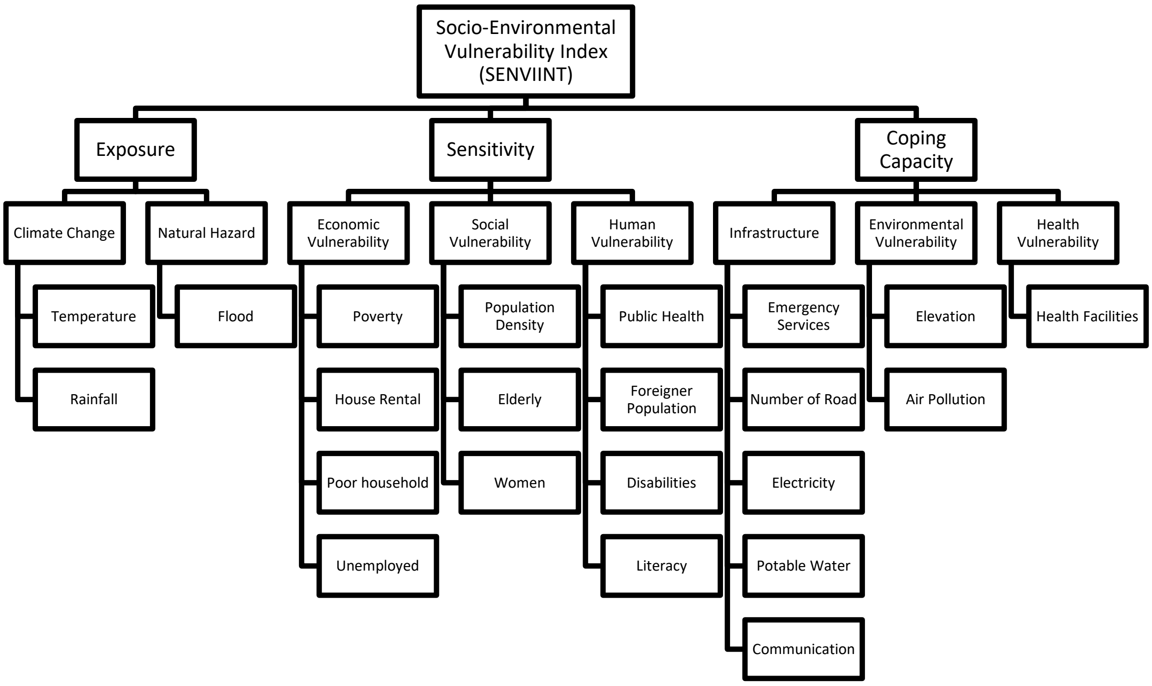

Figure 2.5 Indicator for Sarawak Socio-Environmental Vulnerability Index

2.7 Framework of Socio-Environmental Vulnerability Index (SENVIINT)

The Socio-Environmental Vulnerability Index (SENVIINT) model was formulated in prior research for various objectives. Several studies utilizing SENVIINT have been conducted to examine the correlations and dimensions of urbanization, map out landscapes across different altitude zones, and assess the susceptibility of marginalized populations to climate change (Suroso *et al.*, 2013; Gupta *et al.*, 2020a; Alves, 2021). Meanwhile the Socio-Environmental Vulnerability Index (SENVIINT) was developed for Sarawak embodies a comprehensive approach designed to comprehend and tackle the region's susceptibilities to social and environmental challenges. The model entails a series of steps, commencing with the meticulous selection of indicators that represent factors such as poverty, education, water accessibility and other pertinent aspects. These indicators facilitate the creation of a holistic representation of vulnerability in Sarawak.

Through the collection of data from reputable sources, the model obtains information that is vital for conducting a vulnerability assessment. The normalization process guarantees impartiality in the comparison of indicators by transforming them to a uniform scale. The weight allocation procedure reflects the relative significance of each indicator, which enables the computation of composite vulnerability scores for distinct regions in Sarawak. Spatial analysis and mapping visually illustrate vulnerability patterns, identifying hotspots and areas needing special attention. Validation and sensitivity analyses verify the model's reliability and robustness.

Engaging local communities and stakeholders is a critical aspect, as their knowledge and insights enrich the model's context and relevance. The model's results guide policymakers in making informed decisions and prioritizing interventions to build resilience and address vulnerabilities effectively. Continual improvement and periodic updates ensure the model remains accurate and adapts to changing circumstances. By following these steps, the SENVIINT model empowers Sarawak to proactively tackle socio-environmental vulnerabilities and foster sustainable development in the face of ongoing challenges. Figure 2.6 displays the flowchart delineating the Socio-Environmental Vulnerability (SENVIINT) model of Sarawak.

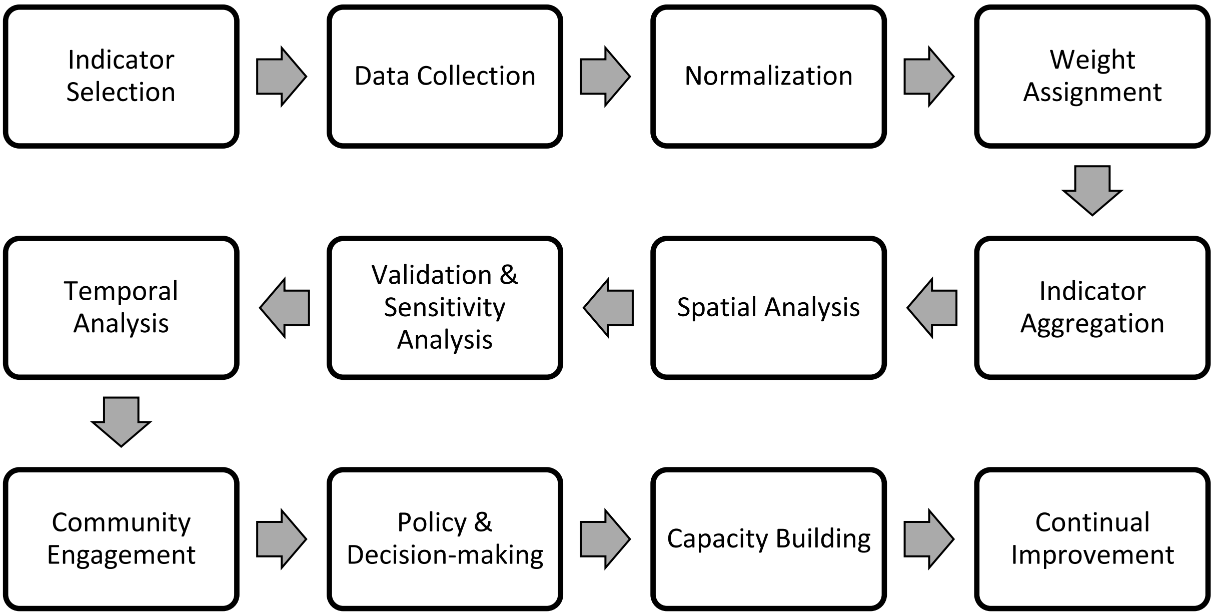

Figure 2.6 Socio-Environmental Vulnerability (SENVIINT) model for Sarawak

The present flowchart provides an overview of the distinct stages implicated in the establishment of the Socio-Environmental Vulnerability (SENVIINT) model for Sarawak. The initial phase of the procedure comprises the identification of pertinent indicators, data collection, and normalization of said data to a uniform standard. Subsequently, weights are allocated to each indicator based on its relative significance in contributing to vulnerability. The indicators are integrated to compute the composite vulnerability score for every geographical unit in Sarawak. Spatial analysis is utilized to facilitate the visualization of vulnerability patterns throughout the region. The dependability of the model is ensured through validation and sensitivity analyses. The temporal analysis entails periodic updates to the data. The involvement of the community and stakeholders is crucial throughout the procedure. The outcomes of the model are utilized to inform policy-making and decision-making. Capacity building is necessary to encourage local ownership and expertise in the use of the SENVIINT model. Continuous improvement guarantees that the model remains relevant and current over time.

2.8 Vulnerability Index Mapping and Integration of Socio-Environmental Vulnerability Index

The utilization of Vulnerability Index Mapping is a highly effective instrument that allows for the evaluation of a region's susceptibility to diverse stressors and risks. In the specific context of Sarawak, Malaysia, where the equilibrium between social welfare and environmental sustainability holds paramount importance, the integration of Socio-Environmental Vulnerability Index (SENVIINT) is deemed an essential measure. This comprehensive approach encompasses both social and environmental aspects, ensuring a more comprehensive comprehension of vulnerability and directing policymakers in the formulation of targeted approaches aimed towards resilience and sustainable development.

The process of Vulnerability Index Mapping commences with the identification and selection of indicators that accurately represent the social, economic, and environmental factors contributing to vulnerability. These indicators may comprise poverty rates, education levels, healthcare accessibility, natural resource availability, climate change impacts, and ecosystem health. The collection of data takes place from various sources, such as government records, surveys, and remote sensing technologies, guaranteeing a robust dataset for analysis. The subsequent phase entails the normalization and aggregation of the chosen indicators. Normalization is utilized to homogenize the data to a uniform scale, thus facilitating the comparison and integration of diverse indicators. The aggregation process involves the merging of the homogenized metrics, typically via weighted summation, to establish a composite Vulnerability Index that represents the general vulnerability of distinct regions within Sarawak.

In order to further augment the evaluation, Spatial Analysis is implemented. Geographical Information Systems (GIS) instruments are employed to chart the Vulnerability Index throughout Sarawak, exhibiting spatial trends and pinpointing areas with varying levels of vulnerability. The resultant vulnerability maps supply pivotal insights into comprehending localized vulnerabilities, such as coastal areas that are confronting sea-level rise, rural communities that are exposed to climate-related hazards, or urban centres that are grappling with social inequalities.

The integration of the Socio-Environmental Vulnerability Index (SENVIINT) serves to enrich the assessment by introducing an additional layer of complexity and nuance. In contrast to traditional vulnerability assessments, SENVIINT explores the interplay between social and environmental factors, resulting in a more comprehensive understanding of the drivers and interactions shaping vulnerability. Thus, it is possible to identify, for instance, poor communities that are particularly vulnerable to environmental degradation due to their reliance on natural resources for subsistence. The integration process involves the assimilation of social and environmental indicators, such as education levels and access to healthcare, biodiversity richness and water availability, respectively. The relative importance of each indicator is reflected in weight assignments, which account for their unique contributions to vulnerability. This holistic approach facilitates a more complete understanding of the factors shaping vulnerability in Sarawak.

Integrating SENVIINT into the Vulnerability Index Mapping provides decision-makers with valuable insights into the complex relationships between human activities and the environment. This knowledge is essential for designing targeted adaptation and mitigation strategies. For instance, policymakers can pinpoint areas with high vulnerability and devise interventions that foster sustainable economic development while preserving natural resources. In summary, the amalgamation of Vulnerability Index Mapping with the integration of Socio-Environmental Vulnerability Index in Sarawak yields a potent symbiosis, which facilitates a comprehensive comprehension and resolution of vulnerabilities in the locality. This all-encompassing approach amalgamates social and environmental dimensions, thereby equipping policymakers with the indispensable instruments required for the promotion of inclusive and sustainable development. This ensures the preservation of the welfare of communities and the environment for posterity. Through collaborative efforts and adaptive strategies, Sarawak can effectively tackle future challenges with resilience and foresight.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

Climate change vulnerability is a complex, multidimensional process influenced by numerous relevant factors i.e burning fossil fuels, cutting down forests and farming livestock are increasingly influencing the climate and the earth's temperature. According to IPCC (2007), the degree to which a system is prone to, vulnerable to, or unable to control or manage the negative consequences of stresses such as variability and extremes in the climate (Das *et al.*, 2020). Accordingly, a system's sensitivity, its capacity for adaptation, and the size, speed, and intensity of stress changes to which it is subjected determine how vulnerable a system is.

3.2 Research Framework

To determine which state will be most impacted by upcoming issues, an assessment of the existing situation is required. To identify the state of sensitivity in Sarawak, a climate change vulnerability index toward the human population has been established and specifically made for the region. First and foremost, based on previous literature and research, the choice to use a wide or a limited range of indicators is heavily influenced by the best data and representative indicators from Malaysia, especially Sarawak state. The creation of a vulnerability index using a variety of indications is typically how quantitative vulnerability assessment is carried out. This study will assess three parts of those vulnerabilities that it deems to be particularly significant, therefore it will specifically examine the exposure, sensitivity, and adaptive capacity. For example, the greater vulnerability was mainly due to high exposure to extreme events and less adaptive capacity, which can affect agricultural production negatively, in combination with high population density with less health facilities.

a) exposure to climate change refers to the size and rate of change in climate factors such as temperature and rainfall, which are known to have an impact on the human population.
b) sensitivity to its effects: the amount to which climate variability or change affects a community; and
c) coping capacity for survive with the effects: the ability of society to either offset the negative consequences of climate change.

The study framework of this research has been divided into three phases as shown in Figure 3.1. The three stages have covered data collection, proposed weighted average, and proposed integration index for vulnerability mapping. The initial stage of the research consists of gathering data from four distinct administrative divisions, which include a total of 14 districts: Kuching, Sibu, Bintulu, and Miri. Data procurement is conducted in collaboration with pertinent government agencies. Subsequently, the collected data undergoes Principal Component Analysis (PCA) to evaluate the suitability and relevance of the selected indicators, aligning with the achievement of objective 1 within this initial phase.

After categorizing all indicators into their respective components, namely Exposure, Sensitivity, and Adaptive capacity, the following step, referred to as stage 2, involves the processes of weighting and aggregation, which contribute to the development of formulas. The final stage involves the organization and normalization of the data, which is a crucial step in the creation of the proposed integration index. This concluding phase precedes the creation of Sarawak's vulnerability map.

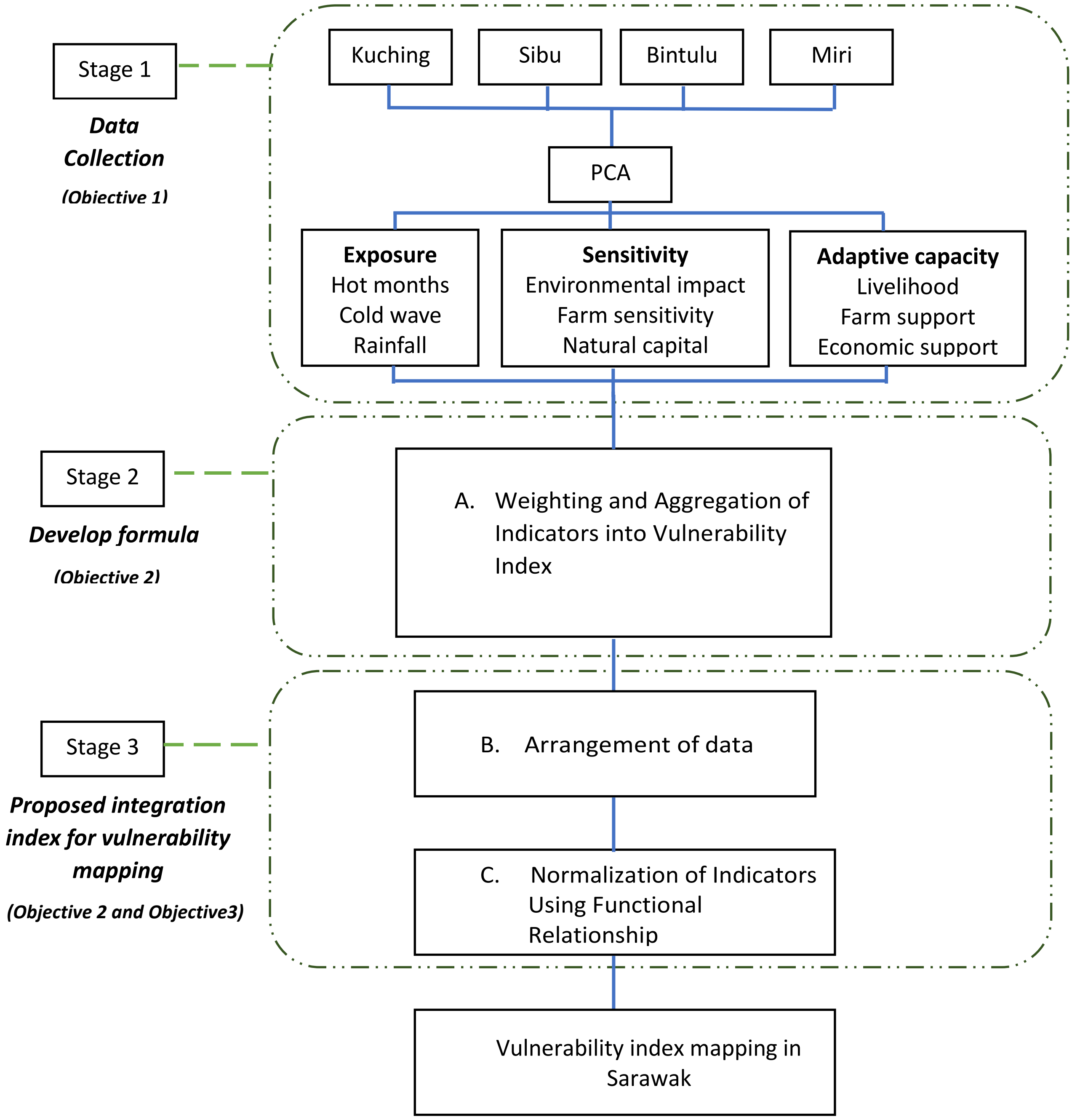

Figure 3.1 The flowchart of assessment of effect of climate change on integrated socio-environmental vulnerability index (SENVIINT) of Sarawak, Malaysia

3.3 Research Area

Sarawak is one of the 13 states in Malaysia situated on the island of Borneo. It is the largest state in terms of land area, covering approximately 124,450 km^2 and is positioned directly above the Equator, the region covers latitudes 0°50' to 5° N and longitudes 109°36' to 115°40' E. The state of Sarawak is bounded by the country of Brunei to the north, the state of Sabah to the northeast, the Kalimantan region of Indonesia to the east and south, and the South China Sea to the west, as shown in Figure 3.2.

Topographically, Sarawak is divided into of three different areas: the coastal lowlands, which have peat swamps and narrow deltaic and alluvial plains; a large area of rolling hills that reach up to 300 meters; and the mountain highlands that go all the way to the border with Kalimantan. It is where Malaysia's longest river, the Batang Rajang, starts in the Iran Mountains and flows southwest to Kapit, where it turns west and flows 563 km to the South China Sea. Agriculture is the mainstay economy of Sarawak, which is mostly focused on cash crops production. Paddy, sago, rubber, and pepper are examples of crops production that have made significant contributions to the economy of Sarawak.

Sarawak consists of 12 divisions: Kuching, Serian, Sri Aman, Samarahan, Sarikei, Betong, Kapit, Mukah, Sibu, Bintulu, Miri, and Limbang. In this study analyzed only 4 divisions of Sarawak consisting of 14 districts (Table 3.1). In 2010, the population of Sarawak was close to 2.4 million, and it has since grown to 2.9 million (Department of Statistics Malaysia, 2021). Most of the population live in the southern, central, and northern parts of the country, especially near the coasts, where most of the country's biggest cities are. Moreover, Sarawak has two different monsoon seasons throughout the year. The northeast monsoon (NE) is known for its heavy rainfall, which occurs between November and March, while the southwest monsoon (SW), which occurs between May and September, is usually more moderate. There are also two short "inter-monsoon" (INT) periods in April (Int-April) and October (Int-Oct). The NE monsoon is the rainiest season, with winds from the east or northeast at 10–20 knots. The SW monsoon, on the other hand, is relatively dry, with light winds from the southwest (below 15 knots) (Saádi *et al.*, 2017; Abid *et al.*, 2021; Muzamil *et al.*, 2022; Isia, Hadibarata, Jusoh, *et al.*, 2023).

