Progress in Disaster Science 20 (2023) 100296

Contents lists available at ScienceDirect

Progress in Disaster Science

journal homepage: www.elsevier.com/locate/pdisas

Spatial multidimensional vulnerability assessment index in urban area- A case study Selangor, Malaysia

Muhammad Wafiy Adli Ramli [a], Nor Eliza Alias [a,b,*], Halimah Mohd Yusof [c], Zulkifli Yusop [b], Shazwin Mat Taib [a], Yusrin Faiz Abdul Wahab [d], Sitti Asmah Hassan [e]

[a] Department of Water and Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia
[b] Centre for Environmental Sustainability and Water Security (IPASA), Research Institute for Sustainable Environment, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia
[c] Faculty of Management, School of Human Resource Development and Psychology, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia
[d] Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
[e] Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia

ARTICLE INFO

Keywords:
Vulnerability
Disaster
Sendai framework
Disaster risk reduction
And industrial urban districts

ABSTRACT

Rapid urbanization has increased the risks to and vulnerabilities of urban systems, society, and organizations. In recent years, urban areas have been exposed to multiple hazards such as floods, landslides, storms, and rising sea levels. To reduce exposed elements' risk of and vulnerability to natural hazards, the first requirement is a better understanding of the vulnerable elements as stated in Sendai Framework. Different concepts and approaches can be employed in vulnerability assessment, depending on the scope and context of the study. In this study, the vulnerability concept was based on six dimensions (social, economic, physical, institutional, environmental, and cultural) adapted from the Method for the Improvement of Vulnerability (MOVE) framework. This approach was applied to three industrial urban districts in Selangor, Malaysia: Sepang, Kuala Langat, and Hulu Langat. These are located in the Langat River catchment and consist of 17 mukim (subdistricts). A spatial vulnerability assessment was conducted to determine the areas of very high vulnerability in this study area. A map was subsequently produced that shows the areas classified into five vulnerability categories (very low, low, medium, high, and very high vulnerability). The findings from all the areas studied identified 5.7% in the very high class, 8.9% in the high class, 33.3% in the medium class, 21.6% in the low class, and 30.5% in the very low class. The multidimensional vulnerability assessment used scientific proof to provide information for better understanding to the government, disaster agencies, and local governments so that policy making, and local disaster risk reduction (DRR) strategies can improve.

1. Introduction

In 2020, 389 disasters were recorded worldwide, affecting 98.4 million people [1]. In 2020 alone, the economic damage caused by disasters was estimated at around USD 171.3 billion [1]. Apart from COVID-19, 2020 was dominated by climate-related disasters, which caused more deaths than other types of disaster [2]. The increasing number of extreme events and the impact of climate change are constantly exacerbating the current dangers and increasing the vulnerability of people and societies [3].

Malaysia was also unable to avoid the impacts of climate and extreme events. The vulnerability to various climate-related disasters has increased in recent years, in part due to climate change [4]. According to the 2020 World Risk Report, Malaysia was categorized as a high-risk country, with high levels of exposure to disaster and climate change [5]. The disaster events that occurred in Malaysia in 2021 demonstrate the need for disaster risk assessments to gain a better understanding at the local level. The impact of climate change has caused several extreme events that have increased the exposure of communities, many organizations, and the social system. Based on the 2021 disaster events, the impact of disasters increases when an area never previously exposed to disaster is affected by such an event. The impact of

* Corresponding author at: Department of Water and Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia.

E-mail addresses: mwadli2@gmail.com (M.W.A. Ramli), noreliza@utm.my (N.E. Alias), halimahmy@utm.my (H.M. Yusof), zulyusop@utm.my (Z. Yusop), shazwin@utm.my (S.M. Taib), yusrin@cream.my (Y.F.A. Wahab), sasmah@utm.my (S.A. Hassan).

https://doi.org/10.1016/j.pdisas.2023.100296
Received 8 November 2022; Received in revised form 20 May 2023; Accepted 31 August 2023
Available online 4 September 2023

disasters has increased over the years, causing more areas to become vulnerable. Rapid urbanization and the increased impact of climate change have exposed vulnerable groups, health systems, and institutions to the potential threat of future hazards [6,7]. The growing effects of disasters in urban settlements necessities considerable attention and preparations to reduce vulnerability and disaster risk [8]. Therefore, assessing the vulnerability of people and societies is key to reducing vulnerability to disaster and building disaster-resilient communities.

2. Vulnerability assessment

Vulnerability is defined as the circumstances influenced by physical, social, economic, and environmental features, as well as the process that enhances individual, societal, institutional, and systematic sensitivity to the impacts of hazards [9]. Vulnerability assessment is a significant and essential component of disaster risk assessment and sustainable science [10]. Measuring vulnerability is a practical step to reducing disaster risk and building resilience in societies [11]. Vulnerability research is always debated as it is based on various natural and social science disciplines and theories. Several frameworks have been developed to measure vulnerability to disasters and climate change.

Previous research has assessed various aspects of vulnerability, such as social [12–14], physical [15,16], socio-economic [17,18], and institutional vulnerability [19]. The Intergovernmental Panel for Climate Change (IPCC) produced a vulnerability framework based on three components: exposure, sensitivity, and resilience [20]. Many studies have adopted this framework because the concepts of exposure, sensitivity, and resilience are regarded as essential aspects of vulnerability research [21]. Although the IPCC concept of vulnerability has been increasingly used in recent years, the application of specific vulnerability indicators or variables still differs depending on the emphasis and scope of each study [22]. Current vulnerability assessment research continues to be divided between social researchers who regard vulnerability as a collection of socio-economic elements and researchers who see vulnerability as the degree of loss of an element at risk [23]. Multidimensional vulnerability assessment (MDVA) was been proposed to bridge this gap and offer a holistic form of vulnerability assessment [24].

MDVA is an integrated approach that would be highly beneficial, suitable, and helpful in the disaster risk-reduction field [25]. Hyogo Framework Action (2005–2015) stated that vulnerability assessment was identified as a multidimensional framework [26]. Research by Birkmann [11] broadened the concept of vulnerability from intrinsic vulnerability into five dimensions (social, physical, economic, environmental, and institutional). Rana and Routray [25] proposed a multidimensional flood vulnerability assessment using another five dimensions: social, economic, physical, institutional, and attitudinal. In contrast, Khalid et al. [27] quantified the multidimensional vulnerability assessment using an index with six dimensions of vulnerability: social, economic, physical, institutional, attitudinal, and gender. The proposed concept included gender as an additional dimension to increase the holistic aspect of vulnerability assessment.

In this study, the multidimensional vulnerability assessment was adapted and expanded from the theoretical framework of the Method for the Improvement of Vulnerability (MOVE). The proposed concept defines vulnerability assessment using six dimensions: social, economic, physical, institutional, environmental, and cultural. The purpose of the proposed framework was to improve disaster risk-reduction policy and it could be applied to multiple types of hazards [28]. The MOVE framework facilitates communication between communities, especially Disaster Risk Management (DRM) and climate change adaptation communities, and the framework is sufficiently simple to be used by people from various disciplines [29].

Several attempts have been made to conduct vulnerability assessments for various disasters, scales, approaches, and scopes in Malaysia. Zahid et al. [30] divided vulnerability assessment into three dimensions - population, social, and biophysical vulnerability - using the data envelopment analysis (DEA) method. However, this study focused only on the vulnerability assessment method and lacks detail regarding vulnerability indicators and concepts, while the relevance of the selected vulnerability indicators could be questioned. Several researchers have focused on specific aspects or scopes, such as physical vulnerability building assessment [16], social vulnerability [31], and school building vulnerability assessment [32], while a Department of Irrigation and Drainage study focused on flood damage assessment [33].

Research is lacking on multidimensional vulnerability assessment, which should focus mainly on developing a holistic approach to assess urban populations using a composite index. Vulnerability assessment based on a composite index measures data quantitatively [13] and simplifies complex data [11]. The primary goal of this study was to develop a spatial multidimensional vulnerability assessment for urban areas based on six dimensions and using a composite index approach.

3. Material and method

This study was based on a multidimensional vulnerability assessment expanded from the MOVE framework proposed by Ramli et al. [34]. Fig. 1 shows the vulnerability conceptual framework for this study with weighted coefficient values. Multidimensional vulnerability was measured quantitatively through various subdimensions and indicators of six dimensions: social, economic, physical, institutional, environmental, and cultural.

3.1. Study area

The study area covered three Selangor districts: Ulu Langat, Kuala Langat, and Sepang. Selangor describe as a 'Golden State' of Malaysia in term of economic because it contributes to almost quarter of growth domestic product (GDP) in Malaysia. These three districts are also described as competitive and ready industrial areas. The Selangor states invest in the industrial sector, making it the largest industrial area in Malaysia. Several development projects have been carried out in this area, including the Cyberjaya Multimedia Super Corridor and Kuala Lumpur International Airport, which, along with additional industrial and settlement areas, have further accelerated the urbanization process. The three districts are located mainly in the Langat River catchment. Each district has its own mukim (subdistricts). All three districts are severely affected when disaster events occur in Malaysia, especially in Selangor. As shown in Fig. 2, the study area consists of 17 mukim. Both Hulu Langat and Kuala Langat have seven mukim. Those in Hulu Langat are Ampang, Kajang, Hulu Langat, Cheras, Beranang, Hulu Semenyih and Semenyih. Kuala Langat consists of the mukim of Bandar, Batu, Jugra, Kelanang, Morib, Tanjung Dua Belas, and Telok Panglima Garang. Meanwhile, Sepang consists of three mukim: Dengkil, Labu, and Sepang.

Historically, this study area has been affected by several types of disasters, including floods, landslides, storms, and forest fires. From 2014 to 2019, there were 176 flood events across Hulu Langat (98 events), Sepang (51), and Kuala Langat (27) [35]. In 2011, a major landslide in Hulu Langat Mukim caused 16 deaths [4,35]. Besides, several areas are susceptible to landslides, such as Ampang, Cheras, Kajang, Dengkil, Labu, and Sepang [36–38]. Flood events occur in 2021 increased the exposure of the area to disaster.