Table 3.1 Basic demographics characteristics by different division and district by 2020-2021

Division	District	Area (km2)	Population	Population density
Miri	Miri	5143	274000	53.276
	Marudi	3079	24200	7.860
	Beluru	3821	26900	7.040
	Subis	4905	68500	13.965
	Telang Usan	9829	22200	2.259
Bintulu	Bintulu	1991	188000	94.425
	Sebauh	5229	30200	5.775
	Tatau	4946	35200	7.117
Sibu	Sibu	2230	278400	124.843
	Kanowit	2254	33400	14.818
	Selangau	3795	26500	6.983
Kuching	Kuching	1498	691300	461.482
	Bau	884	61000	69.005
	Lundu	1812	38200	21.082

Population density, which is a crucial demographic indicator, unveils the level of populace residing within a particular geographical region, commonly quantified in terms of square kilometer or square mile. Kuching, the capital city of Sarawak, serves as a dynamic metropolitan center with a notably high population density within the state. The multifaceted importance of the city as a major economic center, administrative focal point, and cultural core draws in inhabitants from various areas, thus contributing to its dense population. Compared to Sibu, the strategic location nestled along the banks of the Rajang River, serves as a primary trading and commercial epicenter. The population density of the city is influenced by flourishing economic endeavors, a strong educational sector, and a variety of cultural attractions concentrated in the central urban region. The river plays a significant role in facilitating trade, transportation, and the distribution of the population along its winding path.

Meanwhile, Miri, being strategically located near Sarawak's flourishing oil and gas industry as well as its renowned national parks, assumes a crucial position yet another pivotal urban center within the state. The population density of this district is prone to fluctuations, depending on whether one considers the urban core or the surrounding rural environs. Lastly, Population density within the Bintulu district exhibits variation across its diverse regions. The urban nucleus, owing to the presence of industries such as petrochemicals and liquefied natural gas, showcases higher population densities. The Bintulu district demonstrates varying levels of population density across its diverse regions. The urban core, which benefits from the existence of industries such as petrochemicals and liquefied natural gas, displays higher population densities. On the contrary, the rural areas within the district present a distinct demographic landscape, characterized by lower population densities and the coexistence of traditional communities harmoniously with the natural surroundings.

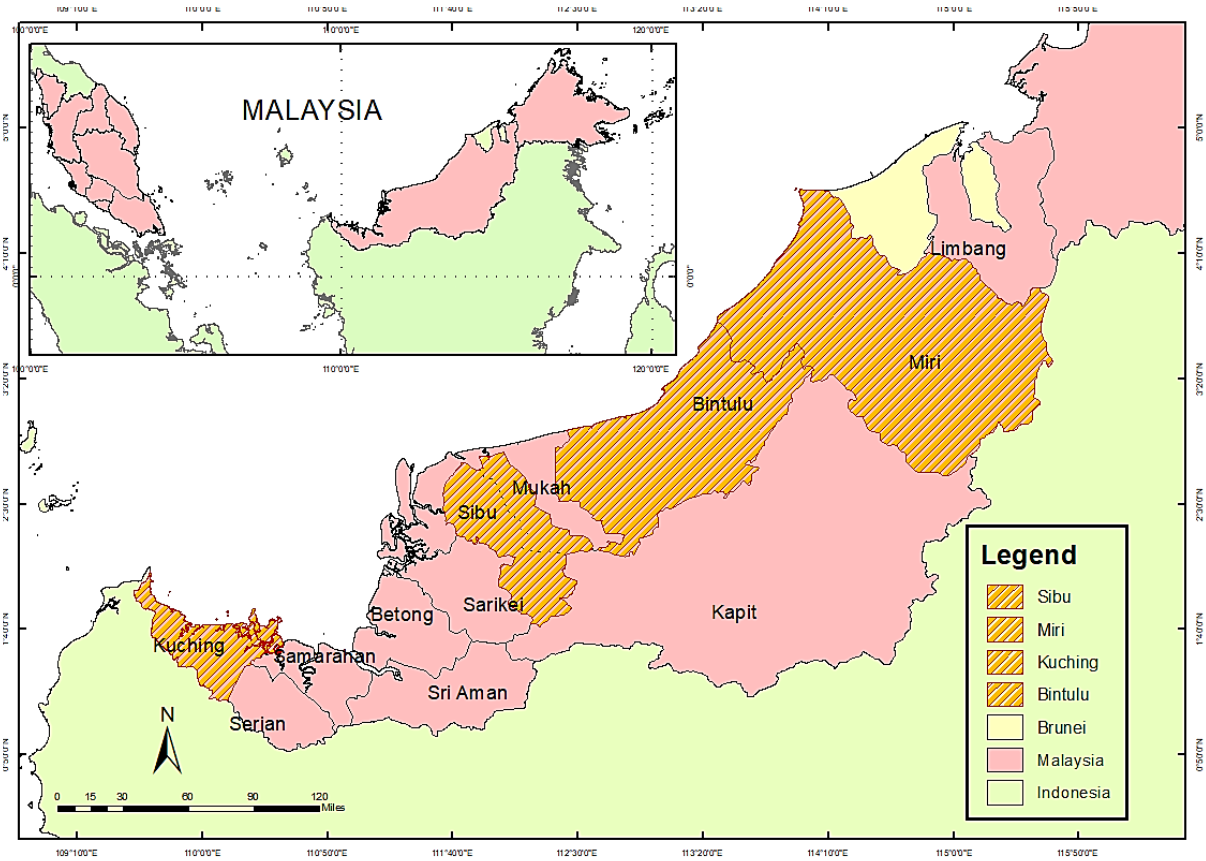

Figure 3.2 Location map of the study area in Sarawak

3.3.1 Kuching Division

Nowadays, Kuching integrates its history with modern infrastructure, displaying a variety of historical landmarks. With a population estimated at 790,000, Kuching represents a thriving and dynamic metropolis. The city celebrates its diverse community throughout the year with a variety of festivals and events, such as the Sarawak Regatta, Chinese New Year festivities, and the Gawai Dayak festival. These events demonstrate the multicultural fabric of traditions, languages, and gastronomy that coexist within the city. Furthermore, Kuching comprises of three districts namely Kuching, Lundu, and Bau, functioning as the main economic center of the region (Figure 3.3). The economy in Kuching is multifaceted and encompasses a range of industries, including manufacturing, tourism, oil and gas, agriculture, and services. The city's location and well-established infrastructure make it appealing for business ventures and investments. Kuching's manufacturing sector specializes in electronics, food and beverages, and textiles. The tourism industry in Kuching is enhanced by its rich cultural heritage and picturesque landscapes.

In addition, the oil and gas sector gains benefits from being located close to offshore reserves. Kuching's conducive climate and fertile soil support its agriculture industry, which yields crops such as rice, fruits, and vegetables. The services industry, including finance, healthcare, and education, also plays a crucial role in the city's economic growth and development. Through its diverse economic sectors, Kuching contributes to the overall economic stability of the region and provides employment opportunities for its residents. Overall, Kuching experiences warm to hot temperatures all year round, with average highs ranging from 30 to 32 degrees Celsius. Similarly, humidity in Kuching is typically high, with fluctuations between 75% and 90%.

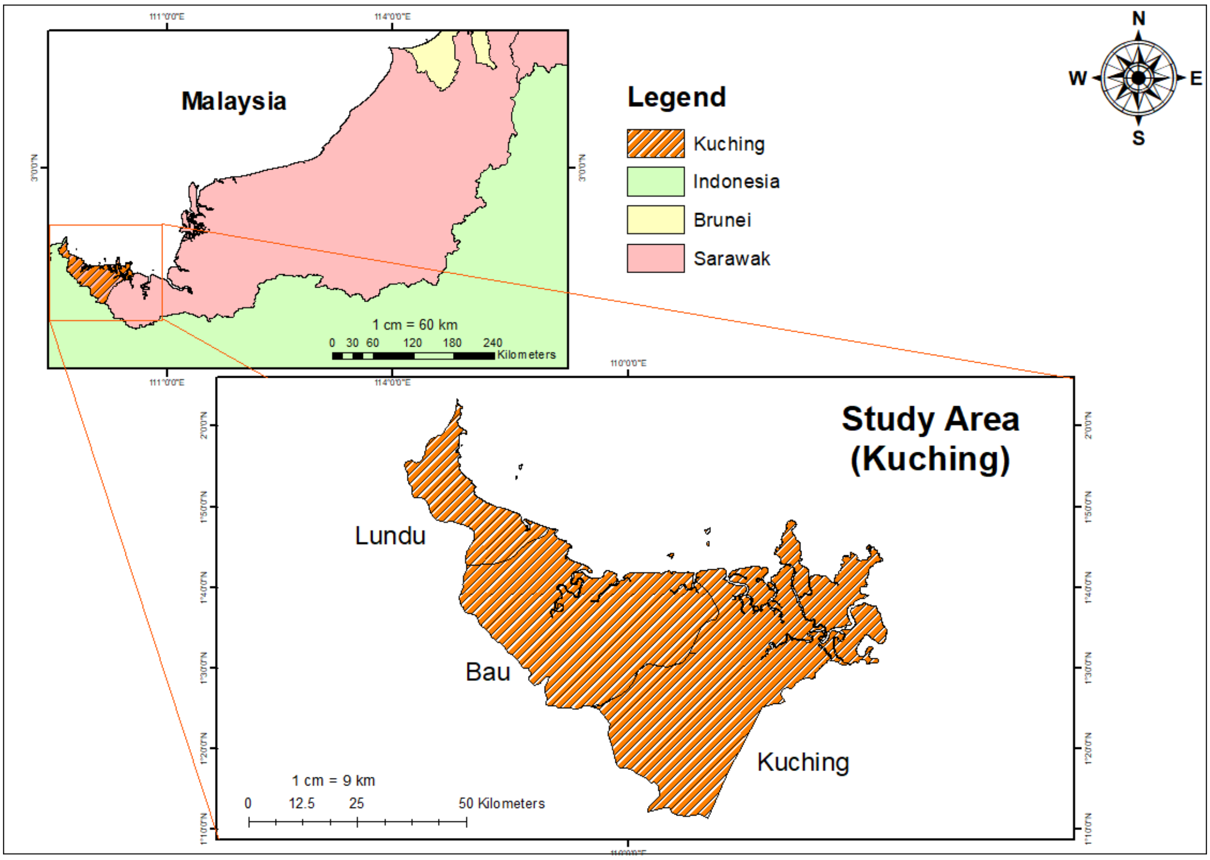

Figure 3.3 Location map of the study area in Kuching

3.3.2 Miri Division

Miri encompassing the districts of Miri, Marudi, Beluru, Subis, and Telang Usan, is the second largest city in Sarawak, following the state capital Kuching, harbors a populace of approximately 415,000 individuals (Figure 3.4). The oil and gas industry has made Miri an essential hub, with several multinational companies operating in the area. Due to its deep-water port located near the coast, Miri is a prime location for offshore oil and gas exploration and production. The oil and gas sector has been a prominent contributor to the economy of Miri and its surrounding regions for numerous decades. The city features an extensively developed infrastructure to support industry, including a large airport, modern highways, and various accommodation options for workers and visitors. In addition to its industrial significance, Miri is renowned for its picturesque beaches and nature reserves.

The city is encompassed by verdant rainforests and hosts several national parks, including the Lambir Hills National Park and the Niah National Park. These parks afford visitors the opportunity to explore the indigenous flora and fauna, embark on hiking expeditions, and relish the natural beauty of the region. Miri also serves as a popular tourist destination for those who seek to luxuriate in the sun, sand, and sea. The city boasts several beaches, including the well-known Tanjung Lobang Beach, celebrated for its crystalline waters and ivory shore. Visitors can engage in various aquatic activities such as snorkeling, scuba diving, and jet skiing or unwind on the beach and bask in the sun. Overall, Miri experiences warm to hot temperatures all year round, with average highs ranging from 28 to 33 degrees Celsius. Similarly, humidity in Kuching is typically high, with fluctuations between 80% and 90%.

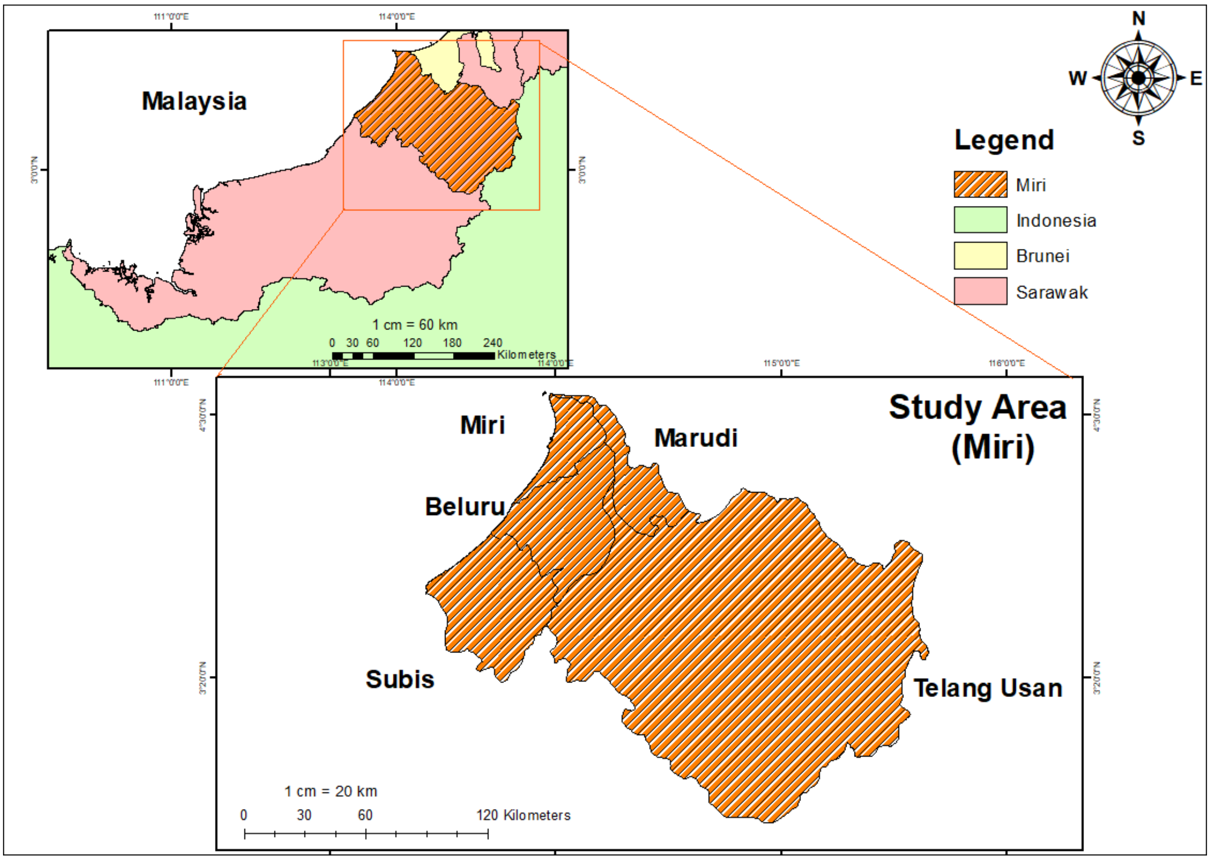

Figure 3.4 Location map of the study area in Miri

3.3.3 Sibu Division

Sibu, which covers the districts of Sibu, Kanowit, and Selangau, is situated in the central region of the state of Sarawak (Figure 3.5). It is the third-largest city in Sarawak, following Kuching and Miri, and has a population of approximately 338,000 individuals. Sibu is a thriving commercial and transportation center that boasts a flourishing timber industry and an active river port. The city's strategic location at the confluence of the Rajang and Igan rivers makes it a crucial center for trade and commerce. The timber industry, particularly the export of tropical hardwoods like meranti, kapur, and balau, is one of Sibu's primary economic drivers. The timber is harvested from the surrounding rainforests and transported to the port for shipment to other parts of the world. The river port in Sibu is also a vital transportation hub, with boats and ferries connecting the city to other parts of Sarawak and neighboring states. The Rajang River, the longest river in Malaysia, flows through Sibu and is a key transportation artery for the region. Overall, Sibu experiences warm to hot temperatures all year round, with average highs ranging from 29 to 32 degrees Celsius. Similarly, humidity in Kuching is typically high, with fluctuations between 80% and 90%.

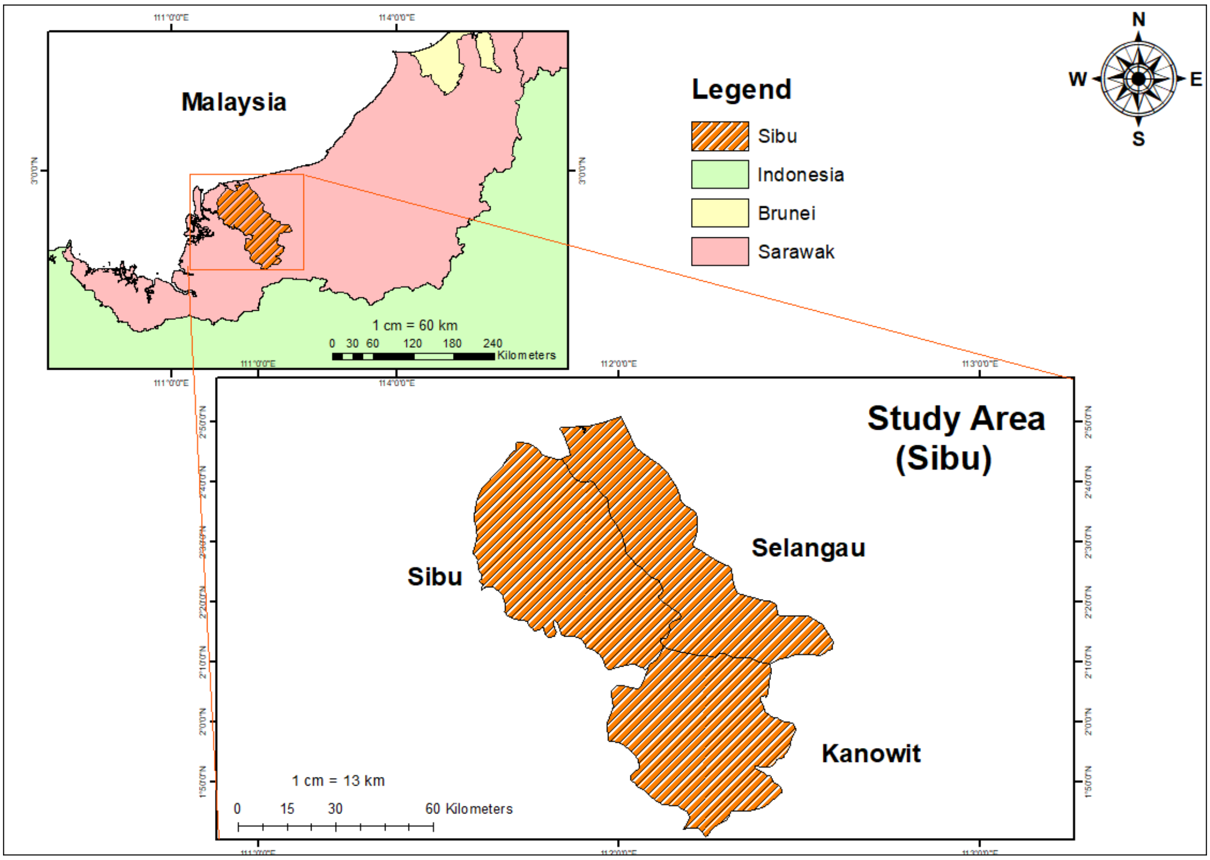

Figure 3.5 Location map of the study area in Sibu

3.3.4 Bintulu Division

Bintulu, situated on the central coast of Sarawak state in Malaysia, encompasses Bintulu, Sebauh, and Tatau districts (Figure 3.5). It is a renowned industrial center and the fourth-largest city in Sarawak. The city's economy heavily relies on the production of natural gas and liquefied natural gas (LNG). Several large natural gas processing plants are in Bintulu, making it a hub for the production and export of LNG. The city's deep-water port plays a crucial role in exporting these resources, facilitating easy transportation to other parts of the world. The production of natural gas and LNG has contributed significantly to the city's growth and provided employment opportunities. Given its strategic location and significance in the natural gas industry, Bintulu is considered a vital city in Malaysia's economic landscape. Sibu experiences warm to hot temperatures throughout the year, with average highs ranging from 30 to 32 degrees Celsius. Similarly, humidity levels in Kuching tend to be high, with fluctuations between 80% and 90%.

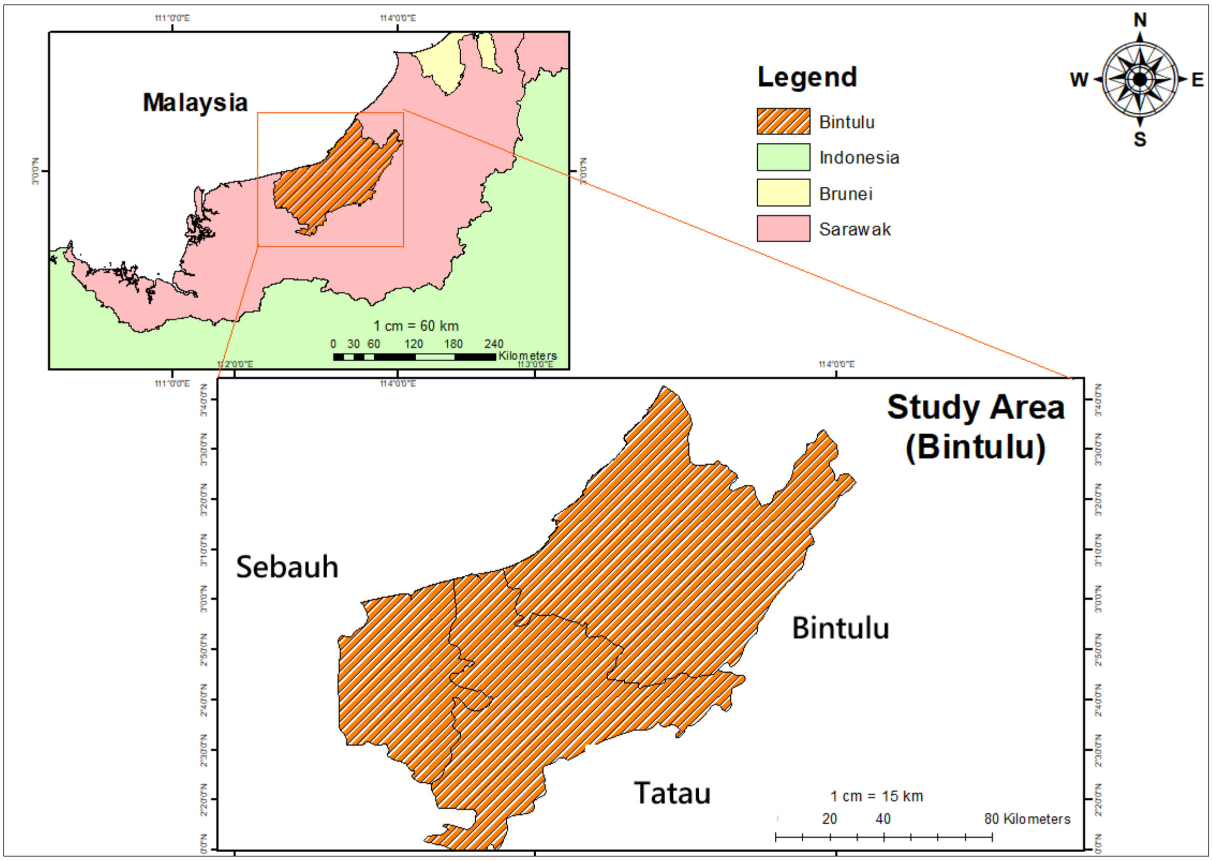

Figure 3.6 Location map of the study area in Bintulu

3.4 Selection of Indicators

Vulnerability indices are numerical formulations that provide a statistical assessment of the changes in value that susceptibility may encounter. These indices are determined using indicators. An indicator refers to a variable that is utilized to express or signify the condition of a given situation or any of its elements at a specific time and location. The data resulting from the analysis of variables is transformed into statistical information, which is presented in a numerical format. All the indicators in this study have been grouped based on their semantic relevance to the essential components that cause vulnerability. The variables were selected by taking into consideration the prior studies, their significance, and the availability of data. Throughout this procedure, a focus was placed on indicators that are particular to the location (Henninger, 1998; Mekonnen et al., 2019; Kumar & Bhattacharjya, 2020b) in the context of Sarawak. Even though there is no academic consensus on socio-environmental vulnerability indicators, however, age, education, income, health and employment are often utilized as indicators (Sarker et al., 2022; Deguen et al., 2022; Ebrahimi et al., 2022).

The identification and determination of socio-environmental vulnerability variables indicates that correlations exist among indicators such as the percentage of elderly, women, children, persons with disabilities, foreigners, population density, and illiterate individuals (Laila, 2013; Kumar and Bhattacharjya, 2020b; Furlan *et al.*, 2021). This is due to the fact that natural disasters have a significant effect on social vulnerabilities, which are linked to certain demographic characteristics such as age group, gender, ethnicity, disability, and educational background. These vulnerable groups are more susceptible to experiencing severe social consequences in the event of exposure to risks. Social variables include things like extreme poverty, low levels of education, the unemployment rate, and the head of the poor household. Those who are poor have a higher likelihood risk of living in slum areas, which may restrict their ability to manage unexpected events and crises efficiently. Both poverty and social vulnerability are contributing factors that limit the ability to manage and overcome difficulties during catastrophic events, either directly or indirectly, highlighting the complex interdependence between these factors (Klasen *et al.*, 2015; Herrera *et al.*, 2018). Individuals from low-income backgrounds often struggle to prepare for natural disasters due to financial limitations, leaving them vulnerable and unable to break free from poverty. A substantial proportion of the population in Sarawak, numbering around 97,000 individuals, grapples with poverty and limited financial resources (*97,000 Households Living in Poverty in Sarawak, Says Minister | Free Malaysia Today (FMT)*; *Malaysia: Poverty Rate by State | Statista*; *Sabah and Sarawak Still among Poorest States, Says Minister | Daily Express Online - Sabah's Leading News Portal*).

The term sensitivity is utilized to denote the extent to which a system is impacted by alterations, whether internal or external. This proposition is suitable for different systems, like the economy and socio-environmental systems. Sensitivity denotes a gauge of how receptive a system or region is to climate-related influences, while taking into account social-environmental factors (Berrouet *et al.*, 2018). The focus of this study is to evaluate the sensitivity of several districts. To assess sensitivity, socio-environmental indicators listed in Table 3.2 were combined. These indicators likely include factors such as elderly, population density, disabilities, and employment rates, all of which can impact how a district responds to changes in climate. By combining these indicators, this study can gain a better understanding of how sensitive each district is to climatic influences and potentially identify areas that may require more attention or resources to mitigate the impacts of climate change.

In terms of coping capacity indicators, there is a correlation between the number of emergency services (police and fire fighter stations) (Grigorescu et al., 2021b; Rufat et al., 2015b; Ebi et al., 2020; Kotcher et al., 2021), the number of beds per 1,000 people (Chan et al., 2019; Fekete, 2019), and the number of first aid centers (for example, pharmacies) (Bigi *et al.*, 2021). Based on this information, the authors propose the number of civil protection personnel per 1000 residents, given that in some countries, health and security services are not equivalent. The selection of several indicators of social vulnerability in this study does not have a universally accepted approach to how to utilize these indicators, and their implementation may vary depending on the location of the study and data availability. The researchers have found that the ability to evacuate vehicles from the affected area is dependent on the quality and accessibility such as roads (Paul, 2014; Payus *et al.*, 2020). However, according to a different analysis from Peduzzi and Kumar and Bhattacharjya, the use of vehicles may involve risks and worsen the extent of damage, as they are susceptible to being carried away by shallow water (Peduzzi, 2019; Kumar and Bhattacharjya, 2020). While this represents a practical situation, the utilization of cars for transportation can prove beneficial if there is a sufficient warning period to allow for organized evacuation. The present study has selected at least one indicator for every vulnerability factor that has been commonly mentioned in the literature review. The chosen indicators were based on their accessibility and ability to represent the variables under consideration, with a focus on the vulnerability factors identified in the literature review. For instance, the percentage of electoral votes (Hofmann *et al.*, 2019; Mietzner, 2021), cannot be used to evaluate the solidarity of society in nondemocratic countries or in countries where people distrust politicians. However, the number of volunteers could be a more appropriate measure for understanding the aspect of unity, but it may pose some difficulties in gathering this data.

Table 3.2 Selected indicators employed for the assessment of socio-environmental vulnerability index (SENVIINT)

Vulnerability components		Indicators	Description (i), data sources (ii) and measurement units (iii)	Abbreviation	Influence of indicators on SENVIINT	Final expression
Exposure	**Climate Change**	Temperature	(i) average of temperature over years; (ii) DID, METMalaysia; (iii) °C	TEMP	If ↑ TEMP, then VULN ↑	+
		Rainfall	(i) amount of rainfall over years; (ii) DID (iii) mm	RAINFALL	If ↑ RAINFALL, then VULN ↑	+
	Natural Hazard	Flood	(i) frequently of severe flood events (ii) DID, NADMA; (iii) unit	FLOOD	If ↑ FLOOD, then VULN ↑	+
Sensitivity	**Economic Vulnerability**	Poverty	(i) number of people live in poverty; (ii) DOSM (iii) %.	POVERTY	If ↑ POVERTY, then VULN ↑	+
		House Rental	(i) number of house rental; (ii) DOSM, (iii) %.	HOUSE_RENT	If ↑ HOUSE_RENT, then VULN ↑	+
		Poor household	(i) number of head of poor household (ii) DOSM (iii) unit.	POOR	If ↑ POOR, then VULN ↑	+
		Unmployed	i) rate of unemployed population from total population (ii) DOSM (iii) %.	UNEMPLOY	If ↑ UNEMPLOY, then VULN ↑	+

Table 3.2 Selected indicators employed for the assessment of socio-environmental vulnerability index (SENVIINT) (cont.)

Vulnerability components		**Indicators**	**Description (i), data sources (ii) and measurement units (iii)**	**Abbreviation**	**Influence of indicators on SENVIINT**	**Final expression**
Sensitivity	**Social Vulnerability**	Population Density	(i) total population over surface; (ii) DOSM (iii) %.	POP_DENS	If ↑ POP_DENS, then VULN ↑	+
		Elderly	(i) persons aged 65 old; (ii) DOSM (iii) %.	ELDERLY	If ↑ ELDERLY, then VULN ↑	+
		Women	(i) number of men over women; (ii) DOSM (iii) %.	WOMEN	If ↑ WOMEN, then VULN ↑	+
	Human Vulnerability	Public Health	(i) the number of patients infected with vector-borne disease; (ii) MOH, (iii) %.	PUB_HEALTH	If ↑ PUB_HEALTH, then VULN ↑	+
		Foreigner Population	(i) number of foreign populations; (ii) DOSM (iii) %.	FOREINER	If ↑ FOREINER, then VULN ↑	+
		Disabilities	(i) population with disabilities (ii) DOSM (iii) %.	DISABLED	If ↑ DISABLED, then VULN ↑	+
		Literacy	(i) rate of literates; (ii) DOSM (iii) % of literates	LITERACY	If ↑ LITERACY, then VULN ↑	+

Table 3.2 Selected indicators employed for the assessment of socio-environmental vulnerability index (SENVIINT) (cont.)

Vulnerability components		Indicators	Description (i), data sources (ii) and measurement units (iii)	Abbreviation	Influence of indicators on SENVIINT	Final expression
Coping Capacity	Infrastructure	Emergency Services	i) number of emergency departments (ii) DOSM (iii) %.	EMERGENCY	If ↑ EMERGENCY, then VULN ↓	-
		Number of Road	(i) Number of roads (ii) PWD (iii) unit	ROAD	If ↑ ROAD, then VULN ↓	-
		Electricity	(i) households with electricity; (ii) Sarawak Energy; (iii) %.	ELECTRICITY	If ↑ ELECTRICITY, then VULN ↓	-
		Potable Water	(i) portable drinking water infrastructure (ii) LAK, LAS, LAKU, JNALB; (iii) %.	POTABLE	If ↑ PORTABLE, then VULN ↓	-
		Communication	(i) number of households with a telephone and internet; (ii) MCMC (iii) %.	COMM	If ↑ COMM, then VULN ↓	-
	Environmental Vulnerability	Elevation	(i) the elevation (ii) NREB: (iii) km.	ELEVATION	If ↑ ELEVATION, then VULN ↓	-
		Air Pollution	(i) rate of air pollution; (ii) DOSM (iii) unit	AIR_POL	If ↑ AIR_POL, then VULN ↓	-
	Health Vulnerability	Health Facilities	(i) number of beds over 1000 inhabitant; (ii) MOH (iii) %.	HEALTH_FAC	If ↑ HEALTH_FAC, then VULN ↓	-

3.5 Data Sources

A total of 22 components have been considered for this study (3 exposure, 11 sensitivity and 8 comping capacity). Most of the data for physical exposure and resistance indicators are secondary data and have been obtained from the Department of Statistics Malaysia (DOSM), Malaysia Department of Irrigation and Drainage (DID), Malaysian Communications and Multimedia Commission (MCMC), Public Works Department (PWD) Sarawak and Ministry of Health Malaysia (MOH). The database comprises essential social information, including population size, age distribution, and data on foreign visitors, carefully amassed during the last ten-yearly census carried out in 2011, in the Sarawak region of Malaysia. Furthermore, the database integrates geographic information at different levels, such as municipal, district, and census tract, which are crucial for the present study. Table 3.2 summarized the 22 indicators with description and Influence of indicators on flood vulnerability. The objective of this table is to provide a complete overview of the indicators and their significance in measuring the level of vulnerability to floods. Exploring each of the indicators and their influence on flood vulnerability in detail can provide a clear understanding of the factors that contribute to the overall vulnerability of a specific area or population. The table presented in this study serves as an advantageous resource for examining and interpreting the results.

Table 3.3 Type of the data sources, units, and years available

Vulnerability components		**Indicators**	**Data Sources**	**Unit**	**Year**
Exposure	Climate Change	Temperature	Department of Irrigation and Drainage	°C	2019 - 2021
		Rainfall	Department of Irrigation and Drainage	mm	2019 - 2021
	Natural Hazard	Flood	Department of Irrigation and Drainage	unit	2019- 2021
Sensitivity	Economic Vulnerability	Poverty	Department of Statistics Malaysia	%	2020
		House Rental	Department of Statistics Malaysia	%	2020
		Poor household	Department of Statistics Malaysia	unit	2020
		Unemployed	Department of Statistics Malaysia	%	2020
	Social Vulnerability	Population Density	Department of Statistics Malaysia	%	2020
		Elderly	Department of Statistics Malaysia	%	2020
		Women	Department of Statistics Malaysia	%	2020
	Human Vulnerability	Public Health	Ministry of Health Malaysia	%	2019 - 2020
		Foreigner Population	Department of Statistics Malaysia	%	2020
		Disabilities	Department of Statistics Malaysia	%	2020
		Literacy	Department of Statistics Malaysia	%	2020

Table 3.3 Type of the data sources, units, and years available (cont.)

Vulnerability components		**Indicators**	**Data Sources**	**Unit**	**Year**
Coping Capacity	Infrastructure	Emergency Services	Department of Statistics Malaysia	%	2020
		Number of Road	Public Works Department Sarawak	km	2020
		Electricity	Sarawak Energy	%	2019-2021
		Potable Water	Kuching Water Board, Sibu Water Board, Laku Management Sdn Bhd, Sarawak Rural Water Supply Department	%	2020
		Communication	Malaysian Communications and Multimedia Commission	%	2020
	Environmental Vulnerability	Elevation	Department of Survey and Mapping Malaysia	km	2020
		Air Pollution	Department of Statistics Malaysia	unit	2020
	Health Vulnerability	Health Facilities	Ministry of Health	%	2019 - 2021

3.6 Data Arrangements and Normalization

The data collected are organized in a matrix format, wherein rows denote varied districts and columns signify diverse vulnerability factors. Table 1 illustrates the different facets of vulnerability along with their respective indicators. In simpler terms, it can be explained that a compilation of Q indicators has been conducted for various regions and districts of P. Furthermore, xij denotes the numerical value of the j^{th} indicator linked to the

i^{th} region. Due to the varying units and ranges of each vulnerability factor, it was necessary to normalize the factor values between the range of 0 and 1. After achieving the normalized number, a corresponding index is established by assigning distinct weightings to all factors.

Normalization is a crucial factor in multivariate statistical analysis due to the presence of large-range variables and others have a small range of variance. As indicators are measured in various units, it is necessary to normalize them to ensure that their values fall within a comparable range of 0 to 1. In the normalization technique that converts the dataset into a specific range of values, within the range of 0-1, is considered a crucial step. Normalization is a crucial factor in multivariate statistical analysis due to the presence of large-range variables and others have a small range of variance. As indicators are measured in various units, it is necessary to normalize them to ensure that their values fall within a comparable range of 0 to 1. In the normalization technique that converts the dataset into a specific range of values, within the range of 0 - 1, is considered a crucial step. The normalization technique has been applied to establish a more robust and long-lasting correlation within the dataset, with the aim of normalizing residuals using transformative methodologies (Wong, 2017). The process of normalization involves considering the functional correlation between the indicator and the desired index. In cases where a positive relationship exists (i.e., an increase in the target index corresponds to an increase in the value of the indicator), indicators are normalized using the formula presented in Equation (1).

$$Y_{ij} = \frac{(x_{ij} - min_{Xij})}{(max_{Xij} - min_{Xij})} \tag{1}$$

In cases where the variable shows a negative functional relationship, Equation (2) is employed for analysis.

$$Y_{ij} = \frac{(max_{Xij} - x_{ij})}{(max_{Xij} - min_{Xij})} \tag{2}$$

Where, Y_{ij} represents the index assigned to the i^{th} indicator associated with the j^{th} district, while xij denotes the actual or observed value of the i^{th} indicator for the j^{th} district.

The maximum and minimum values of the i^{th} indicator among all L (J = 1, ..., 29) districts are denoted by Max{*xij*} and Min{*xij*}, respectively (Appendix A).

3.7 Weighing and Composition of Composite Index

After computing the normalized score, a composite index is created through the assignment of unequal weights to all indicators. Previous studies have demonstrated various techniques for assigning weights to indicators. These methods include equal weighting, such as simple averages of marks as provided by Patnaik and Narain Methods (Rimba *et al.*, 2017), or unequal weighting through expert considerations as employed by Iyengar and Sudarshan (Kumar and Bhattacharjya, 2020a). Additionally, weight may be assigned through multivariate statistical techniques, such as the principal components and methods of cluster analysis (Aroca-Jimenez et al., 2017; Kim and Gim., 2020).

To measure susceptibility, we applied the Iyengar and Sudarshan methodology to assign weights to all contributing factors in this study. Iyengar and Sudarshan (1982) developed an index that utilizes multidimensional data, which was later employed to classify districts based on their financial implementation. The proposed method is statistically dependable and equally satisfactory for the construction of the proposed index. In accordance with the proposed approach of Iyengar and Sudarshan, a hypothesis is put forth that the values of the indicators undergo a shift in the direction that is diametrically opposite to that of the variance (Iyengar and Sudarshan, 1982). The weight of each factor *Wj* is ascertained by

$$W_j = \frac{c}{[Var(x_{ij})]^{1/2}} \tag{3}$$

where c is a normalizing constant, that is

$$c = \left(\sum \frac{1}{\left[Var(x_{ij})\right]^{0.5}} \right)^{-1} \tag{4}$$

The vulnerability composite indicator for social vulnerability factors pertaining to the *i*th district were acquired using formula

$$V_i = \sum W_j \, Y_{ij} \qquad (5)$$

where V_i represents the composite indicator of the i^{th} district, W_j denotes the weight assigned to each indicator, and Y_{ij} signifies the normalized scores of the indicators. It is important to note that the value of W_j falls within the range of 0 to 1. Therefore, $\sum W_j = 1$

To perform a comparative analysis of the indices derived for each vulnerability factor, it is vital to divide the sum of physical exposure and resistance factors by their respective total number of indicators. Therefore, the composite vulnerability index can be calculated for each physical factor as

$$V_E = \left(\frac{\sum W_j Y_{ij}}{n} \right) \qquad (6)$$

where V_E represents the composite vulnerability index for exposure, W_j denotes the weight assigned to each indicator, and Y_{ij} signifies the normalized scores of the indicators, while, n identified the number of indicators. Similarly, the calculation of sensitivity and coping capacity factors is denoted as V_S and V_{CC}, respectively. Finally, the social vulnerability index can be formulated as

$$V_{Index} = V_E + V_S + V_{CC} \qquad (7)$$

3.8 Principle Component Analysis (PCA)

For the creation of the modified SENVIINT (as shown in Table 3.2), a total of 22 variables were carefully selected. To ensure accurate statistical analysis, all variables underwent normalization using percentage, milage, or unit functions. The results of the Principal Component Analysis conducted by the SPSS software version 26.0 produced an array of independent factors, Varimax rotation and Kaiser criterion. Principal component analysis, a data-sensitive technique, is used to reduce the number of factors by identifying a smaller set of components and focusing on the most significant variable that explains the variance in a larger dataset (Aksha *et al.*, 2019). The main objective of PCA analysis is to distill the covariation among the variables and to reduce the data's dimensionality by grouping similar variables into components. Additionally, this analysis facilitates the comprehension of component groups and offers valuable insights when further analyzing the data. The techniques employed to extract components in this study involved Kaiser normalization and Varimax rotation, as developed by Cutter et al. (2003). The components with eigenvalues exceeding 1.0 were extracted and subsequently assigned names that reflect the latent variables. Each component was assigned a cardinality designation of positive or negative (±) to facilitate computation of SENVIINT. The total score was obtained by summing up the scores of each component. The SENVIINT was then computed by summing up the scores of each individual component to arrive at the total SENVIINT score. To avoid using differential weighting of components without empirical or justifiable evidence, an approach employing equal weighting and additive techniques was utilized, as in similar studies (Jha and Gundimeda, 2019; Gupta et al., 2020a). Our adapted SENVIINT for Sarawak was computed by summing up the principal component values for each unit of vulnerability for the components as shown at Equation (7).