3.2. Data sampling and collection

In this study, two sets of data were used, primary and secondary. The primary data for this study were collected from a sampling household survey and institutional interviews held in the study area. Conducted in all three districts, the household survey involved a total of 612 households across Hulu Langat (311), Kuala Langat (188), and Sepang (113). Various methods can be used to determine the adequate number of

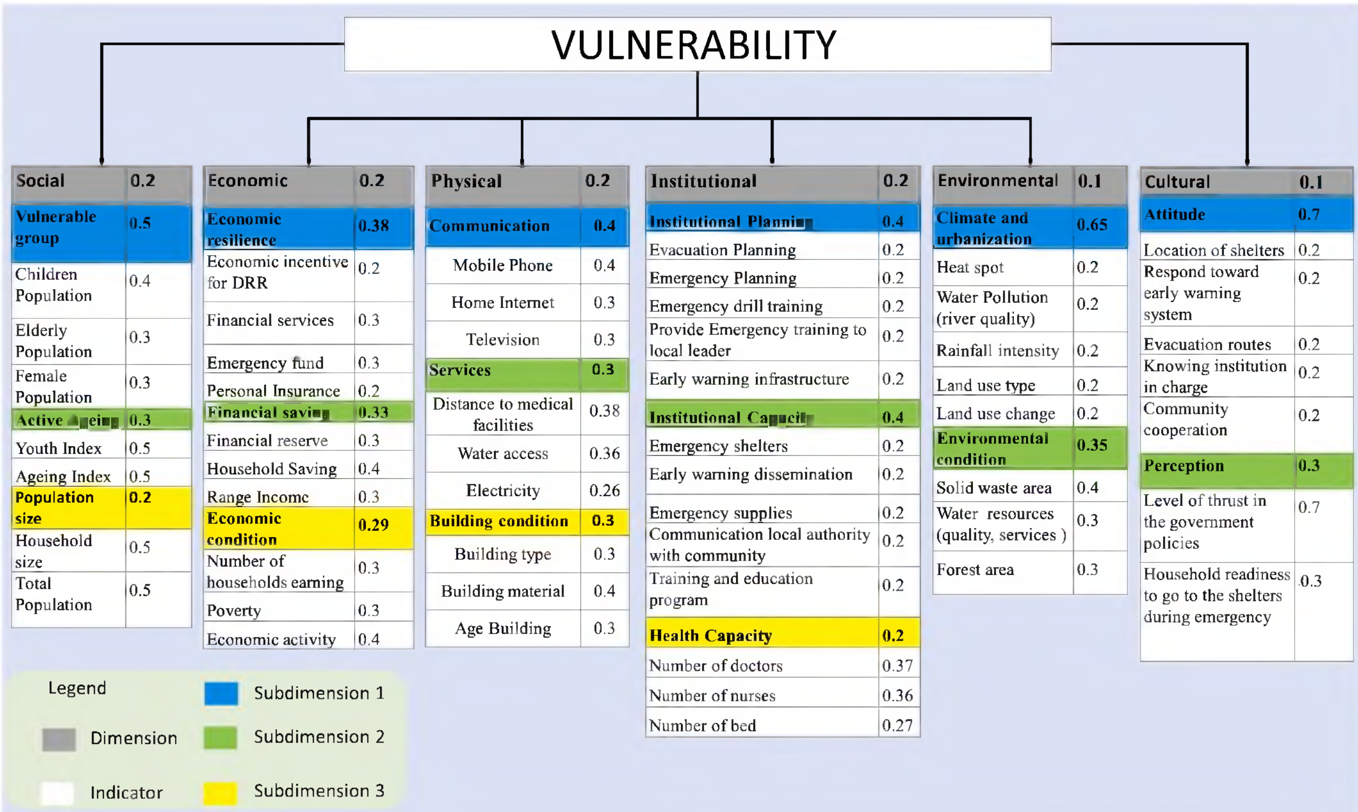

Fig. 1. Multidimensional vulnerability framework [34].

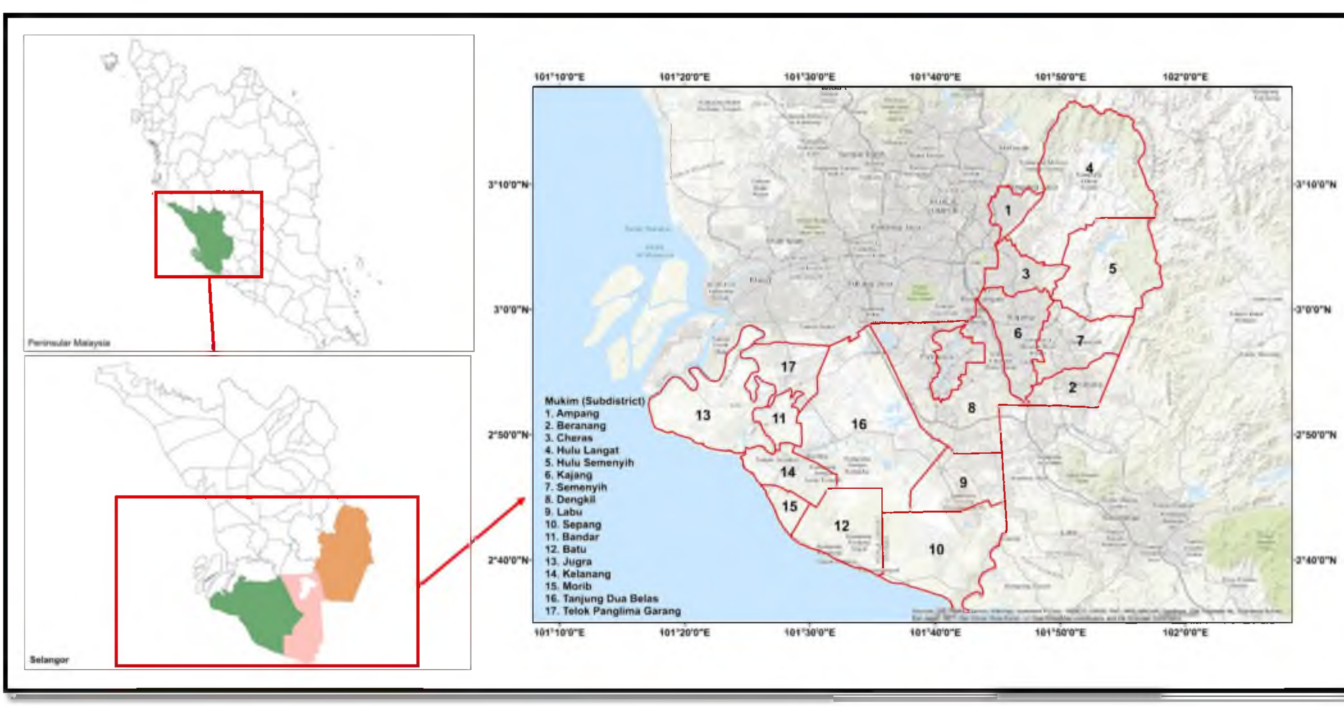

Fig. 2. Study area.

samplings for a study. According to Creswell [39], when the population is over 250,000, the suggested number of samples is at least 384. However, using the Cochran [40]sampling calculation and these 612 samples, this study maintained a confidence level of 95% and a precision value of 0.04. Therefore, the sample size was large enough, based on the 2010 census data from the Department of Statistics Malaysia (DOSM). The number of households in the study area was estimated as 387,311.

Several sources from the local authorities and district offices then needed to be interviewed to obtain data with which to evaluate and determine the indicators related to local authorities (Table 1). The local authorities involved were Sepang Municipal Council, Kajang Municipal Council, Kuala Langat Municipal Council, Ampang Jaya Municipal Council, Sepang District Office, Kuala Langat District Office, and Hulu Langat District Office. Another dataset came from the secondary data collected from government agencies such as the Department of Environmental (DOE), the Ministry of Energy and Natural Resources (KeTSA), the DID, and the DOSM. Table 1 lists the data and sources used in this study. Data were collected based on the district, mukim, household, or lot spatial scale.

3.3. Data analysis and method

3.3.1. Mathematical computation for multidimensional vulnerability index

This study used the index-based approach to multidimensional vulnerability assessment. This approach provided simplified results for comparing vulnerability levels across the study area [9]. The multidimensional concept of this study consists of six dimensions: social, economic, physical, institutional, environmental, and cultural. Each dimension consists of several subdimensions, based on the combination of several indicators. Two approaches can be used to assign weighted coefficients, the equal or unequal method. In this study, each indicator, subdimension, and dimension had its weight (Fig. 1). Unequal weighted approaches are intended to indicate the different levels of importance of each indicator, subdimension, and dimension.

The weights assigned in this study were based on a previous study by Ramli et al. [34] using statistical approaches. The weights assigned for the indicators and subdimensions were based on the subdimension scores calculated from a previous study.

Using the index approach, the first step is to normalize the data in the range of 0 to 1. Eqs. 1 and 2 show the mathematical equations for data normalization using the minimum-maximum normalization method. In Eq. 1, a higher indicator value means greater vulnerability.

$$I_i = \frac{x - min_x}{max_x - min_x} \tag{1}$$

Table 1
Data scale and sources.

Data type	Data scale	Source of Data
Population Data (Female, Children, Older, Household size, Age), Poverty,	Mukim Scale (Population Grid)	DOSM, KeTSA
Poverty, Access to (television, mobile phone, internet, water, electrical)	Mukim and District Scale	DOSM
Land use	Locality Scale (Lot)	PLAN Malaysia
Heat spot and river quality and rainfall intensity	Locality scale	DOE
Building Condition, Solid waste area, forest area	Satellite data + Land use data	Google map and PLAN Malaysia
Health services (doctors, nurses, and beds)	District scale	State Health Office
Evacuation shelters capacity	Mukim scale	Selangor Disaster Management unit (SDMU)
Attitudinal and perception data, range income, economic activity, emergency planning, emergency drill training, water resources quality	Mukim and district scale	Household community survey
Financial reserve for local authority, services, emergency funds, economic incentive for DRR, evacuation planning, provide emergency training to community leader, training and education program and emergency supplies	District and municipal scale	Local authority surveys

$$I_i = \frac{max_x - x}{max_x - min_x} \tag{2}$$

Where I is the normalized value of indicator i; x is the observed value for an indicator I; min_x and max_x are the minimum and maximum values observed for indicator x. Conversely, in Eq. 2, a lower indicator value reflects greater vulnerability. The maximum and minimum values were based on a data range for Malaysia and a previous study. For example, the population data were determined based on the lowest and highest mukim populations in Malaysia. Table 2 shows each indicator of the maximum and minimum value ranges. Therefore, all the indicators were normalized using either Eq. 1 or 2, based on the minimum and maximum values provided. Eq. 3 represents the mathematical formula for identifying the value of each subdimension in a dimension.

$$SD_i = \sum_{2}^{n} WI_i \times I_i \tag{3}$$

Where SD is the value calculated for subdimension i; WI_i is the weight of the indicator assigned for indicator i; and n is the number of indicators in subdimension i. The subdimension index for each dimension, SD_i was calculated as the sum of the indicators. The mathematical formula for the dimension index is shown in Eq. 4.

$$D_i = \sum_{2}^{n} WF_i \times SD_i \tag{4}$$

Where D is the vulnerability dimension for the calculated value i; WF_i is the subdimension weight assigned to subdimension i. The vulnerability dimension index for each dimension, D_i was calculated as the sum of the subdimensions. The mathematical equation for the overall multidimensional vulnerability index is shown in Eq. 5.

$$MDVI = 0.2 \times SVI + 0.2 \times EVI + 0.2 \times PVI + 0.2 \times InVI + 0.1 \times EnVI + 0.1 \times CVI \tag{5}$$

Where $MDVI$ is a multidimensional vulnerability index, SVI is the social vulnerability index, EVI is the economic vulnerability index, PVI is the physical vulnerability index, $InVI$ is the institutional vulnerability index, $EnVI$ is the environmental vulnerability index, and CVI is the cultural vulnerability index.