3.9 Hierarchy Organization of the Vulnerability Index

To ensure the highest degree of accuracy, it is imperative to construct a conceptual model pertaining to the selected criteria. The Analytic Hierarchy Process (AHP) necessitates the breakdown of the decision-making problem into a hierarchy tree, containing sub-criteria. Specifically, AHP mandates the establishment of a goal at the uppermost level, followed by criteria and sub-criteria, which are represented by respective codes. Level partitioning was introduced to establish a lucid hierarchy among indicators. The reachability indicators for each were obtained through a meticulous Analytic Hierarchy Process (AHP). Reachability indicators refer to those that are influenced by others, as well as the indicators themselves. In contrast, the antecedent set comprises the indicators themselves and the ones that influence them. The intersection of the reachability set, and antecedent set yields a comprehensive result for all the indicators. Indicators with identical reachability and intersection sets are assigned level 1. Following the assignment of level 1 to indicators with similar reachability and intersection sets, the first hierarchy level is established, and these indicators are subsequently removed from the process. This process is repeated until the level of each indicator is determined. The process leads to a hierarchical configuration of interdependent variables, as illustrated in Figure 3.7.

The first level of the hierarchical arrangement specifies the purpose of the evaluation, which is the socio-environmental vulnerability index (SENVIINT) in this instance. The following level comprises of three factors that determine vulnerability: Exposure, Sensitivity, and Coping Capacity. Finally, to evaluate the socio-environmental vulnerability criteria, sub-criteria are employed which consist of eight at the third tier and twenty-two at the fourth tier.

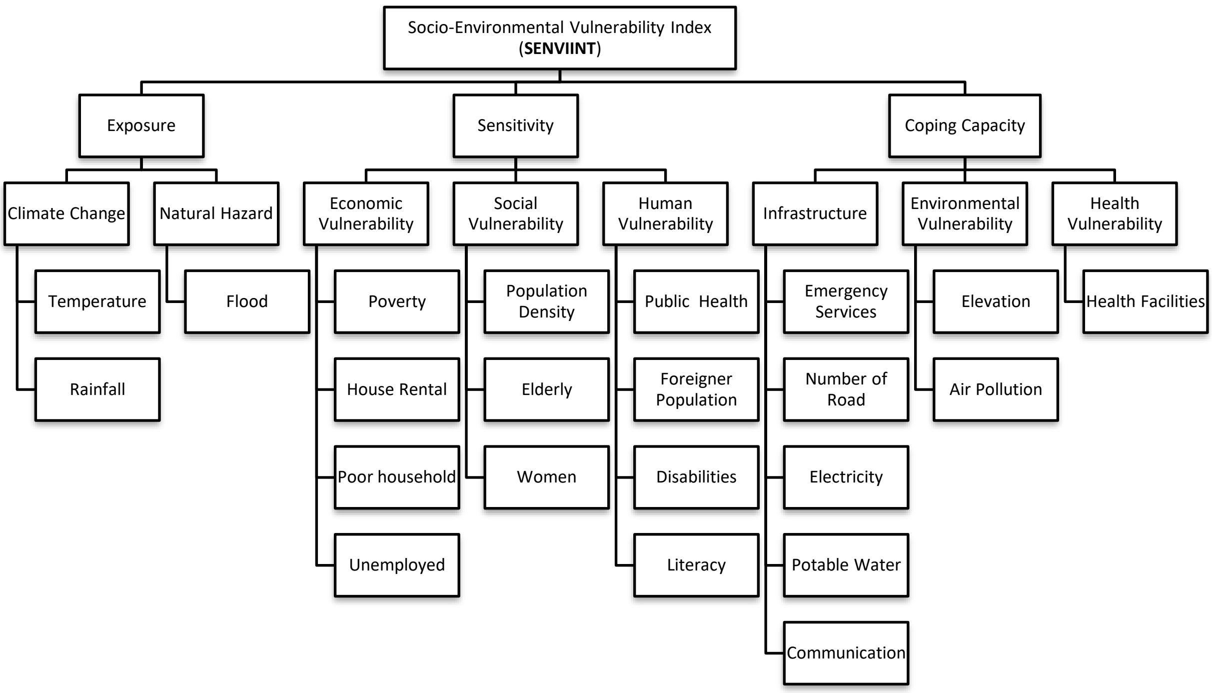

Figure 3.7 The hierarchical organization of vulnerability criteria employed in AHP

3.10 Map of Social Vulnerability

Prior to collecting criterion maps within a GIS framework, it is crucial to convert the variables into standardized units and incorporate them into a spatial database. This is imperative since these variables are measured on distinct scales, such as percentages and density. The standardization of the vulnerability model's criteria was conducted using a linear fuzzy set membership function. Within this function, vulnerability fluctuates linearly from 0 (representing no vulnerability) to 1 (representing complete vulnerability). The standardized functions employed were outlined in Mourato et al. (Mourato *et al.*, 2023). In summary, the levels of vulnerability were determined using the following procedures:

1. Finding and defining vulnerability indicators and data: The vulnerability indicators and data were taken from the literature review and then changed based on the availability of data. Details about the two types of indicators used (ESI and ACI) can be found in Table 3.11.
2. Giving each vulnerability indicator and piece of data a weight: Each indicator and piece of data in ESI and ACI is given a value called "weight". Each piece of data has a value between 0 and1, so the total weight of ESI or ACI is 1.
3. Figuring out the data on vulnerability: The point of calculating the data was to find out what each data was worth. There are two ways to figure out the answer: the ratio method and the scoring method. For the ratio method, the value of each compatibility data was split by the value of the other compatibility data. For example, the population density is the number of people compared to the total area of a village. The number of vulnerable people is the number of women, children, and older people divided by the total number of people in a village. For example, the population density is the number of people compared to the total area of a village. The number of vulnerable people is the number of women, children, and older people divided by the total number of people in a village. The scoring method is used for indicators like built-up area, fishponds, rice fields, people who are vulnerable, population density, living in poverty, source of income, and house types. Some indicators, like education level, access to clean water, sanitation, the number of educational facilities, and the number of health facilities, were given a score.

4. Standardizing each of the calculational results: Standardization is the process of normalising actual numbers or scoring them between 0 to 1 scale to make them more comparable.

Finally, various sub-criteria and criteria maps were computed based on different components to obtain the vulnerability index as shown at Equation (7). Upon obtaining the indexed values for all the factors that contribute to flood vulnerability, encompassing exposure, sensitivity and coping capacity, the indices were subsequently integrated into ArcGIS 10.8 to construct the ultimate vulnerability map. To visually represent the degree of vulnerability in different districts within the Sarawak division, the maps were color-coded. Chapter 4 demonstrates various maps in the ArcGIS system that show the levels of exposure, sensitivity, and adaptive capacity.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this section, the newly created socio-environmental vulnerability index for Sarawak, Malaysia is reviewed and evaluated. Before aggregating, three elements of vulnerability—exposure, sensitivity, and coping capacity—were used to identify a total of 22 indicators. As discussed at previous chapter (3.8: Principle Component Analysis (PCA)), all the chosen indicators must be evaluated and compiled into the Sarawak exposure, sensitivity, and adaptive capacity map separately. Finally, the significant sub-index maps were superimposed on a map of the district in Sarawak vulnerability to climate change. Districts in the Sarawak states are ranked according to their susceptibility to climate change on the map. A thorough baseline of the current situation in Malaysia must be established, along with an understanding of the effects of climate change, the degree of vulnerability, and the national adaptation capacity, for the policy or decision maker to develop and implement appropriate responses and adaptation strategies.

Assessment of vulnerability to climate change is discussed in the context of exposure, sensitivity, and coping capacity of society. Under the exposure component, climate variability and climate related natural hazard recorded for the trends of a period of 40 years from 1980 to 2020. Assessment of sensitivity or the degree to which the population is affected by exposure is described in terms socio-demographic, public health status, poverty, house rent, and economic status. These were considered for the discussion of sensitivity since these are basic requirements for human survival. Given the analysis of exposure and sensitivity, the coping capacity of the population to withstand or recover from the exposure has been discussed in terms of the geographical elevation, road density, emergency services, electricity coverage, potable water supply, communication network.

The analysis and assessment of the climate variability (temperature and rainfall) and climate related natural hazard (flood) components identified in contributing to climate change vulnerability has been carried out in a period of 61 years from 1960 encroaching to

2020. The trends from the past, present, and future have been captured in a linear regression. Beside the climate variability (temperature and rainfall) and climate related natural hazard (flood) components, other components fall under sensitivity and adaptive capacity are assessed in the current year. Therefore, the developed climate changes vulnerability index is applicable with an assumption that the components in sensitivity and adaptive capacity remain unchanged or status quo. The prediction and changes of future climate and climate related hazard with the current infrastructure, human, social economic and environmental conditions have been reflected and considered into the analysis coverage, literacy, and health facilities.

4.2 Principle Component Analysis (PCA)

In the context of principal component analysis (PCA) in Table 4.1, the first principal component was extracted and observed that it only accounted for only 43.3% of the total variance. This indicates that the input variables were not significantly correlated. However, the sixth principal component was found that more than 80% of the variance due to the wide range of observations and variable diversity (Appendix C). Comprehensive descriptions of these six components, including their corresponding signs indicating their impact on social vulnerability and loadings, are featured in Table 4.1. The process of rotation technique employed was Varimax with Kaiser normalization. Additionally, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, commonly used in factor analysis. The obtained value was acceptable with a value of 0.658 and $p>0.05$. Furthermore, the Bartlett's test sphericity with the value 0.012 was acceptable, with a probability of less than 0.05 (Appendix D).

The PCA has revealed six principal components (PC), each with eigenvalues greater than 1.0. The six groups have been appropriately named using loaded terms to create vulnerability profiles. PC1 is referred to as Climate Change and Economic Vulnerability, while PC2 as Socio-demographic Vulnerability. PC3 is titled Migration and Health Vulnerability, PC4 as Emergency Services and Infrastructure Vulnerability, PC5 as Environmental Vulnerability, and PC6 as Health Care Vulnerability. Indicators for these groups have been carefully selected based on their highest weightings and highlighted in bold in both Tables 4.1. PC1 (Climate Change and Economic Vulnerability) exhibits a significant loading of 7 indicators, namely temperature, rainfall patterns, flood events, poverty, house rentals, poor households, and unemployment rate. PC2 (Socio-demographic Vulnerability) has been loaded with 3 indicators, including population density, elderly and women. PC3 (Migration and Health Vulnerability) has been loaded with 4 indicators, namely public health, foreigner population, disabilities, and literacy. PC4 (Emergency and Infrastructure Vulnerability) has been loaded with 5 indicators, including emergency services, number of roads, electricity, potable water, and communication. PC5 (Environmental Vulnerability) has been loaded with 2 indicators, namely elevation and air pollution. PC6 (Health Care Vulnerability) has been loaded with only one indicator: health facilities.

In the context of this study, 6 PC groups of vulnerability factors were identified and analyzed for the year 2020. These factors were carefully examined to assess their impact on vulnerability within the Sarawak region. To visualize and better understand the geographical distribution of vulnerability across the 14 districts of Sarawak, Geographic Information System (GIS) maps were generated. Figures 4.2, 4.4, and 4.6 in the study illustrate the vulnerability scenarios for exposure, sensitivity, and adaptive capacity within the various districts of Sarawak, as determined through Principal Component Analysis (PCA). These visual representations provide valuable insights into how different districts within Sarawak fare in terms of vulnerability, highlighting areas of concern and potential strategies for mitigation and resilience building.

The main city and coastal area of Sarawak face significant vulnerability to extreme climatic events due to their expanding population and limited adaptive capabilities. Similarly, the coastal area of Sarawak has already faced significant hurdles associated with climate change, resulting in vulnerabilities across all six principal components, ranging from PC1 to PC6. The high vulnerability and low adaptive capacity are a major concern in coastal and river regions of Sarawak. The population residing in areas of high vulnerability experiences a heightened exacerbation of health conditions, coupled with limited access of drinking water, inadequate infrastructure, and technology, as well as the degradation of natural resources and its ecosystem.

Table 4.1 List of retained principal component (PC) weights and utilized for the adaptive capacity, exposure, and sensitivity of all indicators related to the Socio-Environmental Vulnerability Index (SENVIINT).

Indicators	PC1	PC2	PC3	PC4	PC5	PC6
Temperature	**0.563**	0.257	0.536	0.013	0.135	-0.379
Rainfall	**0.667**	-0.156	0.445	0.129	-0.040	0.325
Flood	**0.758**	0.131	-0.567	-0.043	-0.225	-0.073
Poverty	**0.969**	0.070	-0.194	-0.054	0.032	0.046
House Rental	**0.893**	0.078	-0.340	-0.185	-0.063	-0.113
Poor household	**0.965**	0.012	-0.216	-0.107	0.013	0.001
Unmployed	**0.963**	-0.001	-0.216	-0.113	0.006	-0.014
Population Density	0.049	**0.674**	0.310	0.325	0.083	0.158
Elderly	0.018	**0.976**	-0.164	-0.052	0.031	0.053
Women	-0.168	**0.698**	0.166	-0.548	0.255	-0.193
Public Health	-0.253	-0.152	**0.582**	0.462	-0.091	-0.228
Foreiner Population	-0.535	-0.137	**0.753**	-0.069	0.134	-0.067
Disabilities	0.318	-0.516	**0.588**	-0.002	0.384	-0.025
Literacy	-0.876	-0.069	**0.328**	0.181	0.024	0.129
Emergency Services	-0.483	0.438	-0.467	**0.475**	0.229	-0.024
Number of Road	0.306	0.289	0.400	**0.479**	-0.044	-0.232
Electricity	-0.850	-0.416	-0.112	**0.087**	-0.073	-0.134
Potable Water	0.461	0.245	0.027	**0.531**	-0.305	0.330
Communication	0.106	-0.433	-0.494	**0.623**	0.345	-0.144
Elevation	0.063	0.411	-0.173	-0.033	**0.671**	0.531
Air Pollution	-0.448	-0.630	-0.562	-0.151	**0.191**	-0.039
Health Facilities	-0.691	0.252	-0.094	-0.186	-0.350	**0.412**
Eigenvalue	9.540	3.110	2.689	1.929	1.203	1.064
Cumulative variance %	43.365	57.502	69.724	78.492	83.962	88.797

The most significant loadings are highlighted with bold shading. KMO score is 0.471 (Appendix D).

The method of selecting weights in such a manner ensures that an individual indicator's significant variation does not excessively influence the overall contribution of the remaining indicators, thereby avoiding distortion in comparisons between various regions. The vulnerability index is evaluated using a numerical scale ranging from 0 to 1, with the highest level of vulnerability being represented by 1 and no vulnerability being indicated by 0. Upon normalization, the distribution of weightage among sub-indexes such as climate, natural hazards, economic vulnerability, social vulnerability, human vulnerability, infrastructure, environmental vulnerability, and health vulnerability is presented in Figure 4.1.

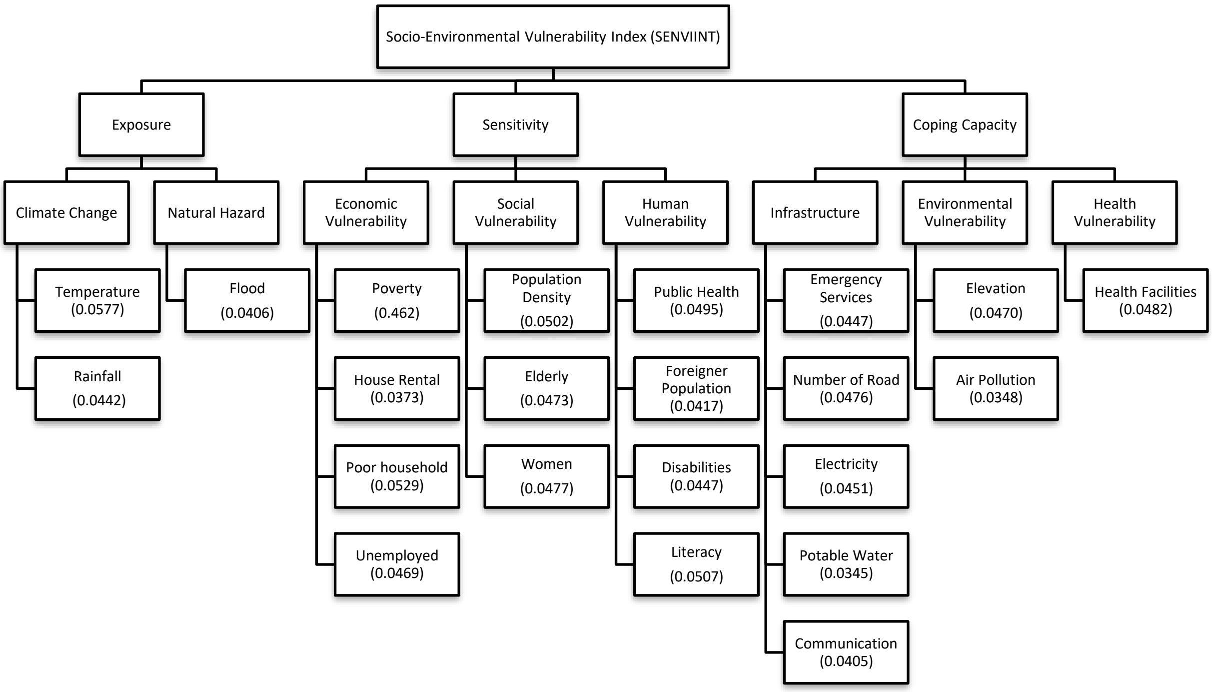

Figure 4.1 Assigning Weights to Individual Sub-Indexes

4.3 Normalization and Weighting

The process of normalization entails transforming the crude data of every indicator into a uniform score that mirrors its comparative standing within the dataset. Normalization is extensively utilized in vulnerability evaluations, research on climate change, and other domains where a range of indicators must be amalgamated to gauge vulnerability with precision. After calculating the normalized values, the composite index was created by giving each indicator an unequal weight. Several strategies were used to allocate weight to the indicators in earlier studies. Certain indicators may hold greater significance or play a more crucial role in comprehending the vulnerability of a certain region or population. Consequently, varying weights are utilized to accurately reflect this uneven distribution of importance. For example, when assessing the vulnerability of urban areas to the effects of climate change on social and environmental aspects, factors such as rising temperatures, rainfall pattern, and disaster event may be given higher weights because of their significant and immediate impact on the vulnerability of these areas.

Equal weights, that is, the simple average of the scores, are provided by Patnaik and Narain Methods (Rimba *et al.*, 2017), or uneven weights are provided by Iyengar and Sudarshan Methods (1982) (Iyengar and Sudarshan, 1982). Multivariate statistical methods, such as the principal components and cluster analysis method, can also be used to figure out the weight (A. Chakraborty and Joshi, 2016; da Silva et al., 2015). In this study, the Iyengar and Sudarshan methods were used to give each indicator of vulnerability a certain amount of weight (Table 4.2). Uneven weight distributions possess the capability to substantially impact the final vulnerability index, given that metrics exhibiting greater weights will exert a more pronounced influence on the comprehensive vulnerability rating. It is of paramount importance to maintain transparency and clarity in the weighting process and a clear rationale for selecting weights are essential to ensure the credibility and reliability of vulnerability assessment.