3.3.2. Geospatial data analysis

The analysis in this study used spatial data, so the process of obtaining the results used the geospatial data analysis approach. ArcGIS 10.8 software was used for data processing and to produce the resulting maps. Several ArcGIS tools were used, including the data editor, data conversion, raster calculator, and data classification tools. The data editor tools were used to input the indicator values in the vector data. The data conversion tools were used to convert the vector data into raster data for the index calculations. The raster calculator tools were then used to normalize the data and calculate the vulnerability index. Lastly, the data classification tools were used to group the data into five classes using the natural breaks method. The data were categorized into five classes: very low, low, medium, high, and very high vulnerability. Therefore, each area in this study was classified into one of these five groups to compare the levels of vulnerability.

4. Result and discussion

The index produced for each dimension was calculated and determined using the methodology outlined in Section 3. The results were presented in map and radar chart form to compare the districts and mukim. The results for each dimension are discussed separately, followed by an overall explanation of multidimensional vulnerability. The levels of vulnerability were categorized into five classes (very low, low, medium, high, and very high).

Table 2
Indicator with the maximum and minimum values.

Dimension	Subdimension	Indicator	Min	Max	Description
Social	Vulnerable group	Children Population	1	78,276	Total children <15 years old
		Older Population	8	322,026	Total older >60 years old
		Women Population	4	155,034	Total female
	Active Aging	Youth index	53.95	4000	Age (15 to 29 years old) per 100 Age (60 and over)
		Aging Index	2.25	370.73	Age (60 and over) per 100 age (15 to 29 years old)
	Population size	Household Size	2.7	6.8	Average household size
		Total Population	22	553,270	Total Population in the area
		Personal Insurance	0	100	Percentage people without insurance
		Local authority emergency fund	1	5	Local authority preparation (1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Financial services provided for DRR	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
	Economic resilience	The economic incentive for DRR	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Household saving	1	5	(1) RM0 – RM 500 (2) RM 500 – RM1000, (3) RM1000-RM1500, (4) RM1500-RM2000, (5) > RM 2000
		Range income	0	12,800	Range income class (B40, M40, T20)
	Economic saving	Financial Reserve	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Economic activity	1	5	(1) Unemployed, (2) Daily income (3) Agriculture, (4) Private Sector (5) Government
	Economic condition	Poverty	0.2	56.6	% People in poverty
Economic		Number of earning member in the household	1	4	(1) 0, (2) 1, (3) 2, (4) >2
		Early warning infrastructure	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Emergency Planning	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Evacuation Planning	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Emergency drill training	1	4	1.No training, 2. 1 per year, 3. 2 per year, 4. 3 and more per year
	Institutional Planning	Provide emergency planning to community leader	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Training and Education programs	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Early Warning Dissemination	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Emergency supplies	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Emergency shelters capacity	0	386	Per 1000 population
Institutional	Institutional Capacity	Regularly communication by local government with community	1	5	(1) minor, (2) incomplete, (3) moderate, (4) Substantial, (5) Comprehensive
		Number of doctors	0.11	3.9	Doctor per 500 populations
		Number of nurses	0.24	3.36	Nurses per 500 populations
Institutional	Health services	Number of hospital beds	0.22	10	Number of beds per 1000 populations
		Television	27	96.8	% Access to television
		Internet	32.8	95.1	% Access to internet
	Telecommunication	Mobile telephone	89	100	% Access to mobile phone
		Electricity	90.5	100	% Access to electricity
		Distance to Medical facilities	0	3000	Kilometre (km)
	Services	Water services	33.6	100	% Access to water services
		Average age of the house	1	40	Number of years
		Building type	0	1	no building, detached, semidetached, and combine building
Physical	Building Condition	Building materials	0	1	0 No building, 0.33 brick and cement, 0.67 semi cement combine woods, and 1. woods
		Land use	0	1	0. Forest area & vacant land 0.2. Agriculture 0.7 Industries/infrastructure 0.8 Commercial area 1.0 Residential
		Land use change	0	100	% of change
		Rainfall intensity	1563	4620.8	Intensity (mm)
	Climate and urbanization	Heat spot	27	40	Degree Celsius
		Water pollution	1	5	Class 1 until Class 5
		Forest area	1	5	(1) Mangrove forest, (2) Dense forest, (3) Moderate forest, (4) Sparse forest, (5)No forest
		Water resource performance (quality)	1	5	(1) Very unsatisfactory, (2) unsatisfactory, (3) Moderate (4) satisfactory, (5) Very satisfactory
Environmental	Environmental condition	Solid waste area	0	2250	(1) 0–250 m, (2) 250 m – 750 m, (3) 750 m – 1250 m, (4) 1250 m – 1750 m, (5) 1550 m – 2250 m
Cultutal	Attitude	Respond Towards Early Warning System	1	3	(1) ready to move, (2) wait and see, (3) Not moving

(*continued on next page*)

Table 2 (*continued*)

Dimension	Subdimension	Indicator	Min	Max	Description
		Know Location of shelters	0	1	Survey: (0) No, (1) Yes
		Know Evacuation routes	0	1	Survey: (0) No, (1) Yes
		Knowing the institutions in charge of the emergency management	0	1	Survey: (0) No, (1) Yes
		Community cooperation when facing disaster	1	5	(1) Very unsatisfactory, (2) unsatisfactory, (3) Moderate (4) satisfactory, (5) Very satisfactory
	Perception	Level of thrust in DRR programs and policies	1	5	Very unsatisfactory, (2) unsatisfactory, (3) Moderate (4) satisfactory, (5) Very satisfactory
		Households not willing to go to a shelter	1	3	Survey: (0) No, (1) Yes

4.1. Social vulnerability

Social vulnerability consists of three subdimensions: vulnerable groups, the active aging index, and the population size. These three subdimensions have their own indicators. The vulnerable group consists of three indicators: the female population, the child population, and the older population. The active aging index consists of two indicators: the youth and the aging index, while the population size has two indicators: the household size and total population. The three subdimensions were used to analyze the levels of vulnerability in the study area. Fig. 3 shows the level of social vulnerability across the three districts, based on the 17 mukim in the study area. Overall, the maximum index value is 0.497, while the minimum index value is 0.175.

In terms of vulnerable groups, the index ranges from the lowest value of 0.005 to the highest value of 0.450. Three mukim (Ampang, Cheras, and Kajang) were classified as very high vulnerability for the vulnerable group subdimension, with a range of 0.351 to 0.450, while very low vulnerability applied to two mukim, Batu and Kelanang in Kuala Langat district. For the second subdimension of social vulnerability, active aging, the index values range from 0.376 to 0.549. Very high vulnerability applied to the active aging subdimension in four mukim in Kuala Langat district (Bandar, Batu, Kelanang, and Morib) and one in Sepang district (Sepang). The very high vulnerability values range between 0.491 and 0.549, compared to very low vulnerability values, which range between 0.376 and 0.380. Only one mukim, Dengkil, was classified into this category. The last social vulnerability subdimension, population size, had an index range minimum value of 0.207 and a maximum value of 0.688. Jugra and Hulu Semenyih Mukim were each classified as having very low vulnerability, while three mukim (Ampang, Cheras, and Kajang), were classified as having very high vulnerability, based on the population size subdimension.

Therefore, as shown in Fig. 3, three mukim were classified as very high vulnerability (Ampang, Cheras, and Kajang), three were in the high-vulnerability class (Semenyih, Dengkil, and Tanjung Dua Belas), five were in the medium-vulnerability class (Hulu Langat, Beranang, Sepang, Batu, and Telok Panglima Garang), four were in the low-vulnerability class (Labu, Bandar, Kelanang, and Morib), and two were in the very low-vulnerability class (Hulu Semenyih and Jugra). The three mukim of Ampang, Cheras, and Kajang fell into the very high-vulnerability class because of their high populations compared to the other mukim. Thus, these three mukim should be the focus of disaster risk assessment in the social vulnerability dimension. The indexes of these three mukim ranged between 0.351 and 0.497.

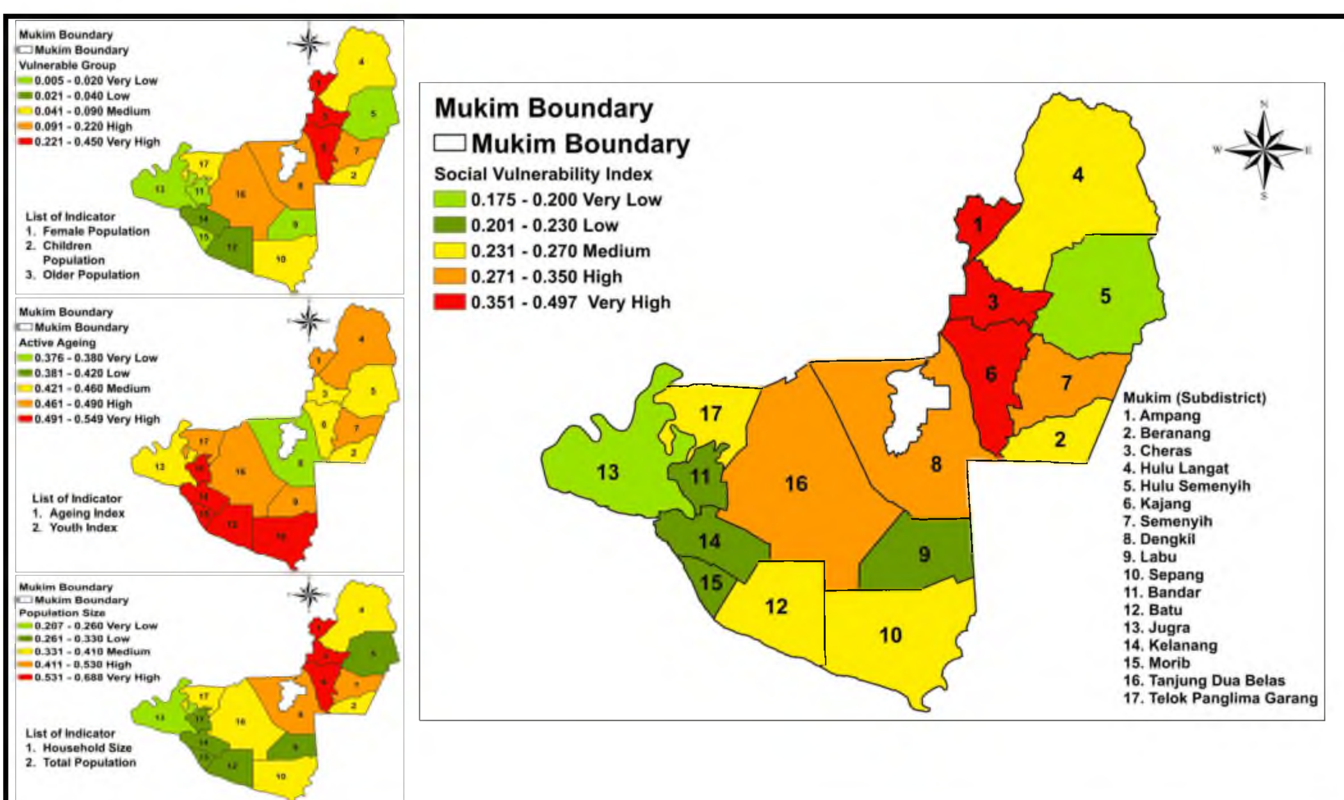

Fig. 3. Social dimension vulnerability map.