Table 4.2 Unequal weight distribution

Vulnerability Index		Exposure			Sensitivity						
Component		Climate Change		Natural Hazard	Economic Vulnerability				Social Vulnerability		
Division	**District**	**Temperature**	**Rainfall**	**Flood**	**Poverty**	**House Rental**	**Poor household**	**Unemployed**	**Population Density**	**Elderly**	**Women**
Miri	Miri	0.8772	0.0773	0.0690	0.1313	0.6779	0.2521	0.3557	0.1111	0.3702	0.3605
	Marudi	0.7899	0.5952	0.2759	0.7475	0.4362	0.0000	0.0872	0.0122	0.0070	0.0052
	Beluru	0.7089	0.2648	0.2069	0.5000	0.0067	0.1154	0.0000	0.0104	0.0070	0.0064
	Subis	0.6456	0.2688	0.0690	0.2677	0.1007	0.1017	0.0000	0.0255	0.0456	0.0590
	Telang Usan	0.0000	0.0000	0.1724	0.5808	0.3490	0.2147	0.0000	0.0000	0.0000	0.0000
Bintulu	Bintulu	1.0000	0.2818	0.0345	0.0000	1.0000	0.0372	0.2282	0.2007	0.2158	0.2298
	Sebauh	0.7089	1.0000	0.0000	0.0657	0.3154	0.0623	0.0000	0.0077	0.0088	0.0076
	Tatau	0.7519	0.1643	0.0345	0.1465	0.7987	0.1296	0.0470	0.0106	0.0175	0.0182
Sibu	Sibu	0.7456	0.4091	0.9655	0.2626	0.9128	0.3450	0.4899	0.2669	0.4070	0.3781
	Kanowit	0.7089	0.5399	0.2759	1.0000	0.2953	0.2384	0.0537	0.0273	0.0228	0.0198
	Selangau	0.6456	0.1121	1.0000	0.6162	0.0403	0.0851	0.0268	0.0103	0.0105	0.0079
Kuching	Kuching	0.9215	0.8651	0.2069	0.1768	0.7181	1.0000	1.0000	1.0000	1.0000	1.0000
	Bau	0.7114	0.6649	0.0345	0.3788	0.0604	0.2689	0.0604	0.1453	0.0649	0.0578
	Lundu	0.6456	0.1121	0.1034	0.4091	0.0000	0.3797	0.0403	0.0410	0.0246	0.0237

Table 4.2 Unequal weight distribution (cont.)

Vulnerability Index		Sensitivity				Coping Capacity							
Component		Human Vulnerability				Infrastructure					Environmental Vulnerability		Health Vulnerability
Division	**District**	**Public Health**	**Foreigner Population**	**Disabili-ties**	**Literacy**	**Emergency Services**	**Number of Road**	**Electricity**	**Potable Water**	**Communi-cation**	**Elevation**	**Air Pollution**	**Health Facilities**
Miri	Miri	1.0000	0.5559	0.4744	0.4330	0.2353	0.8937	0.0331	0.0089	0.0000	0.9538	0.0000	0.7281
	Marudi	0.2769	0.0033	0.0009	1.0000	0.5882	0.9847	0.0438	0.7659	0.5320	0.7181	0.0860	0.8531
	Beluru	0.0000	0.0921	0.0000	0.0000	1.0000	0.9995	0.0000	0.2993	0.4305	0.8726	1.0000	1.0000
	Subis	0.0132	0.6151	0.0000	0.1485	1.0000	0.9360	0.0000	0.1956	0.1203	0.0000	1.0000	1.0000
	Telang Usan	0.0000	0.0428	0.0000	0.0000	1.0000	0.9803	0.0000	1.0000	0.3665	0.6787	1.0000	1.0000
Bintulu	Bintulu	0.3077	1.0000	0.2322	0.4349	0.5882	0.8058	0.0107	0.0281	0.2989	0.9571	0.0430	0.7717
	Sebauh	0.0000	0.2105	0.0005	0.1760	0.6471	0.9935	0.1302	0.8622	0.7895	0.3741	0.1215	0.0000
	Tatau	0.1033	0.1612	0.0110	0.2828	0.8235	0.9432	0.1006	0.7348	0.0564	0.9829	0.0822	0.4426
Sibu	Sibu	0.3077	0.6118	0.4922	0.4452	0.3529	0.5520	0.1361	0.0000	0.2331	0.9506	0.1028	0.8487
	Kanowit	0.2044	0.0000	0.0305	0.3660	0.7647	0.9747	1.0000	0.3378	0.9925	0.8408	0.0935	0.9019
	Selangau	0.1802	0.0296	0.0053	0.0000	0.4706	1.0000	0.1976	0.9037	1.0000	0.6740	0.2766	0.4638
Kuching	Kuching	0.4484	0.0461	1.0000	0.3465	0.0000	0.0000	0.0036	0.0074	0.1560	0.9713	0.1551	0.8198
	Bau	0.0571	0.0362	0.0670	0.4028	0.6471	0.6264	0.1373	0.1304	0.4699	0.7871	0.2486	0.6956
	Lundu	0.0967	0.0461	0.0362	0.4068	0.7059	0.9334	0.6604	0.7200	0.6353	1.0000	0.1925	0.7515

4.4 Proposed Vulnerability Index

The vulnerability index degree denotes the level of vulnerability of a system, community, or region towards specific stressors or hazards. This is a quantitative measure that facilitates the assessment of the extent of vulnerability and provides valuable insights into the potential risks and challenges faced by the entity under consideration. Typically, the index is calculated based on various indicators that reflect exposure, sensitivity, and adaptive capacity. Two probable operational associations exist between vulnerability and its indications. An increase (or reduction) in the value of the indicator can result in an increase (or decrease) in the level of vulnerability, or vice versa. There are two distinct types of Operative Association between vulnerability and their indications. The level of vulnerability is linked to the value of the indicator, which may increase or decrease together.

There are two different types of Operative Association between vulnerability and their indications. First, the vulnerability grows (or decreases) when the indicator's value increases (or decreases) or vice versa. In the study, indicators are normalized using one of two methods, based on their operational relationship with vulnerability. The index vulnerability calculation is often articulated on a scale ranging from 0 to 1, with 0 indicating zero vulnerability and 1 representing the utmost vulnerability (Table 4.3). A heightened value on the vulnerability index denotes an increased susceptibility to stressor impacts, whereas a lower value suggests a greater level of resilience and capacity to endure and rebound from unfavourable circumstances.

Table 4.3 Degree of Index Vulnerability (Monterroso et al., 2014; L. Chakraborty et al., 2021; Malta and da Costa, 2021; Nurul Ashikin et al., 2021)

Level	Risk Sub-Index	Degree of Index Vulnerability
I	0.00 – 0.20	Very Low
II	0.21 – 0.40	Low
III	0.41 – 0.60	Medium
IV	0.61 – 0.80	High
V	0.81 – 1.00	Very High

4.5 Exposure Vulnerability Index Reliability

The analysis of the socio-environmental vulnerability index evaluated the climate change exposure, sensitivity, and coping capacity of society, with the results shown on maps. These maps utilized a color-coding system, ranging from low to high vulnerability, to depict the susceptibility of various districts. Red was used to represent the different indicator scores, with lighter shades representing lower scores and darker shades representing higher scores. Districts with low, moderate, and high vulnerability were identified using the formula (Tang, 2019). Indicators such as temperature, rainfall and flood event were used to determine the overall exposure at the sites surveyed. The average score for the exposure index was 0.0686, which shows that people are exposed to different levels of social change.

The extent of this variability is made apparent by the range of scores depicted in maps (Figure 4.2), which ranges from a minimum score of 0.0007 for the Telang Usan district to a maximum score of 0.9752 for the Kuching district. The districts have been classified into four groups, namely extreme, high, medium, and low, based on their exposure index scores with respect to climate change and variability. Districts such as Kuching, Sibu, Bintulu and Miri are classified as having a high level of exposure. The seasonal northeast and southwest monsoons that occur annually in Sarawak are the primary contributors to this extremely high level of exposure to flood (Saádi *et al.*, 2017). Sarawak experiences heavy precipitation and strong winds from the northeast during the northeast monsoon season, which takes place between November and February. Likewise, the southwest monsoon, which occurs from May to October, results in substantial precipitation and robust winds originating from the southwest. The significant precipitation during the monsoon season in Sarawak has the potential to cause flooding and landslides, resulting in notable consequences for the local population and economy (Saádi et al., 2017; Isia et al., 2023).The map illustrating the flood-prone areas distribution indicates that the south, center, and north regions of Sarawak are the most vulnerable to floods. It is assumed that flooding will occur in the future under similar conditions as in the past and present disasters.

Kuching, with its expanding population and low adaptive capacity, is particularly vulnerable to extreme climatic events. Due to its location between the Sarawak River and the South China Sea, Kuching is prone to flooding, especially during the monsoon season or heavy rainfall. The rapid urbanization and improper land use practices in Kuching have led to the expansion of concrete structures and reduced green spaces, exacerbating the problem. In comparison to Sibu, Bintulu and Miri, the key factor contributing to flooding is inadequate and outdated drainage systems, particularly in certain parts of the area where clogged or undersized drains and culverts impede efficient water flow during heavy rainfall.

The extent of areas affected by flooding is significantly influenced by the elevation, which plays a crucial role in controlling the same. The intensity of runoff is also determined by this factor. As per the general phenomenon, water moves downwards owing to the force of gravity and accumulates in the lower areas, making them more susceptible to flooding. The area with low elevation, such as floodplains and coastal areas, exhibit heightened susceptibility to flooding during periods of heavy rainfall, storm surges, or instances of river overflow. These area function as natural basins where water collects, rendering them vulnerable to inundation.

All these elements contribute to the maximum score on the vulnerability index. The Histogram graph shown that Kuching (0.9752) and Sibu (0.9020) position first and second rank, respectively, in terms of exposure vulnerability to climate change. Besides, Telang Usan and Lundu have the lowest values for exposure indicators such as temperature, rainfall, and flood event when compared to the other districts. As a result, Telang Usan (0.0070), Lundu (0.0464) and Subis (0.0520), have the lowest level of vulnerability and are ranked 10th, 11th, and 12th, respectively, out of all the districts. The exposure index and the relative ranking of the various districts' levels of vulnerability are both graphically represented in Figures 4.1 and 4.2, respectively.

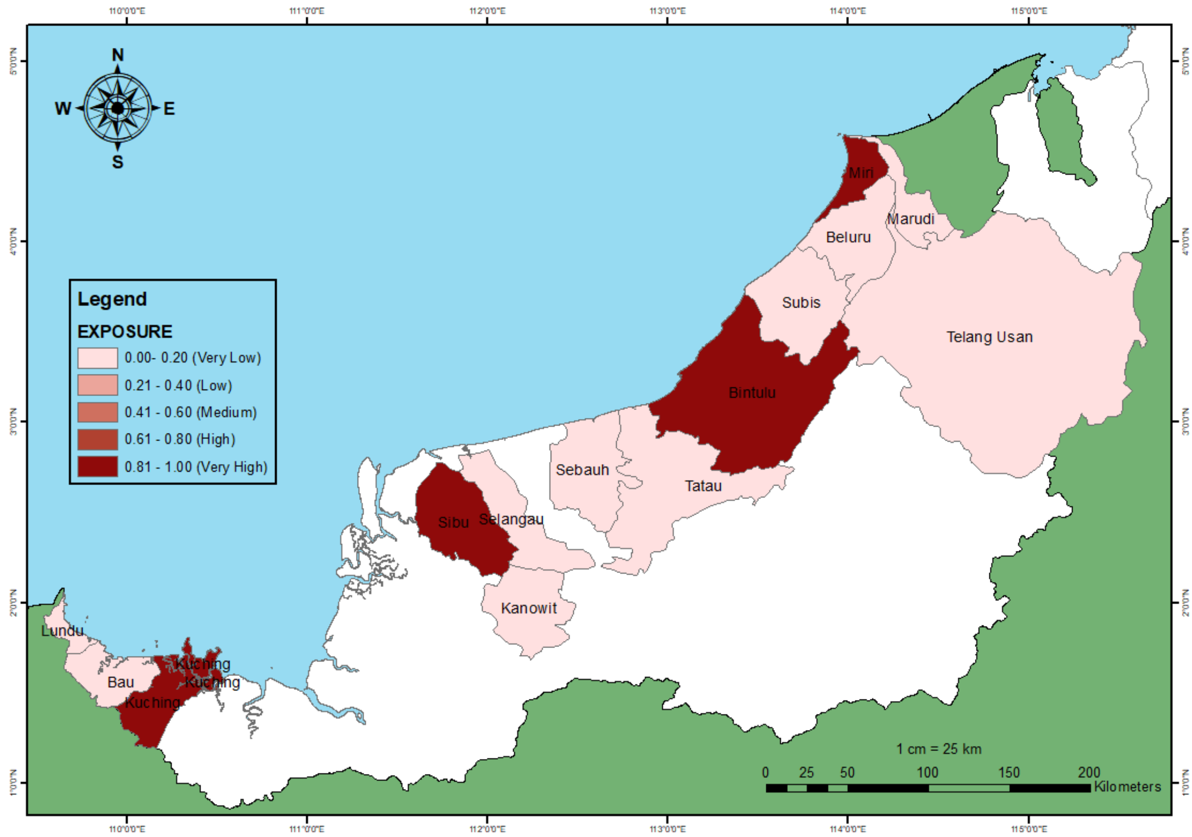

Figure 4.2 Mapping of different level exposure

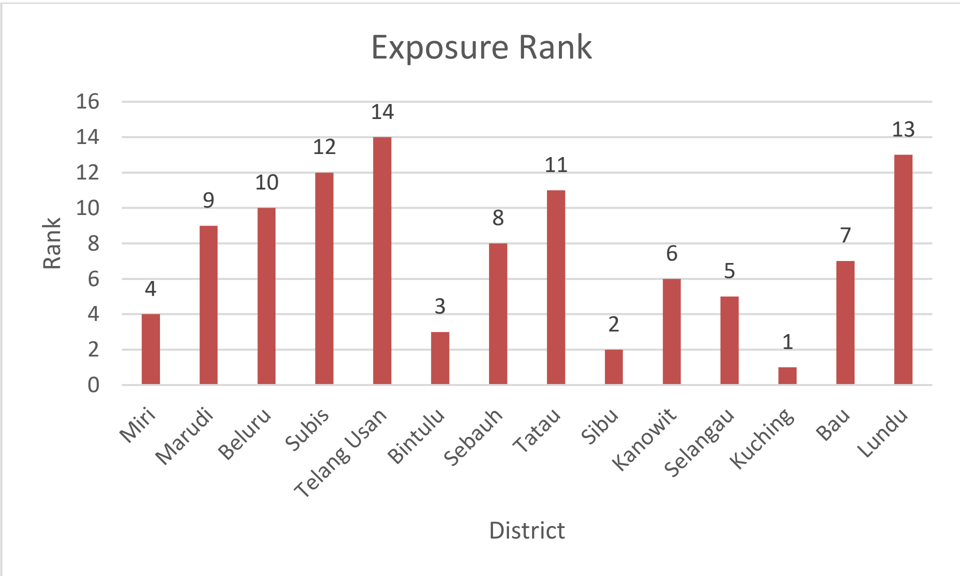

Figure 4.3 Histogram of exposure along with their rank

4.6 Sensitivity Vulnerability Index Reliability

Sensitivity was computed by obtaining an average of eleven indicators spanning three distinct categories of vulnerability, and the results were effectively communicated through the creation of maps (as shown in Figure 4.4). The findings clearly demonstrated that, of all the locations evaluated, Kuching, Miri, Sibu, and Bintulu showcased a remarkable level of sensitivity to the effects of climate change. These districts show the higher scoring in these indicators of population density, poor household, unemployment, elderly, women, and disabilities than the other districts.

The rapid urbanization of areas like Kuching, Sibu, Bintulu, and Miri has brought about a significant modification of natural drainage systems and a substantial increase in impervious surfaces. Due to the presence of dense infrastructure and limited green spaces in urban areas, there is an increased susceptibility to heat islands and urban flooding, which in turn intensifies the sensitivity vulnerability. Additionally, the high population density observed in these districts amplifies their sensitivity vulnerability. The concentration of people and assets in vulnerable areas significantly increases the risk of casualties and damage during climate-related events. This also places additional pressure on resources and services during the disaster response and recovery phase.

The formation of vulnerability is greatly affected by socioeconomic determinants. These determinants, including poverty, insufficient access to resources, and deficient infrastructure, contribute to the sensitivity vulnerability. Communities residing in these regions, that are lacking in financial capacities and resources, frequently face adversities in accommodating the consequences of climate change. Consequently, this renders them more susceptible to hazards associated with climate fluctuations. Moreover, insufficient access to fundamental resources, such as clean water, food, and healthcare, aggravates sensitivity vulnerability. Climatic variations can disturb the accessibility and availability of these resources, particularly in areas that are susceptible to extreme weather phenomena.

The increased susceptibility to heightened sensitivity observed in Kuching, Sibu, Bintulu, and Miri is the result of a combination of geographical, socioeconomic, and environmental factors. Crucial factors such as coastal positioning, urbanization, populace density, and reliance on ecosystems all contribute to this vulnerability. A holistic strategy is necessary to tackle this issue, which entails developing infrastructure that can withstand climate impacts, planning land use in a sustainable manner, and providing targeted socioeconomic assistance to communities that are at risk. By prioritizing the construction of resilience and enhancing adaptive capacity, it is plausible to enhance the safeguarding of the welfare and security of the inhabitants residing in Kuching, Sibu, Bintulu, and Miri. In the pursuit of establishing a sustainable future for vulnerable societies, it is imperative to acknowledge and address the unique challenges they confront in adapting to the repercussions of climate change. This entails recognizing the distinctive difficulties arising from their specific cultural, social, economic, and environmental contexts. These challenges may encompass limited access to resources, deficient infrastructure, outdated technology, and financial constraints. Effectively conforming to the impacts of climate change mandates the recognition of these hurdles and the formulation and implementation of strategies to mitigate them, thereby ensuring an equitable and sustainable trajectory for all.

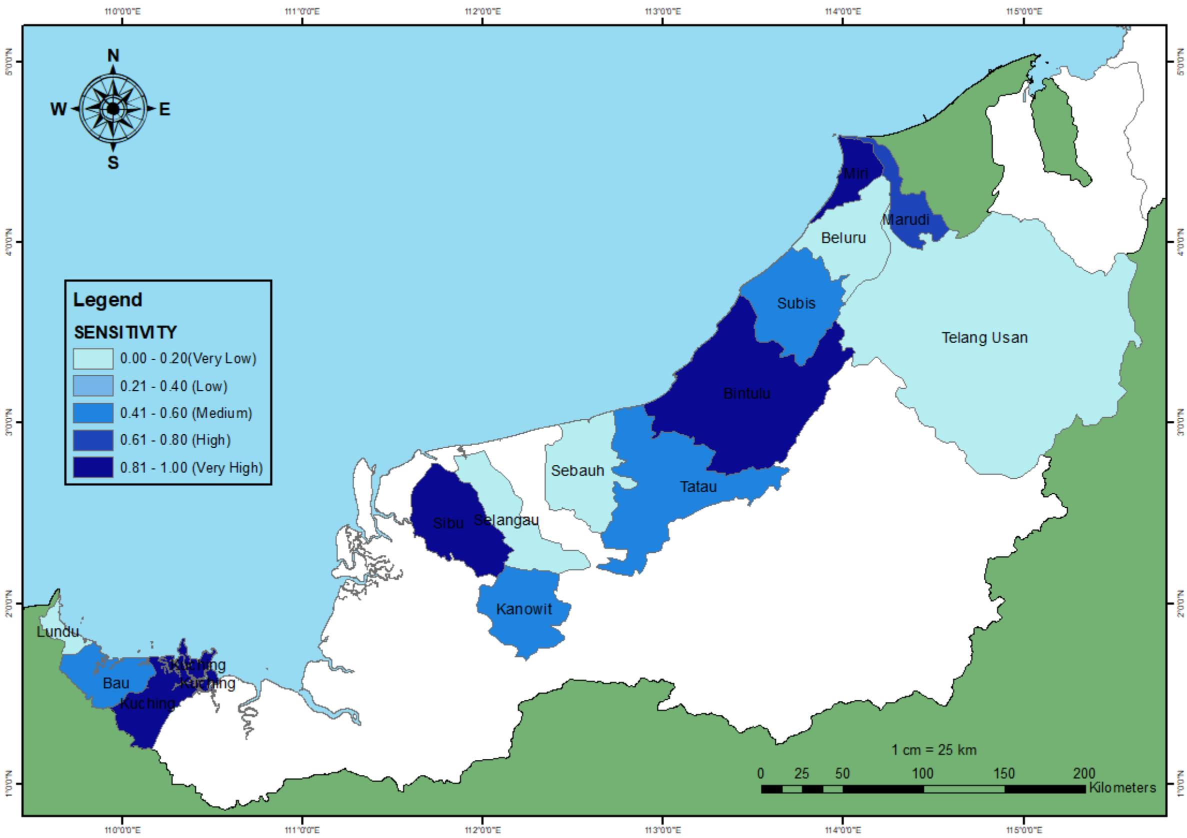

Figure 4.4 Mapping of different level sensitivity

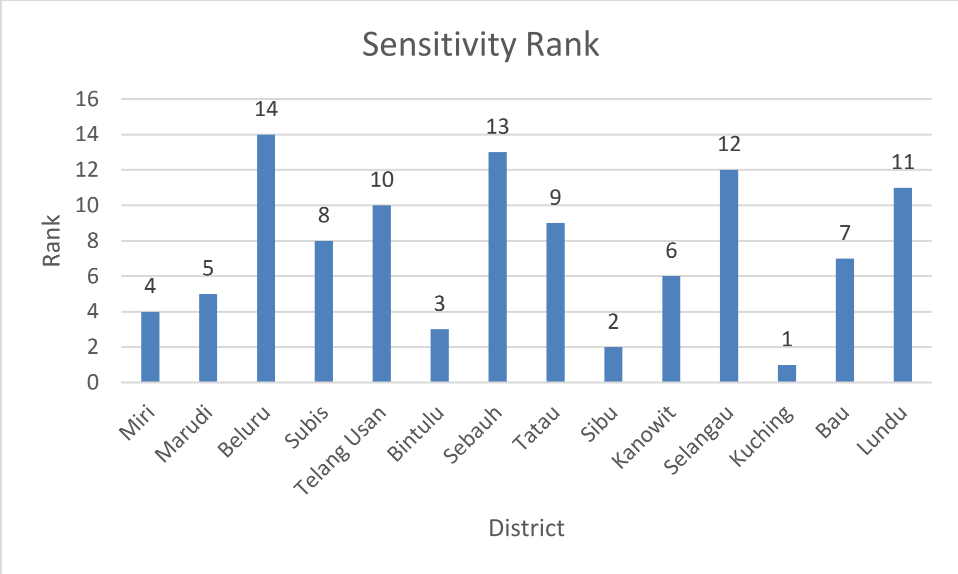

Figure 4.5 Histogram of sensitivity along with their rank

4.7 Coping Capacity Vulnerability Index Reliability

In the case of coping capacity, Kanowit (0.9512) has high resilience toward vulnerability, followed by Telang Usan (0.8854) and Lundu (0.8504), while Kuching and Miri have much less resilience toward vulnerability with a resilience index of 0.0972 and 0.1347, respectively. Therefore, Kanowit, Telang Usan and Lundu have positioned 1 to 3 ranks, respectively, in terms of coping capacity vulnerability to climate change. Miri and Kuching come in at positions 13th and 14th, respectively, among all the districts (Figure 4.7). The measurement of coping capacity levels in the surveyed areas was evaluated using three different indicators consisting of: infrastructure (emergency services, number of road, electricity, portable water and communication), environmental vulnerability (elevation and air pollution), and health vulnerability (health facilities). The results of the index are presented through the generated resistance map (Figure 4.6). According to research findings, individuals who possess knowledge about the potential risks of flooding are likely to exhibit a higher level of resilience to the impact of such disasters (Aznar-Crespo *et al.*, 2021). Additionally, communities with strong social networks will coordinate with each other, in emergency cases to reduce the impact of flooding.

In times of climate change events such as floods, it's crucial for people to have swift access to evacuation routes, emergency supplies, and medical care. Good transportation networks play a vital role in making this possible. They enable people to safely evacuate from flooded areas, ensure a steady supply of emergency essentials, and make it easier for individuals to reach medical services during and after the floods. These interconnected activities are essential for the well-being and safety of communities affected by floods, providing them with the necessary support and resources to navigate through challenging times (Shah et al., 2018; Qureshi et al., 2019). Overall, various factors contribute significantly to the exposure index in different areas. Specifically, Kuching and Miri exhibit elevated levels of elderly, women, children, population density, disabled population, and impoverished households, consequently resulting in a heightened exposure index. These factors collectively contribute to a higher exposure index in these districts compared to others. Conversely, Kanowit, Telang Usan and Lundu districts demonstrate comparatively lower proportions of these factors, leading to a correspondingly diminished exposure index. This means that the vulnerability to certain risks, such as floods, may vary across these areas based on the intensity of these contributing factors.

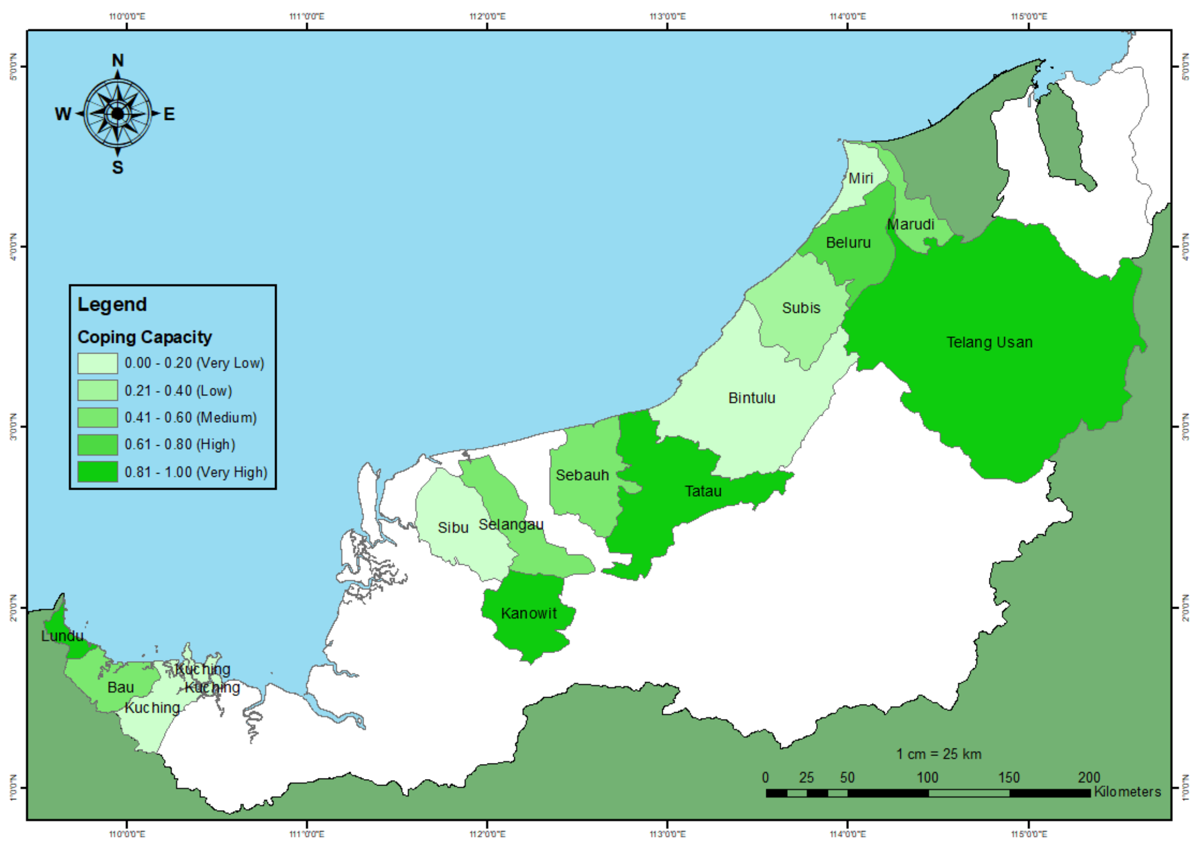

Figure 4.6 Mapping of different level coping capacity

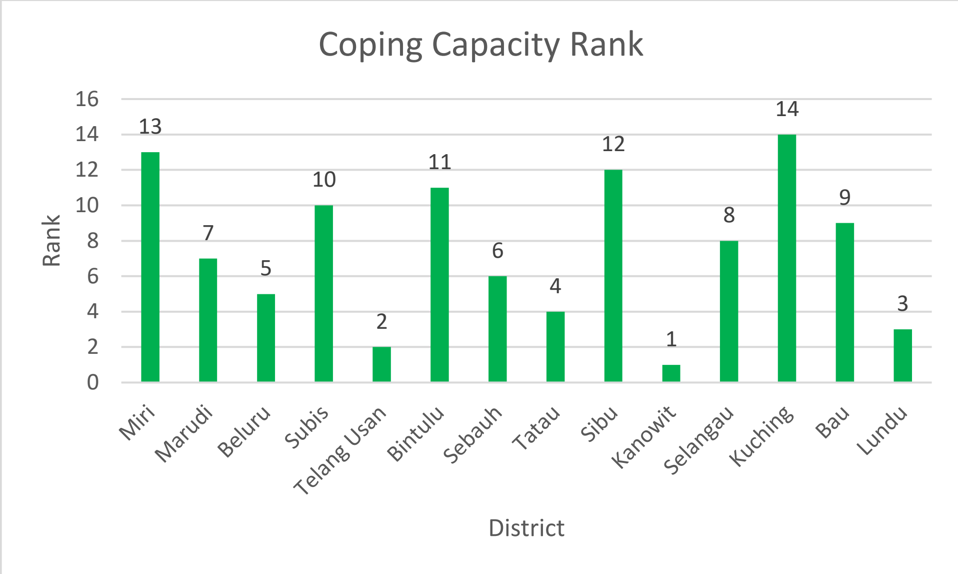

Figure 4.7 Histogram of coping capacity along with their rank

4.8 Socio-Environmental Vulnerability Index (SENVIINT)

The indicators obtained from exposure, sensitivity and coping capacity are of paramount importance in determining the socio-environmental vulnerability to climate change. Exposure indicators offer valuable insights into the level of exposure that a community is confronted with, while sensitivity pertains to the extent to which a system is impacted by all aspects of climate change, whether directly or indirectly affecting its components, in both positive and negative ways. Conversely, coping capacity indicators evaluate the community's capacity to manage and rebound from flood consequences, considering aspects such as accessibility to resources, infrastructure, and social support systems (Tascon-Gonzalez *et al.*, 2020).

There are various processes involved in the process of mapping social vulnerability. In the first instance, relevant indicators are selectively chosen based on the specific context and objectives of the research. Thereafter, the process of data collection and analysis involves the utilization of both methods to obtain both numerical data and community perspectives (Grigorescu *et al.*, 2021b). Oft;en, GIS (Geographic Information System) mapping techniques are employed to illustrate vulnerability levels visually and spatially (Mourato *et al.*, 2023). The social vulnerability scores and their corresponding individual components were visually represented by a color scheme that includes green, yellow, and red, with green representing the lowest score and red representing the highest score. The relationship between exposure and resistance plays a significant role in determining the social vulnerability index of a district. The vulnerability score of each district, as per Equation (7), is influenced by these two factors.

Table 4.4 Rank of Socio-Environmental Vulnerability Index (SENVIINT)

District	Socio-Environmental Vulnerability Index (SENVIINT)	Rank
Kuching	0.9250	1
Sibu	0.8440	2
Bintulu	0.8119	3
Miri	0.8005	4
Marudi	0.5755	5
Lundu	0.3669	6
Kanowit	0.3668	7
Selangau	0.3417	8
Beluru	0.3393	9
Bau	0.3149	10
Telang Usan	0.3026	11
Subis	0.2937	12
Tatau	0.2811	13
Sebauh	0.2760	14

Upon closer examination of all Sarawak districts (Table 4.4), it is apparent that Kuching district is the most susceptible, with a vulnerability index score of 0.925. Consequently, Kuching district requires heightened attention and measures to enhance its resilience against potential risks and hazards. Following closely with a vulnerability index score of 0.844 is the Sibu district. Other districts with considerable vulnerability include Bintulu and Miri, with index scores of 0.8119 and 0.8005, respectively. The increased susceptibility noted in the districts of Kuching, Sibu, Bintulu, and Miri implies that a multitude of factors have played a role in heightening their risk. These factors include high population density, inadequate infrastructure, insufficient access to healthcare services, high poverty rates, and previous exposure to flooding events. In order to identify the districts that are susceptible to climate change, a vulnerability map has been developed (Figure 4. 8). This map provides a visual representation of the districts that possess the most weaknesses, thereby highlighting the areas that require immediate attention and intervention. Marudi ranked 5th with an index score of 0.5755. Even though Marudi is not the most vulnerable district, it still possesses a high degree of vulnerability. The difficulties encountered by Marudi in terms of exposure and resistance factors highlight the need for targeted strategies and interventions to reduce the potential effects of hazards and foster greater resilience.

On the other hand, according to the social vulnerability index, the Sebauh district achieved a score of 0.2760, while Tatau obtained 0.2811, Subis attained 0.2937, Telang Usan received 0.3026, and Bau obtained 0.3149. Therefore, Sebauh district is considered to have the lowest risk level in contrast to all other districts. Meanwhile, according to the vulnerability map, Sebauh, Tatau, Subis, and Telang Usan districts exhibit a relatively lower susceptibility. These districts possess distinct characteristics and abilities that enhance their resilience against climate change-related hazards. Such factors may comprise of lower population density, better infrastructure, improved access to healthcare services, lower poverty rates, and possibly less historical exposure to climate change. Figure 4.9 shows the ranking of all districts according to their vulnerability, with numbers 1 to 14, from the most vulnerable to the least vulnerable.

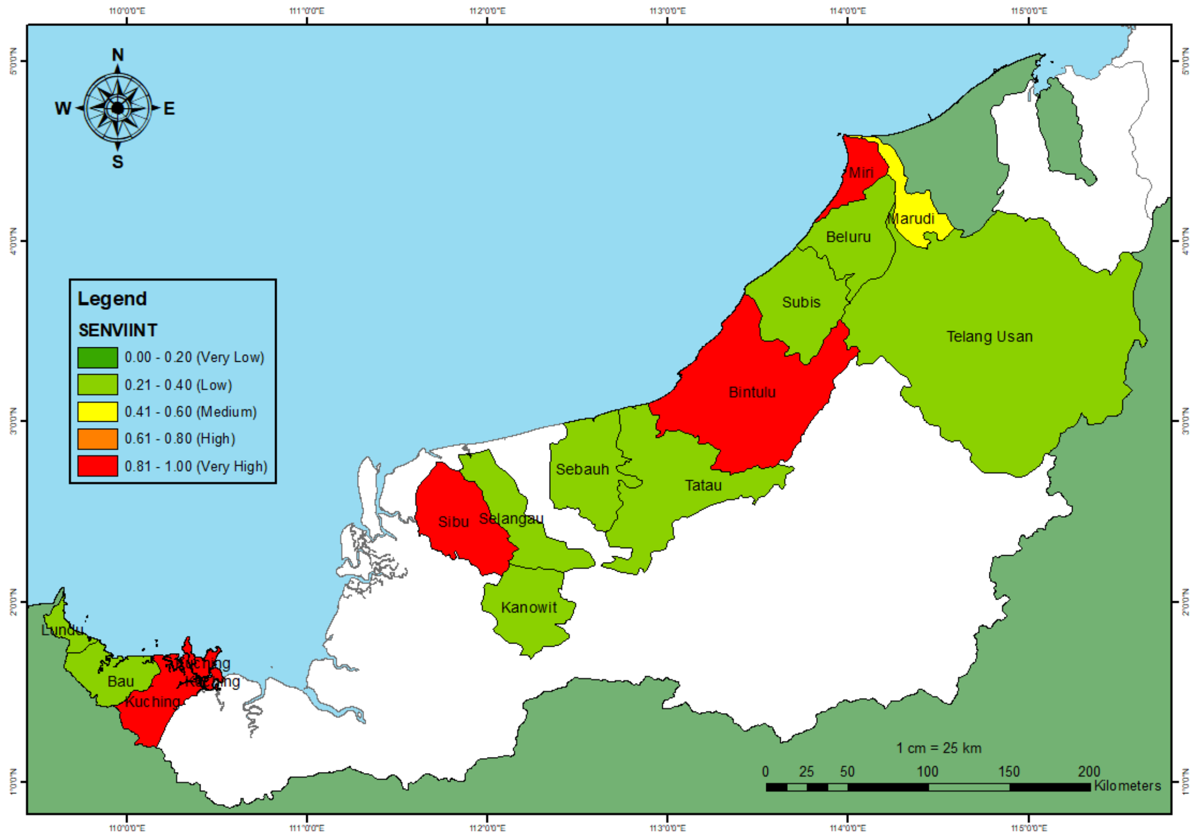

Figure 4.8 Overall socio-environmental vulnerability index (SENVIINT) map

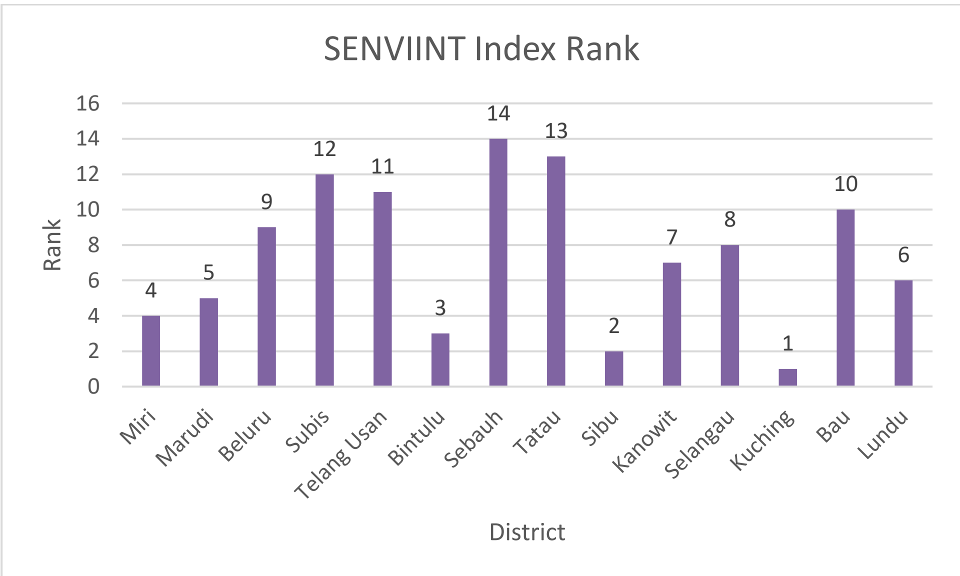

Figure 4.9 Histogram of socio-environmental vulnerability index along with their rank

In conclusion, the development of the Socio-Environmental Vulnerability Index (SENVIINT) in Sarawak provides a valuable tool to evaluate the effects of climate change on social and environmental aspects in the area (Table 4.4). By using an indicator-based approach, this index successfully distinguishes vulnerability factors and their interdependencies, providing crucial insights for policymakers and community planners. The investigation has indicated that Kuching, Sibu, Bintulu, and Miri are districts that possess higher vulnerability to sensitivity. The primary contributory factors include poverty, insufficient access to resources, and inadequate infrastructure. To enhance resilience and effectively manage climate impacts, these districts necessitate targeted interventions and adaptive strategies.