4.2. Economic vulnerability

Economic vulnerability refers to the potential economic losses suffered by an individual or organization. This dimension covers the financial capability, planning, and protection of both persons and organizations, as well as each local goverment's financial budget for preparing for and responding to potential threats [41]. In this study, three economic subdimensions were considered when analyzing economic vulnerability. The first subdimension is economic resilience, which consists of four indicators: economic incentives for DRR, financial services, emergency funds, and personal insurance. The next subdimension is financial saving, whose three subdimensions are financial reserves, household savings, and income range. The last subdimension is economic conditions, which consists of three indicators: the number of earning members in the household, poverty, and economic activity. Fig. 4 shows the results on an economic vulnerability map.

Overall, the economic vulnerability index in these three districts varied from 0.472 to 0.490 for the very low class, 0.491 to 0.510 for the low class, 0.511 to 0.550 for the medium class, 0.551 to 0.580 for the high class, and 0.581 to 0.594 for the very high class. The mukim of Hulu Semenyih, Beranang, and Batu were classified as being of very high economic vulnerability. Compared to the other mukim, Hulu Semenyih and Beranang were very highly vulnerable in two subdimensions, economic resilience and economic conditions, while in Mukim Batu, two subdimensions were very highly vulnerable: financial savings and economic conditions. These values explain why these three mukim were in the very high economic vulnerability class. The subdimensions of all these three have different ranges of minimum to maximum values on their indexes. The economic resilience subdimension index ranges from 0.412 to 0.524, the financial savings subdimension index ranges from 0.640 to 0.813, and the economic conditions subdimension index ranges from 0.280 to 0.506.

Therefore, three mukim were found to have very low economic vulnerability compared to the others - Kajang, Telok Panglima Garang, and Tanjung Dua Belas - while one (Dengkil) was in the low economic vulnerability class. Most mukim examined were classified as being of medium economic vulnerability: Ampang, Cheras, Hulu Langat, Semenyih, Labu, Sepang, and Morib. The main focus needs to be on the other mukim (Bandar, Jugra, and Kelanang) due to their high vulnerability index values.

4.3. Physical vulnerability

The physical vulnerability analysis consists of a specific and detailed household spatial data scale for the building condition subdimension. The other data indicators were based on mukim or district spatial scales. Besides the building condition subdimension, two other physical vulnerability subdimensions were used: communication and services. In total, the physical vulnerability dimension contains nine indicators, with each subdimension having three indicators. Fig. 5 shows the physical vulnerability map with all three subdimensions for all 17 mukim in the study area.

The physical vulnerability index in this study area ranged between 0.044 and 0.471, so the index value was lower compared to the other dimension index values, ranging from 0 to 1. This was because the area also has low index values for communication and services. Most mukim in this area are urban and Selangor is the most developed state in Malaysia, so there are better physical facilities in terms of communication and services. Both the communication and services subdimensions had low index values, ranging from 0.044 to 0.305 and 0.076 to 0.381, respectively. However, a comparison of all the mukim in the study area revealed that several areas (Ampang, Hulu Langat, Cheras, Kajang, Beranang, Semenyih, Tanjung Dua Belas, Jugra, Tanjung Dua Belas, Jugra, Telok Panglima Garang, and Morib) were classified as being of very high physical vulnerability. All these areas of very high physical vulnerability have indexes ranging between 0.351 and 0.471. The

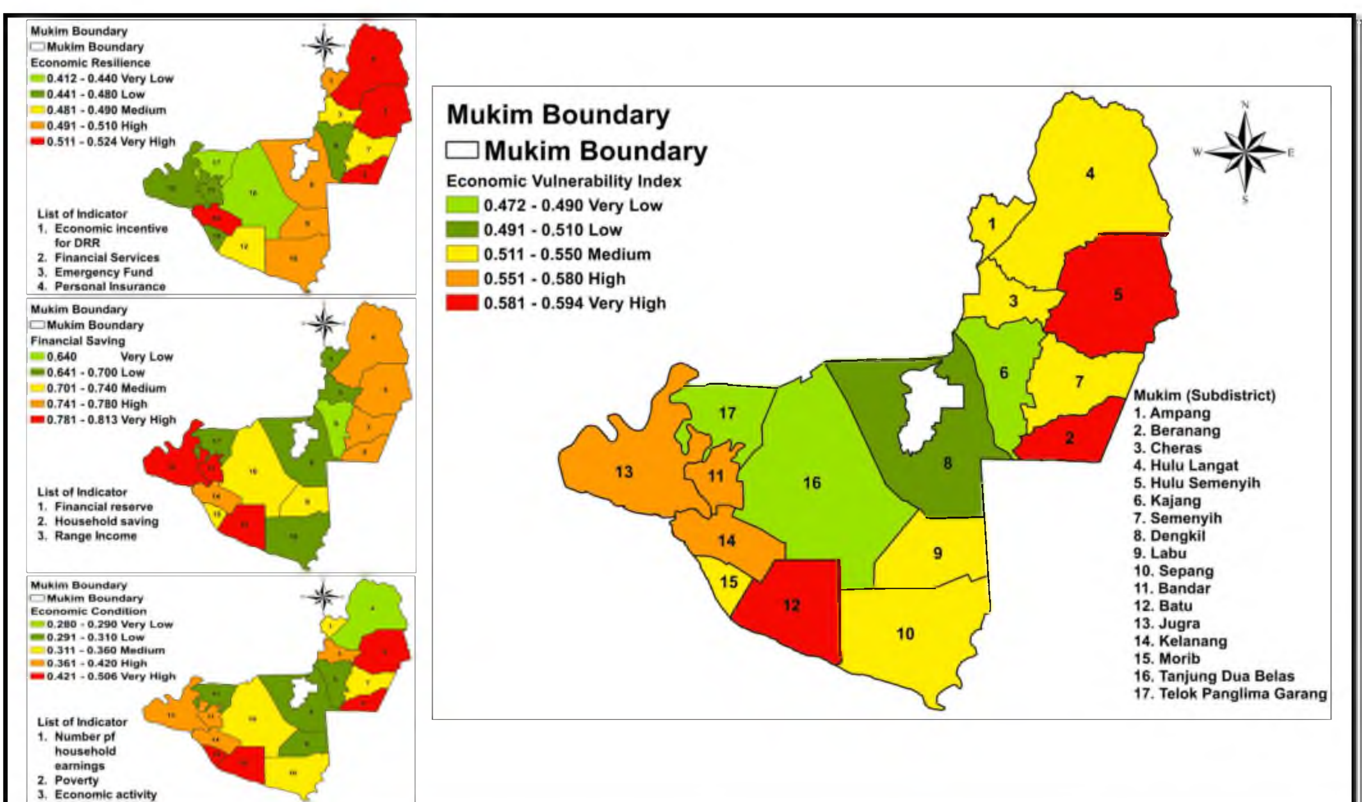

Fig. 4. Economic vulnerability index.

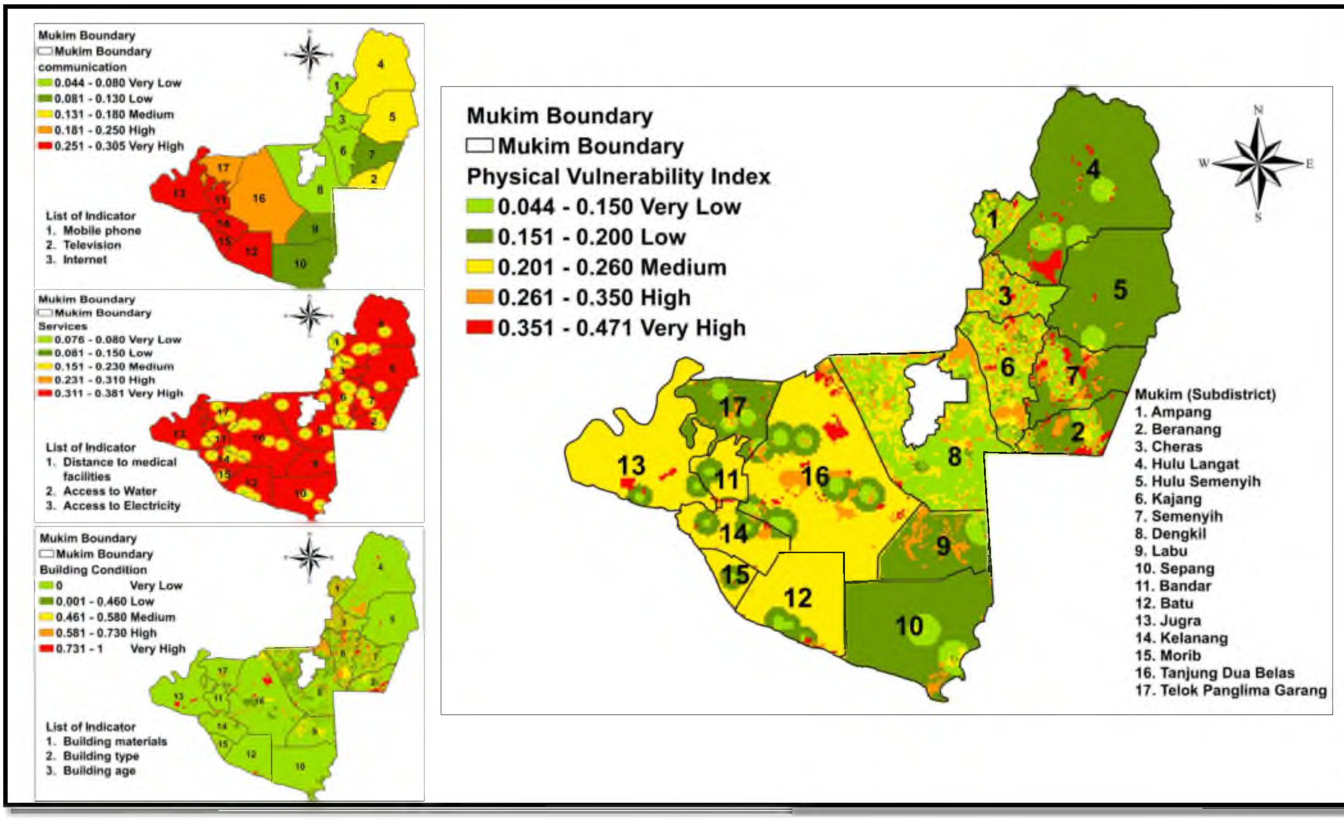

Fig. 5. Physical vulnerability index.