Conversely, other districts with lower sensitivity vulnerability have displayed better economic conditions, resource accessibility, and proactive governance. These favorable factors contribute to their ability to respond more efficiently to climate-related challenges. To effectively tackle the vulnerability issues in Sarawak, it is of utmost importance to implement adaptive measures and enhance the adaptive capacity. By promoting resilience and executing climate adaptation strategies, Sarawak can ensure the safety and welfare of its residents, thereby securing a sustainable future for the region. SENVIINT provides valuable insights and guidance for policymakers to formulate and implement policies that can address distinctive vulnerabilities and promote sustainable development in Sarawak.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The global significance of vulnerability to climate change is evident, extending to Sarawak, Malaysia. Recent evaluations integrating socio-environmental factors in vulnerability index mapping have unveiled significant insights into the region's challenges. Yet, a precise methodology to assess the interplay between social and environmental vulnerability remains lacking. Integrating socio-environmental factors in Sarawak's vulnerability mapping offers a comprehensive understanding, revealing vulnerabilities influenced by demographics, healthcare access, education, and income distribution. Vulnerability assessments across Sarawak's divisions identified exposure as a key factor, with districts like Kuching, Sibu, Bintulu, and Miri exhibiting the highest vulnerability due to flood frequency, low elevations, and social disparities. The study validates vulnerability's multifaceted nature, influenced by exposure, sensitivity, and adaptive capabilities. This research presents an objective and practical approach to vulnerability assessment, emphasizing the need for targeted interventions to address socio-environmental disparities and enhance resilience in Sarawak.

The study delves into vulnerability dynamics by examining exposure, sensitivity, and coping capacity, utilizing the vulnerability index as a quantitative measure. It aims to uncover risks posed by climate change and assess vulnerability levels comprehensively. Through evaluating various indicators and their operational associations, the research reveals the nuanced interplay between socio-environmental factors and vulnerability. Findings offer insights into vulnerability patterns across Sarawak, stressing the necessity of targeted interventions to enhance resilience and mitigate climate change impacts. The analysis elucidates complex socio-environmental interactions, identifying areas of heightened risk and underscoring the importance of intervention. This research provides valuable guidance for policymakers and stakeholders, directing efforts towards sustainable development and effective climate adaptation strategies in Sarawak.

The adaptation of the Socio-Environmental Vulnerability Index (SENVIINT) model for Sarawak signifies a significant advancement in fully grasping and tackling the region's susceptibility to social and environmental obstacles. Expanding on prior research, the SENVIINT model combines various indicators to evaluate levels of vulnerability, such as poverty, education, and water availability. By carrying out thorough data collection and standardization procedures, the model guarantees fairness and precision in vulnerability evaluations throughout different areas of Sarawak. Utilizing spatial analysis helps in illustrating vulnerability trends, assisting policymakers in determining intervention priorities. Involvement of the community enhances the model's context and significance, promoting local ownership and expertise. Particularly, the model points out the uneven spread of vulnerability, underscoring the pressing requirement to tackle socio-economic inequalities and invest in ecosystem preservation and community resilience. These observations provide valuable direction for policymakers and stakeholders, facilitating well-informed decision-making to advance sustainable development and resilience in Sarawak's constantly evolving environment.

The last objective of integrating socio-environmental factors into vulnerability index mapping in Sarawak is to comprehensively assess the region's susceptibility to climate change. This involves evaluating exposure, sensitivity, and coping capacity indicators to understand vulnerability dynamics. GIS mapping techniques visually represent vulnerability patterns across Sarawak, highlighting districts like Kuching (0.925), Sibu (0.844), Bintulu (0.8119), and Miri (0.8005) as highly susceptible due to factors such as poverty and inadequate infrastructure. Conversely, districts like Sebauh (0.2760) exhibit lower vulnerability, attributed to better economic conditions and proactive governance. The Socio-Environmental Vulnerability Index (SENVIINT) serves as a crucial tool for policymakers, guiding targeted interventions to enhance resilience and mitigate climate impacts. By promoting resilience and executing climate adaptation strategies, Sarawak can ensure the safety and welfare of its residents, securing a sustainable future for the region with insights from SENVIINT.

In conclusion, incorporating socio-environmental aspects into vulnerability index mapping in Sarawak has revealed important insights into the area's susceptibility to climate change. Variations in vulnerability among different areas highlight the pressing need for specific policies to tackle socio-economic disparities and promote fairness in climate resilience initiatives. Moreover, the investigation emphasizes the vital role of untouched ecosystems in enhancing resilience against climate impacts, highlighting the importance of preservation and sustainable woodland management techniques. Furthermore, the significance of community resilience has been recognized, highlighting the necessity to allocate funds to capacity-building projects and improve access to resources to promote adaptive reactions at the grassroots level. These outcomes provide valuable guidance for decision-makers, stakeholders, and local communities as they collaborate to tackle climate change impacts and pave the way for a more sustainable, just, and resilient future for all Sarawak residents.

5.2 Recommendations

The current work has identified certain recommendations that can be implemented to streamline the obtained results. These recommendations entail a more comprehensive study of vulnerability in Sarawak. The following are three recommendations for future studies based on the title "Assessment of Effect of Climate Change on Integrated Social-Environmental Vulnerability (SENVIINT) of Sarawak, Malaysia":

1. Implementation of Longitudinal Analysis for Temporal Trends: A longitudinal study is recommended to effectively monitor the evolution of integrated social-environmental vulnerability in Sarawak over a period of time. The proposed approach entails gathering data at various intervals in the future and analyzing trends to ascertain whether vulnerability is increasing, decreasing, or remaining stable. This analysis will aid policymakers in proactively anticipating and strategizing for future climate change impacts.

2. Engagement of the Community and Local Stakeholder: Future studies should prioritize the implementation of local stakeholder engagement. It is strongly advised that the research process involves active participation from local communities, indigenous groups, and other relevant stakeholders. Through engaging with those who are most directly affected by climate change, researchers can gain invaluable

insights into their experiences, perspectives, and adaptation strategies. This approach leads to more contextually relevant findings and recommendations, as researchers engage with the people most directly impacted by climate change.

3. Investigate the Correlation Between Socio-Environmental and Economic Vulnerabilities: This entails examining the intricate linkages between environmental vulnerabilities, such as susceptibility to extreme weather conditions and shifting ecosystems, and socio-economic vulnerabilities. The study should delve into the ways in which environmental modifications, including amplified flooding or diminished agricultural yields, gravely affect the socio-economic prosperity of individuals and communities residing in Sarawak.

By incorporating multiple perspectives into the assessment of SENVIINT in Sarawak, future studies can provide a more holistic understanding of how climate change affects the well-being and resilience of communities in the region. This, in turn, can inform more effective policy and adaptation measures to address the complex challenges posed by climate change.

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A) Example calculation of increase and decrease by using equation (1) and (2)

Example Calculation (increase)

District	Temperature (mean)
Miri	0.0152
Marudi	0.0160
Bintulu	0.0209
Sebauh	0.0167
Tatau	0.0167
Sibu	0.0159
Kanowit	0.0157
Selangau	0.0173
Kuching	0.0148
Bau	0.0135
Lundu	0.0151

Min (X_{ij})

$$Y_{ij} = \frac{\{X_{ij} - Min(X_{ij})\}}{\{Max(X_{ij}) - Min(X_{ij})\}}$$

$$Y_{ij} = \frac{\{0.0152 - 0.0135\}}{\{0.0209 - 0.0135\}} = 0.2297$$

District	Normalization
Miri	0.2297
Marudi	0.3378
Bintulu	1
Sebauh	0.4324
Tatau	0.4324
Sibu	0.3243
Kanowit	0.2973
Selangau	0.5135
Kuching	0.1757
Bau	0
Lundu	0.2162

Example Calculation (decrease)

District	Male	Female	Gender Ratio
Miri	145200	128900	1.1265
Marudi	12300	12000	1.0250
Bintulu	102100	85900	1.1886
Sebauh	17400	12800	1.3594
Tatau	18900	16300	1.1595
Sibu	143700	134700	1.0668
Kanowit	16500	16800	0.9821
Selangau	13600	12900	1.0543
Kuching	352000	339300	1.0374
Bau	31800	29300	1.0853
Lundu	20100	18100	1.1105

Max (X_{ij})

$$Y_{ij} = \frac{\{Max(X_{ij}) - X_{ij}\}}{\{Max(X_{ij}) - Min(X_{ij})\}}$$

$$Y_{ij} = \frac{\{1.3594 - 1.1265\}}{\{1.3594 - 0.9821\}} = 0.61$$

District	Normalization
Miri	0.6174
Marudi	0.8864
Bintulu	0.4527
Sebauh	0
Tatau	0.5298
Sibu	0.7755
Kanowit	1
Selangau	0.8088
Kuching	0.8534
Bau	0.7265
Lundu	0.6597

B) Pearson Correlation Matrix

Variables	Temperature (+)	Rainfall (+)	Flood (+)	Poverty (+)	House Rental (+)	Poor household (+)	Unmployed (+)	Population Density (+)	Elderly (+)	Women (+)	Public Health (+)	Foreiner Population (+)	Disabilities (+)	Literacy (+)	Emergency Services (-)	Number of Road (-)	Electricity (-)	Potable Water (-)	Communication (-)	Elevation (-)	Air Pollution (-)	Health Facilities (-)
Temperature (+)	1	0.244	-0.024	-0.380	0.394	0.142	0.438	0.384	0.426	0.429	0.487	0.380	0.433	0.459	-0.576	-0.351	-0.023	-0.591	-0.148	0.288	-0.643	-0.211
Rainfall(+)	0.244	1	0.313	0.154	-0.248	-0.179	-0.113	-0.036	-0.132	-0.138	-0.232	-0.254	-0.157	0.054	-0.198	0.008	0.110	0.204	0.665	-0.324	-0.313	-0.608
Flood(+)	-0.024	0.313	1	0.314	0.030	0.033	0.166	0.048	0.101	0.081	0.054	-0.049	0.132	-0.086	-0.305	-0.093	0.075	0.054	0.316	0.112	-0.091	0.041
Poverty(+)	-0.380	0.154	0.314	1	-0.502	-0.149	-0.352	-0.323	-0.397	-0.404	-0.239	-0.626	-0.404	0.087	0.305	0.336	0.567	0.352	0.628	-0.014	0.187	0.389
House Rental(+)	0.394	-0.248	0.030	-0.502	1	0.194	0.584	0.422	0.540	0.538	0.523	0.576	0.577	0.364	-0.494	-0.408	-0.289	-0.397	-0.551	0.434	-0.514	-0.044
Poor household(+)	0.142	-0.179	0.033	-0.149	0.194	1	0.842	0.895	0.857	0.855	0.298	-0.210	0.832	0.016	-0.616	-0.879	0.060	-0.394	-0.254	0.372	-0.153	0.191
Unmployed(+)	0.438	-0.113	0.166	-0.352	0.584	0.842	1	0.947	0.992	0.989	0.580	0.169	0.990	0.232	-0.838	-0.914	-0.217	-0.590	-0.433	0.407	-0.353	0.145
Population Density(+)	0.384	-0.036	0.048	-0.323	0.422	0.895	0.947	1	0.956	0.960	0.360	0.036	0.920	0.127	-0.728	-0.964	-0.203	-0.526	-0.342	0.315	-0.238	0.131
Elderly(+)	0.426	-0.132	0.101	-0.397	0.540	0.857	0.992	0.956	1	0.999	0.575	0.184	0.993	0.157	-0.815	-0.916	-0.244	-0.610	-0.458	0.353	-0.294	0.141
Women(+)	0.429	-0.138	0.081	-0.404	0.538	0.855	0.989	0.960	0.999	1	0.569	0.190	0.989	0.151	-0.806	-0.914	-0.250	-0.609	-0.462	0.341	-0.285	0.144
Public Health (+)	0.487	-0.232	0.054	-0.239	0.523	0.298	0.580	0.360	0.575	0.569	1	0.339	0.644	0.392	-0.739	-0.299	-0.109	-0.500	-0.391	0.420	-0.518	0.075
Foreiner Population(+)	0.380	-0.254	-0.049	-0.626	0.576	-0.210	0.169	0.036	0.184	0.190	0.339	1	0.223	0.074	-0.123	-0.048	-0.339	-0.564	-0.499	-0.082	-0.101	0.087
Disabilities(+)	0.433	-0.157	0.132	-0.404	0.577	0.832	0.990	0.920	0.993	0.989	0.644	0.223	1	0.183	-0.843	-0.889	-0.229	-0.633	-0.471	0.405	-0.340	0.139
Literacy (+)	0.459	0.054	-0.086	0.087	0.364	0.016	0.232	0.127	0.157	0.151	0.392	0.074	0.183	1	-0.375	-0.161	0.088	-0.201	-0.114	0.282	-0.614	0.102
Emergency Services(-)	-0.576	-0.198	-0.305	0.305	-0.494	-0.616	-0.838	-0.728	-0.815	-0.806	-0.739	-0.123	-0.843	-0.375	1	0.704	0.108	0.427	0.156	-0.426	0.676	0.193
Number of Road(-)	-0.351	0.008	-0.093	0.336	-0.408	-0.879	-0.914	-0.964	-0.916	-0.914	-0.299	-0.048	-0.889	-0.161	0.704	1	0.207	0.586	0.374	-0.319	0.248	-0.140
Electricity(-)	-0.023	0.110	0.075	0.567	-0.289	0.060	-0.217	-0.203	-0.244	-0.250	-0.109	-0.339	-0.229	0.088	0.108	0.207	1	0.124	0.626	0.197	-0.291	0.016
Potable Water(-)	-0.591	0.204	0.054	0.352	-0.397	-0.394	-0.590	-0.526	-0.610	-0.609	-0.500	-0.564	-0.633	-0.201	0.427	0.586	0.124	1	0.502	-0.225	0.157	-0.394
Communication(-)	-0.148	0.665	0.316	0.628	-0.551	-0.254	-0.433	-0.342	-0.458	-0.462	-0.391	-0.499	-0.471	-0.114	0.156	0.374	0.626	0.502	1	-0.121	-0.111	-0.300
Elevation(-)	0.288	-0.324	0.112	-0.014	0.434	0.372	0.407	0.315	0.353	0.341	0.420	-0.082	0.405	0.282	-0.426	-0.319	0.197	-0.225	-0.121	1	-0.507	0.106
Air Pollution(-)	-0.643	-0.313	-0.091	0.187	-0.514	-0.153	-0.353	-0.238	-0.294	-0.285	-0.518	-0.101	-0.340	-0.614	0.676	0.248	-0.291	0.157	-0.111	-0.507	1	0.487
Health Facilities(-)	-0.211	-0.608	0.041	0.389	-0.044	0.191	0.145	0.131	0.141	0.144	0.075	0.087	0.139	0.102	0.193	-0.140	0.016	-0.394	-0.300	0.106	0.487	1

C) Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Temperature .	9.541	43.366	43.366	9.541	43.366	43.366	7.562	34.371	34.371
Rainfall	3.110	14.137	57.503	3.110	14.137	57.503	3.216	14.618	48.989
Flood	2.689	12.222	69.725	2.689	12.222	69.725	3.092	14.055	63.044
Poverty	1.929	8.767	78.492	1.929	8.767	78.492	2.468	11.219	74.262
House Rental	1.204	5.471	83.962	1.204	5.471	83.962	1.887	8.578	82.841
Poor household	1.064	4.835	88.797	1.064	4.835	88.797	1.311	5.957	88.797
Unmployed	0.816	3.708	92.506						
Population Density	0.594	2.698	95.204						
Elderly	0.467	2.124	97.328						
Women	0.230	1.043	98.371						
Public Health	0.174	0.790	99.161						
Foreiner Population	0.152	0.690	99.851						
Disabilities	0.033	0.149	100.000						
Literacy	5.374E-16	2.443E-15	100.000						
Emergency Services	4.639E-16	2.108E-15	100.000						
Number of Road	4.104E-16	1.865E-15	100.000						
Electricity	1.471E-16	6.687E-16	100.000						
Potable Water	7.051E-17	3.205E-16	100.000						
Communication	-1.039E-16	-4.721E-16	100.000						
Elevation	-2.071E-16	-9.413E-16	100.000						
Air Pollution	-4.630E-16	-2.105E-15	100.000						
Health Facilities	-5.387E-16	-2.448E-15	100.000						

Extraction Method: Principal Component Analysis.

D) Kaiser-Meyer-Olkin Measure and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.471
Bartlett's Test of Sphericity	Approx. Chi-Square	0.012
	df	6
	Sig.	0.016

E) Raw Data – Exposure

1. Temperature

Division	District	Temperature	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	27.83	6.93	0.8772152	0.97	0.1227848		
	Marudi	27.14	6.24	0.7898734	1.66	0.2101266	Max =	28.80
	Beluru	26.5	5.60	0.7088608	2.30	0.2911392	Min =	20.90
	Subis	26	5.10	0.6455696	2.80	0.3544304	Max- Min =	7.90
	Telang Usan	20.9	0.00	0	7.90	1		
Bintulu	Bintulu	28.8	7.90	1	0.00	0		
	Sebauh	26.5	5.60	0.7088608	2.30	0.2911392		
	Tatau	26.84	5.94	0.7518987	1.96	0.2481013		
Sibu	Sibu	26.79	5.89	0.7455696	2.01	0.2544304		
	Kanowit	26.5	5.60	0.7088608	2.30	0.2911392		
	Selangau	26.34	5.44	0.6886076	2.46	0.3113924		
Kuching	Kuching	28.18	7.28	0.921519	0.62	0.078481		
	Bau	26.52	5.62	0.7113924	2.28	0.2886076		
	Lundu	26	5.10	0.6455696	2.80	0.3544304		

2. Rainfall

Division	District	Rainfall	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	2905.66	93.61	0.0772627	1117.97	0.9227373		
	Marudi	3533.2	721.15	0.5952145	490.43	0.4047855	Max =	4024
	Beluru	3132.91	320.86	0.2648277	890.72	0.7351723	Min =	2812.05
	Subis	3137.7	325.65	0.2687813	885.93	0.7312187	Max- Min =	1212
	Telang Usan	2812.05	0.00	0	1211.58	1		
Bintulu	Bintulu	3153.52	341.47	0.2818386	870.11	0.7181614		
	Sebauh	4023.63	1211.58	1	0.00	0		
	Tatau	3011.13	199.08	0.1643144	1012.50	0.8356856		
Sibu	Sibu	3307.69	495.64	0.4090857	715.94	0.5909143		
	Kanowit	3466.19	654.14	0.5399066	557.44	0.4600934		
	Selangau	3860.16	1048.11	0.865077	163.47	0.134923		
Kuching	Kuching	3284.13	472.08	0.38964	739.50	0.61036		
	Bau	3617.58	805.53	0.6648591	406.05	0.3351409		
	Lundu	2947.85	135.80	0.112085	1075.78	0.887915		

2. Flood event

Division	District	Flood event	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	3	2.00	0.0689655	27.00	0.9310345		
	Marudi	9	8.00	0.2758621	21.00	0.7241379	Max =	30
	Beluru	7	6.00	0.2068966	23.00	0.7931034	Min =	1.00
	Subis	3	2.00	0.0689655	27.00	0.9310345	Max- Min =	29
	Telang Usan	6	5.00	0.1724138	24.00	0.8275862		
Bintulu	Bintulu	2	1.00	0.0344828	28.00	0.9655172		
	Sebauh	1	0.00	0	29.00	1		
	Tatau	2	1.00	0.0344828	28.00	0.9655172		
Sibu	Sibu	29	28.00	0.9655172	1.00	0.0344828		
	Kanowit	9	8.00	0.2758621	21.00	0.7241379		
	Selangau	30	29.00	1	0.00	0		
Kuching	Kuching	7	6.00	0.2068966	23.00	0.7931034		
	Bau	2	1.00	0.0344828	28.00	0.9655172		
	Lundu	4	3.00	0.1034483	26.00	0.8965517		

F) Raw Data – Sensitivity

1. Poverty

Division	District	Incidence of absolute poverty (%)	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	4.7	2.60	0.1313131	17.20	0.8686869		
	Marudi	16.9	14.80	0.7474747	5.00	0.2525253	Max =	21.90
	Beluru	12	9.90	0.5	9.90	0.5	Min =	2.10
	Subis	7.4	5.30	0.2676768	14.50	0.7323232	Max- Min =	19.80
	Telang Usan	13.6	11.50	0.5808081	8.30	0.4191919		
Bintulu	Bintulu	2.1	0.00	0	19.80	1		
	Sebauh	3.4	1.30	0.0656566	18.50	0.9343434		
	Tatau	5	2.90	0.1464646	16.90	0.8535354		
Sibu	Sibu	7.3	5.20	0.2626263	14.60	0.7373737		
	Kanowit	21.9	19.80	1	0.00	0		
	Selangau	14.3	12.20	0.6161616	7.60	0.3838384		
Kuching	Kuching	5.6	3.50	0.1767677	16.30	0.8232323		
	Bau	9.6	7.50	0.3787879	12.30	0.6212121		
	Lundu	10.2	8.10	0.4090909	11.70	0.5909091		