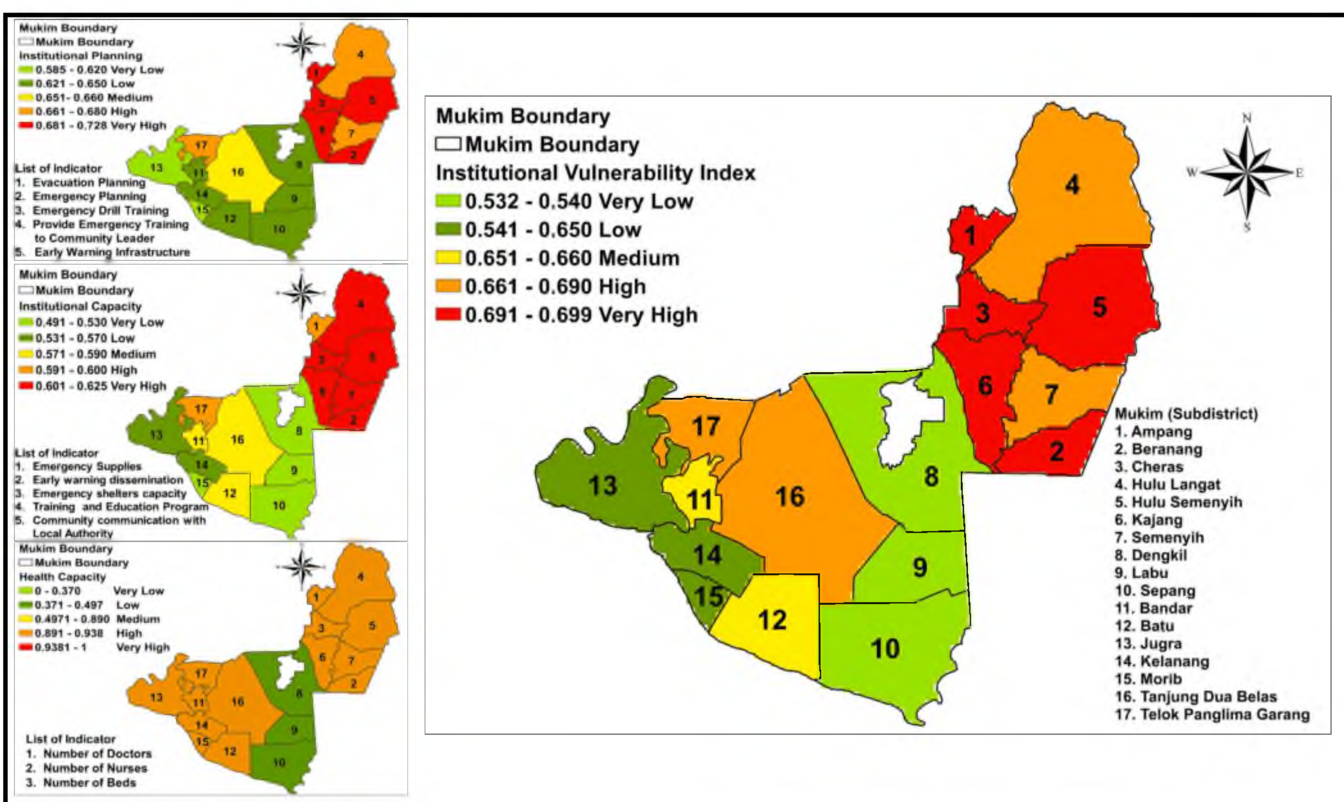

Fig. 6. Institutional vulnerability index.

building condition subdimension influenced the areas with very high physical vulnerability because these were more highly populated. More populated areas have many buildings, some of which have high vulnerability because of their physical condition in terms of age, type, and materials. Other areas - such as plantations, open space, and forest - have very low or low physical vulnerability because there are no buildings.

4.4. Institutional vulnerability

Institutional vulnerability is rarely applied or discussed as a vulnerability dimension in disaster vulnerability assessment. This type of vulnerability is related to the resilience and preparedness of local organizational structures, governance structures, and local institutions to face future disasters [42]. In this study, institutional vulnerability contains thirteen indicators classified into three subdimensions. The first subdimension, institutional planning, consists of five indicators: evacuation planning, emergency planning, emergency drill planning, providing emergency drill training to community leaders, and early warning infrastructure. The next subdimension is institutional capacity, which also has five indicators: emergency supplies, early warning dissemination, emergency shelter capacity, training and education programs, and community communication with the local authority. The last subdimension of institutional vulnerability is health capacity, consisting of three indicators: the number of doctors, number of nurses, and number of hospital beds. Fig. 6 shows the results of the institutional vulnerability index assessment in this study area.

The results from the analysis show the index range between the 17 mukim is between 0.532 and 0.699. There is very high institutional vulnerability in Hulu Langat District because five mukim there fall into the very high institutional vulnerability class (Ampang, Cheras, Kajang, Hulu Semenyih, and Beranang) and two mukim fall into the high institutional vulnerability class (Hulu Langat and Semenyih). Therefore, the range index in Hulu Langat is between 0.661 and 0.699. Hulu Langat has very high institutional vulnerability compared to other districts because of the very high vulnerability in terms of institutional planning and institutional capacity, as well as the high vulnerability in terms of health capacity. Comparing these three districts, Sepang District has very low vulnerability, with all three mukim in the very low vulnerability class. The index range in Sepang District is between 0.532 and 0.50. The last district, Kuala Langat, has two mukim with high vulnerability (Telok Panglima Garang and Tanjung Dua Belas), two with medium vulnerability (Bandar and Batu), and three with low vulnerability (Jugra, Kelanang, and Morib).

4.5. Environmental vulnerability

Environmental vulnerability relates to the amount to which the ecosystem has degraded, and environmental variables may influence the vulnerability of an afflicted region [43]. The environmental vulnerability discussed in this study was based on two subdimensions: environmental conditions and climate and urbanization. The climate and urbanization subdimension has five indicators: heat spots, river quality, rainfall intensity, land use types, and land use change. Meanwhile, the environmental conditions subdimension consists of solid waste areas, water resources, and forest areas. In Fig. 7, the environmental vulnerability results are shown in the detailed map.

The index range for the overall environmental vulnerability index is from 0.227 to 0.566. The very high vulnerability index was found to be mainly located in Cheras, Kajang, Dengkil, Beranang, and Semenyih because these areas are the most urbanized. The very high environmental vulnerability index ranged between 0.450 and 0.566. Most areas in the very high or high vulnerability classes are highly populated or have experienced considerable changes in land use. However, most areas in the very low or low vulnerability classes are forest or protected, as well as being unpopulated or less populated. Besides, some areas in

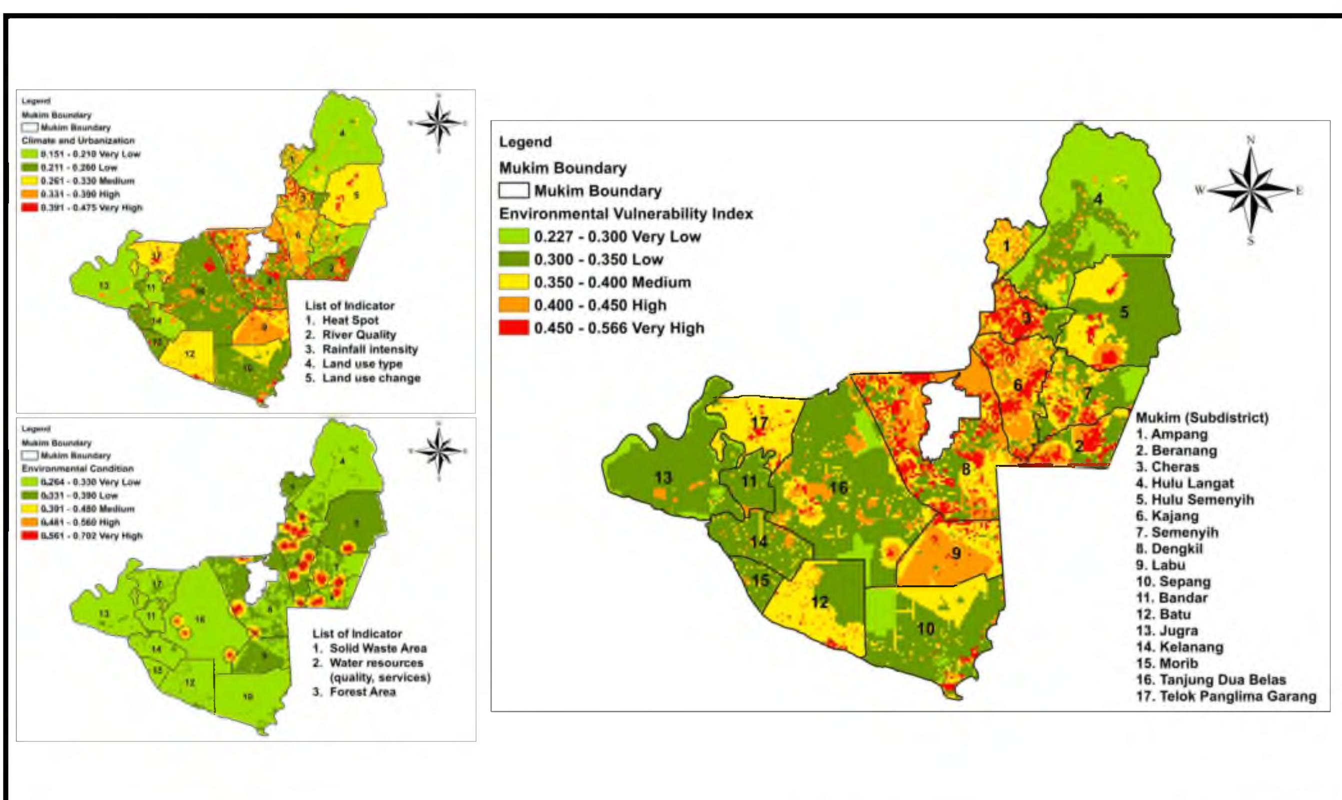

Fig. 7. Environmental vulnerability index.

mukim such as Jugra, Kelanang, Bandar, and Sepang are plantations. The urbanization factor plays a major role in the environmental vulnerability index increase in the study areas.

4.6. Cultural vulnerability

The last dimension in this study is cultural vulnerability. This dimension has been less researched, discussed, and analyzed compared to the others. Cultural vulnerability in this study focuses on intangible qualities, that is, the subdimensions of attitude and perception. The attitude subdimension focuses on five indicators to evaluate community and household responses and attitudes to disaster. The five indicators are (1) do people know the locations of the evacuation shelters in their area, (2) do people respond to the early warning system during a disaster, (3) do they know the evacuation routes to the safest places, (4) do they know the institution in charge when a disaster occurs, and (5) the community cooperation in their area. The second subdimension, perception, has two indicators: people's level of trust in government DRR policies and household readiness to go to the emergency shelters provided by the local authorities. Fig. 8 shows the results of the cultural vulnerability index, including the indexes of the two subdimensions of attitude and perception.

The results from the cultural vulnerability index map show the minimum vulnerability index value is 0.282 and the maximum value is 0.5649. Mukim Jugra has a very low cultural vulnerability index, between 0.270 and 0.320. This mukim has the lowest vulnerability in both the attitude and perception subdimensions, meaning that households in Mukim Jugra respond better when a disaster happens, while they also trust the government and local authority DRR works more than the other mukim in the study area. However, three mukim were classified as having very high vulnerability: Ampang, Cheras, and Labu. The index range for these three is between 0.4901 and 0.5649. Overall, three mukim are in the high vulnerability class (Semenyih, Kajang, and Dengkil), six are in the medium vulnerability class (Hulu Semenyih, Beranang, Sepang, Bandar, Morib, and Telok Panglima Garang) and four are in the low vulnerability class (Hulu Langat, Tanjung Dua Belas, Kelanang, and Batu).

4.7. Multidimensional vulnerability index

This study analyzed and observed six vulnerability dimensions in 17 mukim from three districts. For comparison purposes, Fig. 9 shows the chart for the average six-dimensional index for this study area. Based on this chart, most mukim in the study area have higher vulnerability in the institutional dimension compared to the other dimensions, except Mukim Labu. In Mukim Labu, the highest vulnerability dimension is the cultural dimension, followed by the institutional and economic dimensions. In this study area overall, to reduce the overall susceptibility to disaster, the focus should be on the institutional dimension, followed by the economic dimension. There is still a lack of effort on the part of the government and local authorities regarding disaster planning and enhancing the capacity to reduce the disaster risk. The local authorities need to improve their practice of DRR and educate people to improve attitudes to, knowledge of, and perceptions of disaster management. However, the results also show that, on average, the areas have low vulnerability in the physical dimension compared to the other five dimensions. This is because the areas have better physical communication facilities and access to basic services such as electricity and water. The economic dimension is another concern in this study area because, based on the results, many mukim have the highest vulnerability in this dimension. The economic dimension is especially important in terms of the capacity of people, organizations, and local authorities to recover from post-disaster events.

The results from the combination of six dimensions show the index range for the MDVI is between 0.347 and 0.510. The values for the very low MDVI classes are between 0.370 and 0.390, with the areas of very

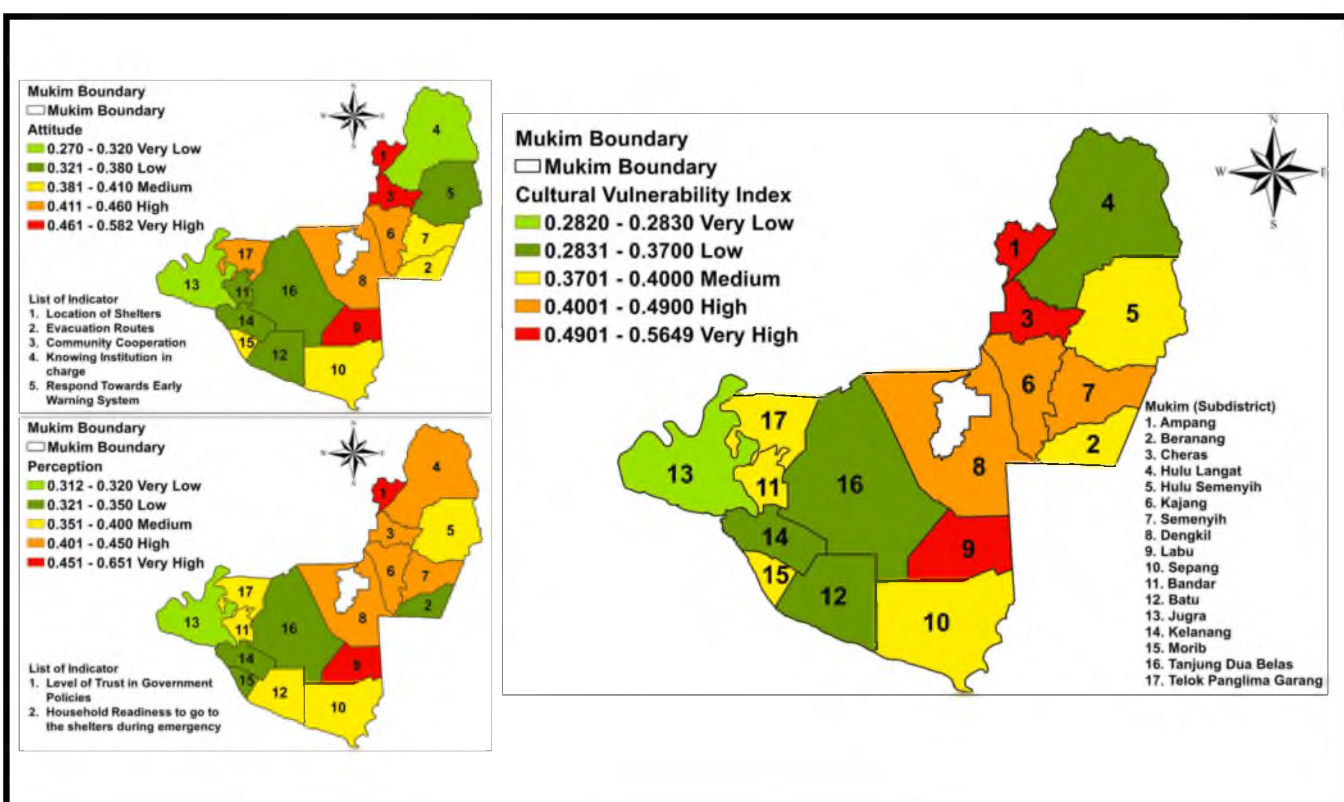

Fig. 8. Cultural vulnerability index.

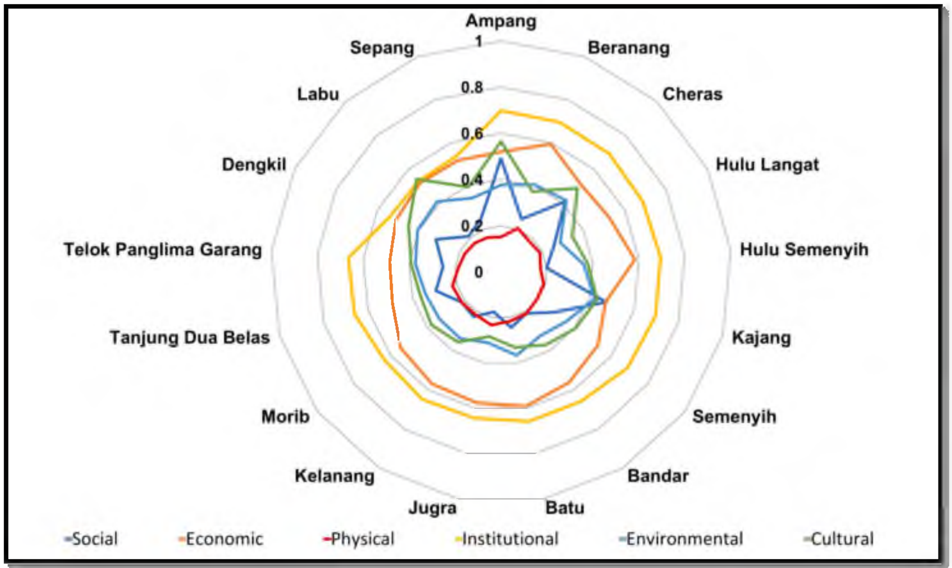

Fig. 9. Average of six dimension in each mukim.

low vulnerability being in the Dengkil, Labu, Sepang, and Jugra Mukim. However, in three mukim - Ampang, Cheras, and Kajang - most areas are classified in the very high or high vulnerability classes. The index range for the very high class is between 0.451 and 0.510, while the high-class index values range from 0.421 to 0.45. Areas of several other mukim are classified as having very high vulnerability, but these are small. For example, areas of Mukim Tanjung Dua Belas fall into all five classes, but most areas are in the medium vulnerability class. The detailed results presented in the MDVI map are shown in Fig. 10.

Table 3 shows the specific and detailed results from the spatial analysis, based on the map in Fig. 10. Overall, 5.7% of the study areas are classified as being in the very high MDVI class, 8.9% in the high MDVI class, 33.3% in the medium MDVI class, 21.6% in the low MDVI class, and 30.5% in the very low MDVI class. The area with the largest proportion in the very high MDVI class is Ampang, with 85.49% of this area in the very high MDVI class, while the average index is 0.47. The highest average MDVI value is also in Ampang and the lowest average MDVI value is in Sepang, 0.37. Mukim Sepang also has 0% of its area in the very high MDVI class, with 97.77 of the area in the very low vulnerability class. Four other Mukim also have 0% of their area in the very high MDVI class: Labu, Bandar, Jugra, and Morib. Based on the study area overall, the average index value is 0.41, the minimum value is 0.34, and the maximum value is 0.51.