2. House Rental

Division	District	Rent %	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	11.1	10.10	0.6778523	4.80	0.3221477
	Marudi	7.5	6.50	0.4362416	8.40	0.5637584
	Beluru	1.1	0.10	0.0067114	14.80	0.9932886
	Subis	2.5	1.50	0.1006711	13.40	0.8993289
	Telang Usan	6.2	5.20	0.3489933	9.70	0.6510067
Bintulu	Bintulu	15.9	14.90	1	0.00	0
	Sebauh	5.7	4.70	0.3154362	10.20	0.6845638
	Tatau	12.9	11.90	0.7986577	3.00	0.2013423
Sibu	Sibu	14.6	13.60	0.9127517	1.30	0.0872483
	Kanowit	5.4	4.40	0.295302	10.50	0.704698
	Selangau	1.6	0.60	0.0402685	14.30	0.9597315
Kuching	Kuching	11.7	10.70	0.7181208	4.20	0.2818792
	Bau	1.9	0.90	0.0604027	14.00	0.9395973
	Lundu	1	0.00	0	14.90	1

Max = 16
Min = 1.00
Max- Min = 15

3. Poor household

Division	District	Head of poor household	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	1644	1031.00	0.2520782	3059.00	0.7479218
	Marudi	613	0.00	0	4090.00	1
	Beluru	1085	472.00	0.1154034	3618.00	0.8845966
	Subis	1029	416.00	0.1017115	3674.00	0.8982885
	Telang Usan	1491	878.00	0.2146699	3212.00	0.7853301
Bintulu	Bintulu	765	152.00	0.0371638	3938.00	0.9628362
	Sebauh	868	255.00	0.0623472	3835.00	0.9376528
	Tatau	1143	530.00	0.1295844	3560.00	0.8704156
Sibu	Sibu	2024	1411.00	0.3449878	2679.00	0.6550122
	Kanowit	1588	975.00	0.2383863	3115.00	0.7616137
	Selangau	961	348.00	0.0850856	3742.00	0.9149144
Kuching	Kuching	4703	4090.00	1	0.00	0
	Bau	1713	1100.00	0.2689487	2990.00	0.7310513
	Lundu	2166	1553.00	0.3797066	2537.00	0.6202934

Max = 4703.00
Min = 613.00
Max- Min = 4090.00

4. Unemployed

Division	District	Unemployed	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	5300	5300.00	0.3557047	9600.00	0.6442953
	Marudi	1300	1300.00	0.0872483	13600.00	0.9127517
	Beluru	0	0.00	0	14900.00	1
	Subis	0	0.00	0	14900.00	1
	Telang Usan	0	0.00	0	14900.00	1
Bintulu	Bintulu	3400	3400.00	0.2281879	11500.00	0.7718121
	Sebauh	0	0.00	0	14900.00	1
	Tatau	700	700.00	0.0469799	14200.00	0.9530201
Sibu	Sibu	7300	7300.00	0.4899329	7600.00	0.5100671
	Kanowit	800	800.00	0.0536913	14100.00	0.9463087
	Selangau	400	400.00	0.0268456	14500.00	0.9731544
Kuching	Kuching	14900	14900.00	1	0.00	0
	Bau	900	900.00	0.0604027	14000.00	0.9395973
	Lundu	600	600.00	0.0402685	14300.00	0.9597315

Max = 14900.00
Min = 0.00
Max- Min = 14900.00

5. Population Density

Division	District	Population density (per km2)	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	53.276298	51.02	0.1110956	408.21	0.8889044
	Marudi	7.8596947	5.60	0.0121968	453.62	0.9878032
	Beluru	7.0400419	4.78	0.010412	454.44	0.989588
	Subis	13.965341	11.71	0.0254924	447.52	0.9745076
	Telang Usan	2.2586224	0.00	0	459.22	1
Bintulu	Bintulu	94.424912	92.17	0.2007004	367.06	0.7992996
	Sebauh	5.7754829	3.52	0.0076583	455.71	0.9923417
	Tatau	7.1168621	4.86	0.0105793	454.37	0.9894207
Sibu	Sibu	124.84305	122.58	0.2669386	336.64	0.7330614
	Kanowit	14.818101	12.56	0.0273494	446.66	0.9726506
	Selangau	6.9828722	4.72	0.0102875	454.50	0.9897125
Kuching	Kuching	461.48198	459.22	1	0.00	0
	Bau	69.004525	66.75	0.1453452	392.48	0.8546548
	Lundu	21.081678	18.82	0.0409889	440.40	0.9590111

Max = 461
Min = 2.26
Max- Min = 459

6. Elderly

Division	District	Elderly (Age 65+)	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	22600	21100.00	0.3701754	35900.00	0.62982456
	Marudi	1900	400.00	0.0070175	56600.00	0.99298246
	Beluru	1900	400.00	0.0070175	56600.00	0.99298246
	Subis	4100	2600.00	0.045614	54400.00	0.95438596
	Telang Usan	1500	0.00	0	57000.00	1
Bintulu	Bintulu	13800	12300.00	0.2157895	44700.00	0.78421053
	Sebauh	2000	500.00	0.0087719	56500.00	0.99122807
	Tatau	2500	1000.00	0.0175439	56000.00	0.98245614
Sibu	Sibu	24700	23200.00	0.4070175	33800.00	0.59298246
	Kanowit	2800	1300.00	0.022807	55700.00	0.97719298
	Selangau	2100	600.00	0.0105263	56400.00	0.98947368
Kuching	Kuching	58500	57000.00	1	0.00	0
	Bau	5200	3700.00	0.0649123	53300.00	0.93508772
	Lundu	2900	1400.00	0.0245614	55600.00	0.9754386

Max = 58500
Min = 1500.00
Max- Min = 57000

7. Women

Division	District	Female	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	128900	118600.00	0.3604863	210400.00	0.6395137
	Marudi	12000	1700.00	0.0051672	327300.00	0.9948328
	Beluru	12400	2100.00	0.006383	326900.00	0.993617
	Subis	29700	19400.00	0.0589666	309600.00	0.9410334
	Telang Usan	10300	0.00	0	329000.00	1
Bintulu	Bintulu	85900	75600.00	0.2297872	253400.00	0.7702128
	Sebauh	12800	2500.00	0.0075988	326500.00	0.9924012
	Tatau	16300	6000.00	0.0182371	323000.00	0.9817629
Sibu	Sibu	134700	124400.00	0.3781155	204600.00	0.6218845
	Kanowit	16800	6500.00	0.0197568	322500.00	0.9802432
	Selangau	12900	2600.00	0.0079027	326400.00	0.9920973
Kuching	Kuching	339300	329000.00	1	0.00	0
	Bau	29300	19000.00	0.0577508	310000.00	0.9422492
	Lundu	18100	7800.00	0.0237082	321200.00	0.9762918

Max = 339300
Min = 10300.00
Max- Min = 329000

8. Public Health

Division	District	Vector-borne disease	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	455	455.00	1	0.00	0
	Marudi	126	126.00	0.2769231	329.00	0.7230769
	Beluru	0	0.00	0	455.00	1
	Subis	6	6.00	0.0131868	449.00	0.9868132
	Telang Usan	0	0.00	0	455.00	1
Bintulu	Bintulu	140	140.00	0.3076923	315.00	0.6923077
	Sebauh	0	0.00	0	455.00	1
	Tatau	47	47.00	0.1032967	408.00	0.8967033
Sibu	Sibu	140	140.00	0.3076923	315.00	0.6923077
	Kanowit	93	93.00	0.2043956	362.00	0.7956044
	Selangau	82	82.00	0.1802198	373.00	0.8197802
Kuching	Kuching	204	204.00	0.4483516	251.00	0.5516484
	Bau	26	26.00	0.0571429	429.00	0.9428571
	Lundu	44	44.00	0.0967033	411.00	0.9032967

Max =	455.00
Min =	0.00
Max- Min =	455.00

9. Foreigner Population

Division	District	Foreigner (%)	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	6.4	4.90	0.1849057	21.60	0.8150943
	Marudi	2.3	0.80	0.0301887	25.70	0.9698113
	Beluru	12.4	10.90	0.4113208	15.60	0.5886792
	Subis	28	26.50	1	0.00	0
	Telang Usan	8.2	6.70	0.2528302	19.80	0.7471698
Bintulu	Bintulu	16.4	14.90	0.5622642	11.60	0.4377358
	Sebauh	22.8	21.30	0.8037736	5.20	0.1962264
	Tatau	15.3	13.80	0.5207547	12.70	0.4792453
Sibu	Sibu	6.9	5.40	0.2037736	21.10	0.7962264
	Kanowit	1.5	0.00	0	26.50	1
	Selangau	5.2	3.70	0.1396226	22.80	0.8603774
Kuching	Kuching	1.9	0.40	0.0150943	26.10	0.9849057
	Bau	2.6	1.10	0.0415094	25.40	0.9584906
	Lundu	5	3.50	0.1320755	23.00	0.8679245

Max =	28
Min =	1.50
Max- Min =	27

10. Disabilities

Division	District	Disability	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	5044	5044.00	0.4744169	5588.00	0.5255831		
	Marudi	10	10.00	0.0009406	10622.00	0.9990594	Max =	10632
	Beluru	0	0.00	0	10632.00	1	Min =	0.00
	Subis	0	0.00	0	10632.00	1	Max- Min =	10632
	Telang Usan	0	0.00	0	10632.00	1		
Bintulu	Bintulu	2469	2469.00	0.2322235	8163.00	0.7677765		
	Sebauh	5	5.00	0.0004703	10627.00	0.9995297		
	Tatau	117	117.00	0.0110045	10515.00	0.9889955		
Sibu	Sibu	5233	5233.00	0.4921934	5399.00	0.5078066		
	Kanowit	324	324.00	0.030474	10308.00	0.969526		
	Selangau	56	56.00	0.0052671	10576.00	0.9947329		
Kuching	Kuching	10632	10632.00	1	0.00	0		
	Bau	712	712.00	0.0669676	9920.00	0.9330324		
	Lundu	385	385.00	0.0362114	10247.00	0.9637886		

11. Literacy

Division	District	Literacy	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	82.437075	82.44	0.4330247	107.94	0.5669753		
	Marudi	190.375	190.38	1	0.00	0	Max =	190.38
	Beluru	0	0.00	0	190.38	1	Min =	0.00
	Subis	28.261538	28.26	0.1484519	162.11	0.8515481	Max- Min =	190.38
	Telang Usan	0	0.00	0	190.38	1		
Bintulu	Bintulu	82.790155	82.79	0.4348793	107.58	0.5651207		
	Sebauh	33.5	33.50	0.1759685	156.88	0.8240315		
	Tatau	53.837838	53.84	0.2827989	136.54	0.7172011		
Sibu	Sibu	84.748252	84.75	0.4451648	105.63	0.5548352		
	Kanowit	69.684211	69.68	0.3660366	120.69	0.6339634		
	Selangau	0	0.00	0	190.38	1		
Kuching	Kuching	65.963279	65.96	0.3464913	124.41	0.6535087		
	Bau	76.688889	76.69	0.4028307	113.69	0.5971693		
	Lundu	77.447059	77.45	0.4068132	112.93	0.5931868		

G) Raw Data – Coping Capacity

1. Emergency Services

Division	District	Total polis and Fire stations	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	13	13.00	0.7647059	4.00	0.2352941		
	Marudi	7	7.00	0.4117647	10.00	0.5882353	Max =	17
	Beluru	0	0.00	0	17.00	1	Min =	0.00
	Subis	0	0.00	0	17.00	1	Max- Min =	17
	Telang Usan	0	0.00	0	17.00	1		
Bintulu	Bintulu	7	7.00	0.4117647	10.00	0.5882353		
	Sebauh	6	6.00	0.3529412	11.00	0.6470588		
	Tatau	3	3.00	0.1764706	14.00	0.8235294		
Sibu	Sibu	11	11.00	0.6470588	6.00	0.3529412		
	Kanowit	4	4.00	0.2352941	13.00	0.7647059		
	Selangau	9	9.00	0.5294118	8.00	0.4705882		
Kuching	Kuching	17	17.00	1	0.00	0		
	Bau	6	6.00	0.3529412	11.00	0.6470588		
	Lundu	5	5.00	0.2941176	12.00	0.7058824		

2. Number of Road

Division	District	Road Density	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	0.2970	0.25	0.1062551	2.08	0.8937449		
	Marudi	0.0848	0.04	0.0152825	2.30	0.9847175	Max =	2.38
	Beluru	0.0504	0.00	0.0005239	2.33	0.9994761	Min =	0.05
	Subis	0.1983	0.15	0.0639583	2.18	0.9360417	Max- Min =	2.33
	Telang Usan	0.0952	0.05	0.0197494	2.29	0.9802506		
Bintulu	Bintulu	0.5020	0.45	0.1941865	1.88	0.8058135		
	Sebauh	0.0643	0.02	0.0064747	2.32	0.9935253		
	Tatau	0.1817	0.13	0.0568064	2.20	0.9431936		
Sibu	Sibu	1.0938	1.04	0.4479588	1.29	0.5520412		
	Kanowit	0.1081	0.06	0.0252687	2.27	0.9747313		
	Selangau	0.0492	0.00	0	2.33	1		
Kuching	Kuching	2.3810	2.33	1	0.00	0		
	Bau	0.9204	0.87	0.373595	1.46	0.626405		
	Lundu	0.2045	0.16	0.0666121	2.18	0.9333879		

3. Electricity

Division	District	Electricity	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	99.72	8.17	0.9668639	0.28	0.0331361
	Marudi	99.63	8.08	0.956213	0.37	0.043787
	Beluru	100	8.45	1	0.00	0
	Subis	100	8.45	1	0.00	0
	Telang Usan	100	8.45	1	0.00	0
Bintulu	Bintulu	99.91	8.36	0.9893491	0.09	0.0106509
	Sebauh	98.9	7.35	0.8698225	1.10	0.1301775
	Tatau	99.15	7.60	0.8994083	0.85	0.1005917
Sibu	Sibu	98.85	7.30	0.8639053	1.15	0.1360947
	Kanowit	91.55	0.00	0	8.45	1
	Selangau	98.33	6.78	0.8023669	1.67	0.1976331
Kuching	Kuching	99.97	8.42	0.9964497	0.03	0.0035503
	Bau	98.84	7.29	0.8627219	1.16	0.1372781
	Lundu	94.42	2.87	0.339645	5.58	0.660355

Max =	100.00
Min =	91.55
Max- Min =	8.45

4. Potable Water

Division	District	Portable water (%)	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)
Miri	Miri	99	66.90	0.9911111	0.60	0.0088889
	Marudi	47.9	15.80	0.2340741	51.70	0.7659259
	Beluru	79.4	47.30	0.7007407	20.20	0.2992593
	Subis	86.4	54.30	0.8044444	13.20	0.1955556
	Telang Usan	32.1	0.00	0	67.50	1
Bintulu	Bintulu	97.7	65.60	0.9718519	1.90	0.0281481
	Sebauh	41.4	9.30	0.1377778	58.20	0.8622222
	Tatau	50	17.90	0.2651852	49.60	0.7348148
Sibu	Sibu	99.6	67.50	1	0.00	0
	Kanowit	76.8	44.70	0.6622222	22.80	0.3377778
	Selangau	38.6	6.50	0.0962963	61.00	0.9037037
Kuching	Kuching	99.1	67.00	0.9925926	0.50	0.0074074
	Bau	90.8	58.70	0.8696296	8.80	0.1303704
	Lundu	51	18.90	0.28	48.60	0.72

Max =	99.60
Min =	32.10
Max- Min =	67.50

5. Communication

Division	District	Communication (%)	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	271.8	53.20	1	0.00	0		
	Marudi	243.5	24.90	0.4680451	28.30	0.5319549	Max =	272
	Beluru	248.9	30.30	0.5695489	22.90	0.4304511	Min =	218.60
	Subis	265.4	46.80	0.8796992	6.40	0.1203008	Max- Min =	53
	Telang Usan	252.3	33.70	0.6334586	19.50	0.3665414		
Bintulu	Bintulu	255.9	37.30	0.7011278	15.90	0.2988722		
	Sebauh	229.8	11.20	0.2105263	42.00	0.7894737		
	Tatau	268.8	50.20	0.943609	3.00	0.056391		
Sibu	Sibu	259.4	40.80	0.7669173	12.40	0.2330827		
	Kanowit	219	0.40	0.0075188	52.80	0.9924812		
	Selangau	218.6	0.00	0	53.20	1		
Kuching	Kuching	263.5	44.90	0.843985	8.30	0.156015		
	Bau	246.8	28.20	0.5300752	25.00	0.4699248		
	Lundu	238	19.40	0.3646617	33.80	0.6353383		

6. Elevation

Division	District	Elevation	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	9.81	2.38	0.0461509	49.19	0.9538491		
	Marudi	21.97	14.54	0.2819469	37.03	0.7180531	Max =	59.00
	Beluru	14	6.57	0.1273997	45.00	0.8726003	Min =	7.43
	Subis	59	51.57	1	0.00	0	Max- Min =	51.57
	Telang Usan	24	16.57	0.3213108	35.00	0.6786892		
Bintulu	Bintulu	9.64	2.21	0.0428544	49.36	0.9571456		
	Sebauh	39.71	32.28	0.6259453	19.29	0.3740547		
	Tatau	8.31	0.88	0.0170642	50.69	0.9829358		
Sibu	Sibu	9.98	2.55	0.0494474	49.02	0.9505526		
	Kanowit	15.64	8.21	0.1592011	43.36	0.8407989		
	Selangau	24.24	16.81	0.3259647	34.76	0.6740353		
Kuching	Kuching	8.91	1.48	0.0286989	50.09	0.9713011		
	Bau	18.41	10.98	0.2129145	40.59	0.7870855		
	Lundu	7.43	0.00	0	51.57	1		

7. Air Pollution

Division	District	Air Pollution Index	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	53.50	53.50	1	0.00	0		
	Marudi	48.90	48.90	0.9140187	4.60	0.0859813	Max =	53.50
	Beluru	0.00	0.00	0	53.50	1	Min =	0.00
	Subis	0.00	0.00	0	53.50	1	Max- Min =	53.50
	Telang Usan	0.00	0.00	0	53.50	1		
Bintulu	Bintulu	51.20	51.20	0.9570093	2.30	0.0429907		
	Sebauh	47.00	47.00	0.8785047	6.50	0.1214953		
	Tatau	49.10	49.10	0.917757	4.40	0.082243		
Sibu	Sibu	48.00	48.00	0.8971963	5.50	0.1028037		
	Kanowit	48.50	48.50	0.9065421	5.00	0.0934579		
	Selangau	38.70	38.70	0.7233645	14.80	0.2766355		
Kuching	Kuching	45.20	45.20	0.8448598	8.30	0.1551402		
	Bau	40.20	40.20	0.7514019	13.30	0.2485981		
	Lundu	43.20	43.20	0.8074766	10.30	0.1925234		

8. Health Facilities

Division	District	Num. of bed/ 1000 people	Xi-Min(Xi)	Index (+)	Max(Xi)-Xi	Index (-)		
Miri	Miri	746.59401	746.59	0.2719382	1998.86	0.7280618		
	Marudi	403.33333	403.33	0.1469095	2342.12	0.8530905	Max =	2745
	Beluru	0	0.00	0	2745.45	1	Min =	0.00
	Subis	0	0.00	0	2745.45	1	Max- Min =	2745
	Telang Usan	0	0.00	0	2745.45	1		
Bintulu	Bintulu	626.66667	626.67	0.2282561	2118.79	0.7717439		
	Sebauh	2745.4545	2745.45	1	0.00	0		
	Tatau	1530.4348	1530.43	0.5574431	1215.02	0.4425569		
Sibu	Sibu	415.52239	415.52	0.1513492	2329.93	0.8486508		
	Kanowit	269.35484	269.35	0.0981094	2476.10	0.9018906		
	Selangau	1472.2222	1472.22	0.5362399	1273.23	0.4637601		
Kuching	Kuching	494.8461	494.85	0.180242	2250.61	0.819758		
	Bau	835.61644	835.62	0.3043636	1909.84	0.6956364		
	Lundu	682.14286	682.14	0.2484626	2063.31	0.7515374		