5. Comparison with the flood event 2021

In this section, the MDVI map produced was compared with the impacts of the disaster events in 2021. The comparison is based on the

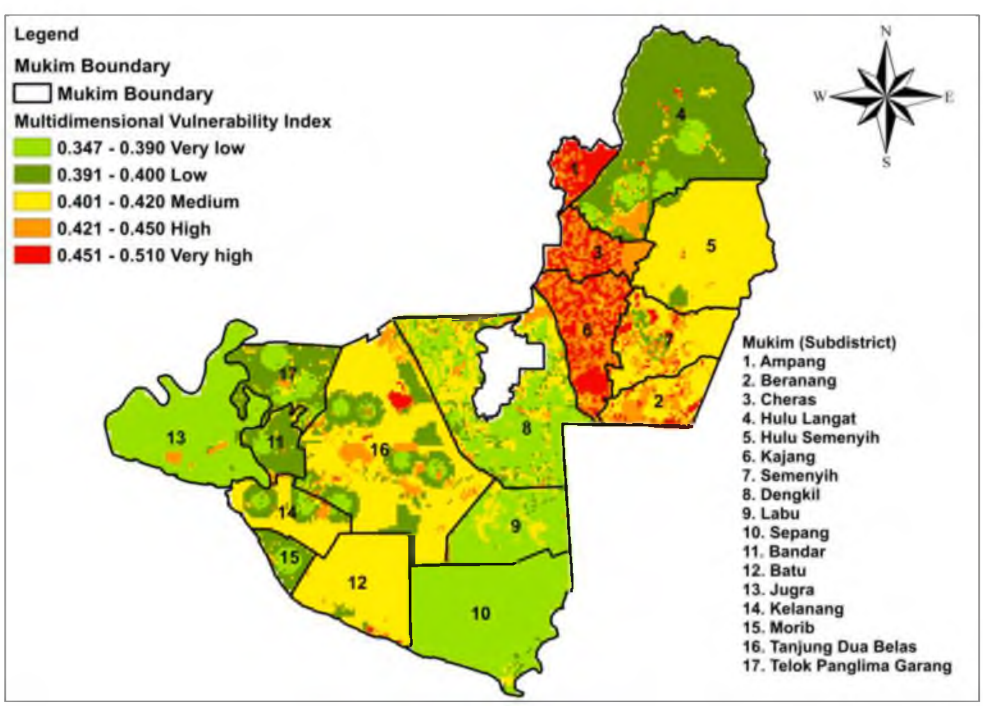

Fig. 10. MDVI map.

Table 3
MDVI Spatial analysis result.

Mukim	Area Percentage %					Average Index	Min Index	Max Index
	Very High	High	Medium	Low	Very Low			
Ampang	85.49	14.09	0.36	0	0.06	0.47	0.39	0.51
Cheras	43.99	54.56	1.28	0.17	0.00	0.45	0.39	0.51
Kajang	50.33	47.37	1.8	0.26	0.24	0.45	0.37	0.50
Beranang	11.06	34.34	54.24	0.09	0.27	0.43	0.39	0.48
Semenyih	7.99	19.14	65.79	6.56	0.51	0.42	0.39	0.49
Batu	0.13	1.33	95.15	2.79	0.13	0.41	0.38	0.46
Hulu Langat	0.35	4.45	3.57	80.78	10.84	0.40	0.37	0.48
Bandar	0	2.57	9.15	74.94	13.34	0.40	0.37	0.45
Hulu Semenyih	0.14	0.99	93.61	5.03	0.23	0.40	0.38	0.47
Kelanang	0.36	4.72	57.36	26.86	10.70	0.40	0.38	0.46
Tanjung Dua Belas	1.65	9.14	60.31	23.20	5.69	0.40	0.36	0.46
Telok Panglima Garang	0.01	3.66	9.60	61.00	25.73	0.40	0.37	0.46
Jugra	0	2.20	0.36	1.78	95.65	0.39	0.36	0.44
Morib	0	1.18	10.50	60.12	28.21	0.39	0.38	0.43
Dengkil	0.26	6.63	27.30	11.06	54.75	0.39	0.36	0.48
Labu	0.00	0.51	13.84	3.16	82.49	0.38	0.35	0.44
Sepang	0	0	1.17	1.06	97.77	0.37	0.34	0.41
Total	5.7	8.9	33.3	21.6	30.5	0.41	0.34	0.52

1. Multidimensional Vulnerability Assessment.
2. Index Based Approach.
3. Disaster risk reduction
4. Industrial Urban Area
5. Disaster Risk Management
6. Selangor, Malaysia

early results from a DOSM flood disaster impact report [44]. The section aims to compare and discuss the impacts of the 2021 flood events and the new MDVI map. Fig. 11 shows the map of the locations in the study area most severely affected during the disaster events of 2021. In total, 61 locations in these three districts were classified by the DOSM as having been affected. Based on the MDVI map, six locations were classified as having very high vulnerability and four locations were in areas of high vulnerability. Of the locations, most (27) were in areas of very low vulnerability, 12 were in areas of low vulnerability and 11 were located in areas of medium vulnerability.

Based on the DOSM report, the locations affected in 2021 had several disaster management-related issues that exacerbated the conditions. According to the DOSM report, the first issue the community faced during the flood events of 2021 was being trapped in their houses because of a late evacuation. The next issue was the late response from the agency involved in supplying help such as food, medical supplies, and basic equipment like warm clothes and blankets. Assistance to flood victims was slow since the agencies involved were unable to enter the

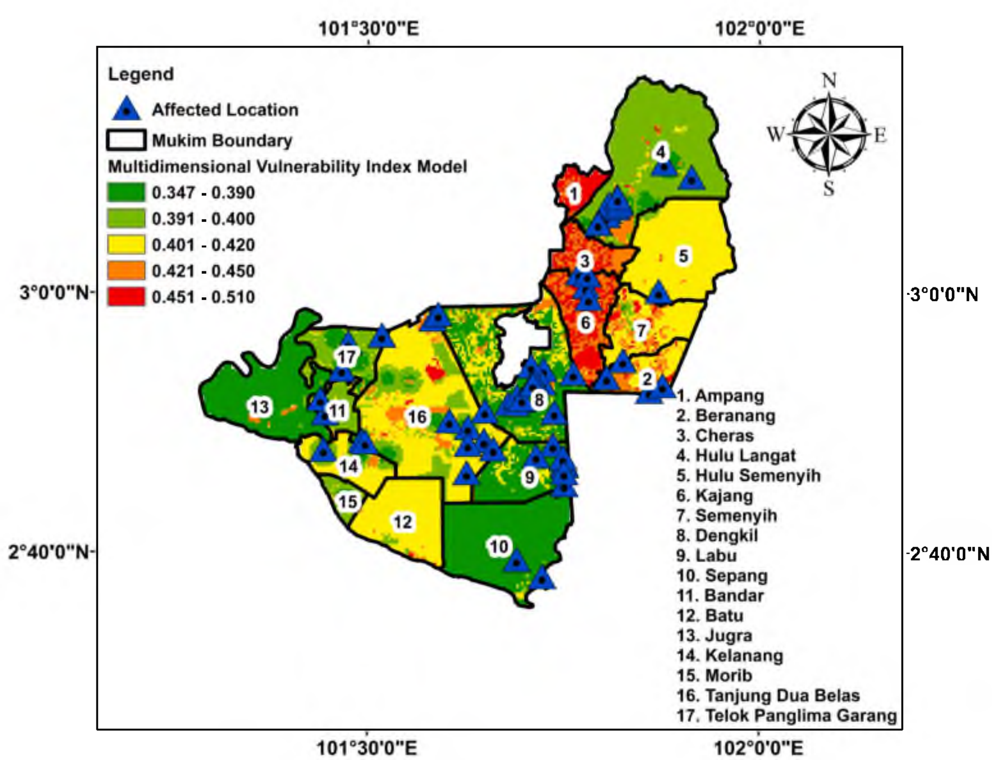

Fig. 11. Affected location during the flood 2021

disaster area due to the lack of preparation for a disaster of that size. According to a statement from the Prime Minister, the government's lack of preparation at the local level in the face of disasters led to the lack of coordination and the delayed response in carrying out rescue operations and giving help [45]. The multidimensional vulnerability assessment discussed in the previous section also showed that the study area had higher vulnerability, especially in institutional terms. The lack of institutional planning and capacity was demonstrated by the lack of inter-agency coordination between the local and federal authorities. Institutional capacity needs to be strengthened by involving local governments in emergency response and preparedness planning [46]. The lack of awareness among the community was another reason why victims became trapped in their houses during the events. Raising each individual's level of awareness and understanding would enable them to develop a positive attitude and perception when confronted with a disaster [47]. The lack of awareness programs, emergency drill training, and communication between local governments and communities also increased the vulnerability of this area. This was demonstrated in the 2021 flood events, especially in Selangor, where coordination between agencies was lacking and people did not know what to do before or during a disaster. Intangible vulnerability factors such as risk perception are complex to measure but contribute to increasing the impact of a disaster.

6. Conclusion

This research indicates that disaster vulnerability should be viewed as a combination of the social, economic, physical, institutional, environmental, and cultural dimensions, while the authors proposed a multidimensional theory from the MOVE framework to assess vulnerability. A combination of spatial and holistic approaches provided specific information about areas classified as vulnerable and enabled the complexity of multiple vulnerability indicators to be better presented. Overall, the study findings provide a clear picture of the multidimensional and aggregate vulnerability of urban areas in both spatial and non-spatial terms. The highest MDVI value is 0.510 and the lowest is 0.347. Compared to the other five dimensions, the most vulnerable dimension in this study area was found to be institutional. All the mukim have the highest institutional vulnerability, except for Labu, whose highest vulnerability is in the cultural dimension. Mukim Ampang is the most vulnerable area, with 85.49% of the area having very high vulnerability and 14.09% having high vulnerability, in terms of the overall MDVI. However, for the total area, only 5.7% is in the very high MDVI class and 8.9% is in the high MDVI class.

The multidimensional vulnerability analysis in this study explained varied information about vulnerability and provides the decision maker with a policy-making tool based on science. This scientific-based information is vital for the implementation of effective disaster risk management. The approach used in this study could provide the information needed by local governments to improve the DRR strategies in their organization for future disaster events. Based on the index range provided using this approach, local governments can set goals to reduce vulnerability, reduce the number of very highly vulnerable areas, develop mitigation measures, allocate DRR budgets, and engage in proper planning for different dimensions of the disaster risk components. Furthermore, the multidimensional vulnerability assessment could be used by NADMA, the main agency, to evaluate local governments and other agencies involved in DRM. The multidimensional vulnerability assessment indicators in this study cover all the phases of disaster management cycles: preparedness, mitigation, response, and recovery; this would lead to a better understanding at the local level as stated in Sendai Framework. The proposed approach could provide the information needed to improve the disaster planning and management mechanism in Directive No 20, a national policy.

Credit authorship contribution statement.

Muhammad Wafiy Adli: Conceptualization, Methodology, Software, Data Collection, Data analysis, Data curation, Writing – original draft, Writing review & editing. **Nor Eliza Alias**: Software, Formal analysis, Data curation, Conceptualization, Methodology, Writing - original draft, Writing -review & editing**. Halimah Mohd Yusof**: Data Collection, Design Questionnaire, Supervision. **Zulkifli Yusop**: Conceptualization, Methodology, Supervision, Project administration, Project Funding, Writing review & editing. **Shazwin Mat Taib**: Conceptualization, Methodology, Supervision. **Yusrin Faiz Abdul Wahab**: Data collection and Writing reviews. **Sitti Asmah Hassan:** Supervision, writing review.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Nor Eliza Alias reports financial support was provided by Malaysian Ministry of Education.

Data availability

Data will be made available on request.

Acknowledgement

The authors would like to express their gratitude to the Malaysian Ministry of Education for funding through the Fundamental Research Grant Scheme (FRGS) (FRGS/1/2018/WAB05/UTM/02/6) [R.J130000.7851.5F032], UTM Fundamental Research Grant [Q.J130000.2551.20H75], Malaysia Research University Network Grant [R.J130000.7851.4L897], UTMShine [Q.J130000.2451.09G92], and UTM ZAMALAH for sponsorship.

References

[1] CRED & UNDRR. Global trends and perspectives Executive Summary. 2021. p. 8.
[2] EM-DAT. The International Disaster Database. 2021. https://www.emdat.be/database (accessed April 5, 2021).
[3] IPCC. Global warming of 1.5° C: summary for policymakers. Intergov Panel Clim Chang 2018:1–24.
[4] CEDMHA. Malaysia: disaster management reference handbook 2016. Centre for excellence in disaster managment and humanitarian assistance. 2016.
[5] Behlert B, Diejobst R, Felgentreff C, Manandhar T, Mucke P, Pries L, et al. World Risk Report 2020 Focus: Forece Displacement and Migration. 2020.
[6] CEDMHA. Malaysia Disaster Management Reference Handbook. 2019.
[7] Esmaiel A, Abdrabo KI, Saber M, Sliuzas RV, Atun F, Kantoush SA, et al. Integration of flood risk assessment and spatial planning for disaster management in Egypt. Prog Disaster Sci 2022;15:100245. https://doi.org/10.1016/j.pdisas.2022.100245.
[8] IPCC. Managing the risks of extreme events and disasters to advance climate change adaptation. Intergovernmental Panel of Climate Change; 2012. https://doi.org/10.1017/cbo9781139177245.
[9] UNISDR. National Disaster Risk Assessment: Governance system, methodologies, and use of results. Consultati. United Nation Office for Disaster Risk Reduction (UNISDR); 2017.
[10] Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, et al. A framework for vulnerability analysis in sustainability science. Proc Natl Acad Sci 2003;100:8074–9. https://doi.org/10.1073/pnas.1231335100.
[11] Birkmann J. Measuring vulnerability to promote disaster-resilient societies: conceptual frameworks and definitions. Meas vulnerability to Nat Hazards. Towar Disaster Resilient Soc 2006;01:9–54. https://doi.org/10.1111/j.1539-6975.2010.01389.x.
[12] Cutter SL, Boruff BJ, Shirley WL. Social vulnerability to environmental hazards. Soc Sci Q 2003;84:242–61. https://doi.org/10.1111/1540-6237.8402002.
[13] Tate E. Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. Nat Hazards 2012;63:325–47. https://doi.org/10.1007/s11069-012-0152-2.
[14] Frigerio I, Carnelli F, Cabinio M, De Amicis M. Spatiotemporal pattern of social vulnerability in Italy. Int J Disaster Risk Sci 2018;9:249–62. https://doi.org/10.1007/s13753-018-0168-7.
[15] Nguyen KA, Liou YA, Terry JP. Vulnerability of Vietnam to typhoons: a spatial assessment based on hazards, exposure and adaptive capacity. Sci Total Environ 2019;682:31–46. https://doi.org/10.1016/j.scitotenv.2019.04.069.
[16] Usman Kaoje I, Abdul Rahman MZ, Idris NH, Tam TH, Mohd Sallah MR. Physical flood vulnerability assessment of buildings in Kota Bharu, Malaysia: an indicator-based approach. Int J Disaster Resil Built Environ 2020. https://doi.org/10.1108/IJDRBE-05-2020-0046.

[17] Dolman DI, Brown IF, Anderson LO, Warner JF, Marchezini V, Santos GLP, et al. Re-thinking socio-economic impact assessments of disasters : The 2015 flood in Rio Branco, Brazilian Amazon. Int J Disaster Risk Reduct 2018;31:212–9. https://doi.org/10.1016/j.ijdrr.2018.04.024.
[18] Karuppusamy B, Leo George S, Anusuya K, Venkatesh R, Thilagaraj P, Gnanappazham L, et al. Revealing the socio-economic vulnerability and multi-hazard risks at micro-administrative units in the coastal plains of Tamil Nadu, India. Geomat Nat Haz Risk 2021;12:605–30. https://doi.org/10.1080/19475705.2021.1886183.
[19] Lopez-Martinez F, Gil-Guirado S, Perez-Morales A. Who can you trust? Implications of institutional vulnerability in flood exposure along the Spanish Mediterranean Coast. Environ Sci Policy 2017:29–39.
[20] IPCC. Climate Change 2001. Synthesis Report. IPCC Third Assessment Report (TAR). 2001.
[21] Karunarathne AY, Lee G. Developing a multi-facet social vulnerability measure for flood disasters at the micro-level assessment. Int J Disaster Risk Reduct 2020;49: 101679. https://doi.org/10.1016/j.ijdrr.2020.101679.
[22] Robielos RAC, Lin CJ, Senoro DB, Ney FP. Development of vulnerability assessment framework for disaster risk reduction at three levels of geopolitical units in the Philippines. Sustain 2020;12:1–27. https://doi.org/10.3390/su12218815.
[23] Karagiorgos K, Thaler T, Hübl J, Maris F, Fuchs S. Multi-vulnerability analysis for flash flood risk management. Nat Hazards 2016:82. https://doi.org/10.1007/s11069-016-2296-y.
[24] Menoni S, Molinari D, Parker D, Ballio F, Tapsell S. Assessing multifaceted vulnerability and resilience in order to design risk-mitigation strategies. Nat Hazards 2012;64:2057–82. https://doi.org/10.1007/s11069-012-0134-4.
[25] Rana IA, Routray JK. Multidimensional model for vulnerability assessment of urban flooding: an empirical study in Pakistan. Int J Disaster Risk Sci 2018;9: 359–75. https://doi.org/10.1007/s13753-018-0179-4.
[26] United Nations. International strategy for disaster reduction Hyogo framework for action 2005-2015: building the resilience of nations. World Conf Disaster Reduct 2005:25. https://doi.org/10.1017/CBO9781107415324.004.
[27] Khalid Z, Meng X, Ahmed I, Su X. Holistic Multidimensional Vulnerability Assessment: An empirical investigation on rural communities of the Hindu Kush Himalayan region, Northern Pakistan. Int J Disaster Risk Reduct 2021;62.
[28] Welle T, Depietri Y, Angignard M, Birkmann J, Renaud F, Greiving S. Vulnerability assessment to heat waves, floods, and earthquakes using the MOVE framework: Test case Cologne, Germany. Elsevier Inc; 2014. https://doi.org/10.1016/B978-0-12-410528-7.00005-9.
[29] Birkmann J, Cardona OD, Carreño ML, Barbat AH, Pelling M, Schneiderbauer S, et al. Framing vulnerability, risk and societal responses: the MOVE framework. Nat Hazards 2013;67:193–211. https://doi.org/10.1007/s11069-013-0558-5.
[30] Zahid Z, Saharizan NS, Hamzah P, Hussin SAS, Khairi SSM. Multi-dimensional flood vulnerability assessment using data envelopment analysis. AIP Conf Proc 2017:1905. https://doi.org/10.1063/1.5012219.
[31] Sauti NS, Daud ME, Kaamin M. Construction of an integrated social vulnerability index to identify spatial variability of exposure to seismic hazard in Pahang. Malaysia Int J Des Nat Ecodynam 2020;15:365–72. https://doi.org/10.18280/ijdne.150310.
[32] Kamarudin AF, Ibrahim A, Ibrahim Z, Madun A, Daud ME. Vulnerability assessment of existing low-rise reinforced concrete school buildings in low seismic region using ambient noise method. Adv Mat Res 2014;3:483–9. https://doi.org/10.4028/www.scientific.net/AMR.931-932.483.
[33] Department of Irrigation and Drainage Malaysia (DID). National Register of River Basins Updating of Condition of Flooding in Malaysia. Volume 2.5: State Report for Johor. Dep Irrig Drainage, Malaysia2; 2003. p. 1–45.
[34] Ramli MWA, Alias NE, Yusof HM, Yusop Z, Taib SM. Development of a local, integrated disaster risk assessment framework for Malaysia. Sustain 2021:13. https://doi.org/10.3390/su131910792.
[35] Izumi T, Matsuura S, Mohd Yusof AF, Razak KA, Morighuchi S, Kure S, et al. Disaster risk report: Undesratnding landslide and flood risk for science-based disaster risk reduction in the state of Selangor. 2019. https://doi.org/10.11408/jierp1982.1983.4_58.
[36] Lee S, Pradhan B. Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models. Landslides 2007;4:33–41. https://doi.org/10.1007/s10346-006-0047-y.
[37] Othman AN, Mohd WMNW, Noraini S. Accuracy assessment of landslide prediction models. IOP Conf Ser Earth. Environ Sci 2014:18. https://doi.org/10.1088/1755-1315/18/1/012078.
[38] Muhamad N, Reza MIH, Pereira JJ. Landslide susceptibility maps to support urban Landuse decision-making: case study of the Langat Sub-Basin. Selangor War Geol 2017;43:340.
[39] Creswell J. Qualitative Inquiry and Research Design: Choosing among Five Approaches:International student addition. SAGE Publications, Inc; 2013.
[40] Cochran. Cochran_1977_Sampling_Techniques_Third_Edition.pdf. 1977.
[41] Kienberger S, Contreras D, Zeil P. Spatial and holistic assessment of social, economic, and environmental vulnerability to floods-lessons from the Salzach River basin, Austria. Elsevier Inc; 2014. https://doi.org/10.1016/B978-0-12-410528-7.00003-5.
[42] Tedim F, Garcin M, Vinchon C, Carvalho S, Desramaut N, Rohmer J. Comprehensive vulnerability assessment of forest fires and coastal Erosion: Evidences from case-study analysis in Portugal. In: Assess. Vulnerability to Nat. Hazards A Eur. Perspect. Elsevier Inc; 2014. p. 149–77. https://doi.org/10.1016/B978-0-12-410528-7.00007-2.
[43] Hernândez ML, Carreño ML, Castillo L. Methodologies and tools of risk management: hurricane risk index (HRi). Int J Disaster Risk Reduct 2018;31: 926–37. https://doi.org/10.1016/j.ijdrr.2018.08.006.
[44] DOSM. Laporan Khas Impak Banjir 2021. 2021.
[45] Abd Manap AN. Pelbagai faktor masalah pengurusan banjir di Selangor - PM. Ber Hari; 2021.
[46] UNISDR. Disaster resilience measurements stocktaking of ongoing efforts in developing systems for measuring resilience united nations development programme. 2014. https://doi.org/10.1007/978-1-4020-6359-6_3359.
[47] Gerdan S. Determination of disaster awareness, attitude levels and individual priorities at Kocaeli University. Eurasian J Educ Res 2014:159–76.