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Development of Flood Vulnerability and Risk Indices for Kelantan District, Peninsular Malaysia

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ABSTRACT

Natural hazards are inevitable which required proper monitoring and application of mitigation measures to reduce vulnerability and risk. Flood is one of the most common natural hazards in Malaysia. The present study was conducted to identify vulnerable flood zones using flood vulnerability and risk indices and to minimize flood damage by suggesting mitigation measures. Four sub-districts of the Kelantan state, Peninsular Malaysia were selected based on the availability of the data and flooding history. For this purpose, demographic, social, economic, and flood event data were collected to develop flood vulnerability and risk index. Descriptive and inferential statistics were used to analyze the results. The results revealed that developed flood vulnerability and risk indices accurately predict high-priority zones. Overall, it was found that flood risk is relatively higher in a rural area compared to an urban area.

INTRODUCTION

Flooding is a frequent natural hazard that causes the loss of human lives and the economy. Spatio-temporal patterns of flooding can be influenced by uncontrolled construction of buildings and land-use changes. The primary cause of the flooding is a storm which is due to high rainfall in a short duration. In high rainfall conditions, the intensity of flood is generally accelerated by settlements along the floodplains. Additionally, other factors include topographic variation, geomorphological changes, dense drainage networks, engineering structures, and dynamic climatic conditions.

Flooding is common in Malaysia which causes 90 percent losses due to natural hazards. The average annual flood damage is approximately US100 million (Chan 2015). In the state of Kelantan, the Kelantan River bank periodically overflow from November to February. Under the 50-year flood situation at Kusial Bridge, the projected flood volume is around 6 billion m3. In 1926 and 1967, significant flooding occurred and in the year 1967 floods, 84 percent of the population of Kelantan (537,000 people) was badly affected (Hassan & Rozi 2006). About 125,000 individuals have been evacuated and 38 have drowned.

Resilience principles must be implemented to provide adequate protection against the rising trend of flash flooding and its effects on civilization. To create a clear theoretical and practical foundation for flood resilience, the idea of flood vulnerability in flood-prone areas needs to be addressed. Although, several methods of flood impact assessment have been developed (Penning-Rowsell et al. 2005, Yahya et al. 2016). Adaptation and advancement of theory, methodology, and practice in vulnerability assessment involve sudden changes in the present city areas. Although the definition of vulnerability is closely linked to susceptibility, impact assessment begins with a quantitative approach. This applies not only to retrospective evaluations but even to a large degree to prospective cases where future flood impact assessments can address the disruption of the socio-economic backbones of society and their effects on regional, national, and even transnational networks, due to the increasing availability of data. Due to the influence of several factors, vulnerability varies in different conditions (Ibrahim et al. 2017). The cumulative impact of several factors can be assessed using a vulnerability index. The primary task of vulnerability index development is to identify the most vulnerable area to flooding which is an important tool in flood management.

A significant unit of the population is affected by flood risk in Peninsular Malaysia. Rapid increment in settlement on floodplains causes exposure of a large number of people and property to flooding risk (JICA 1982). Vulnerability increases due to inaccurate responses from the public living in floodplains. Flood mitigation should be able to address severe risks in an area. Information about the level of danger,

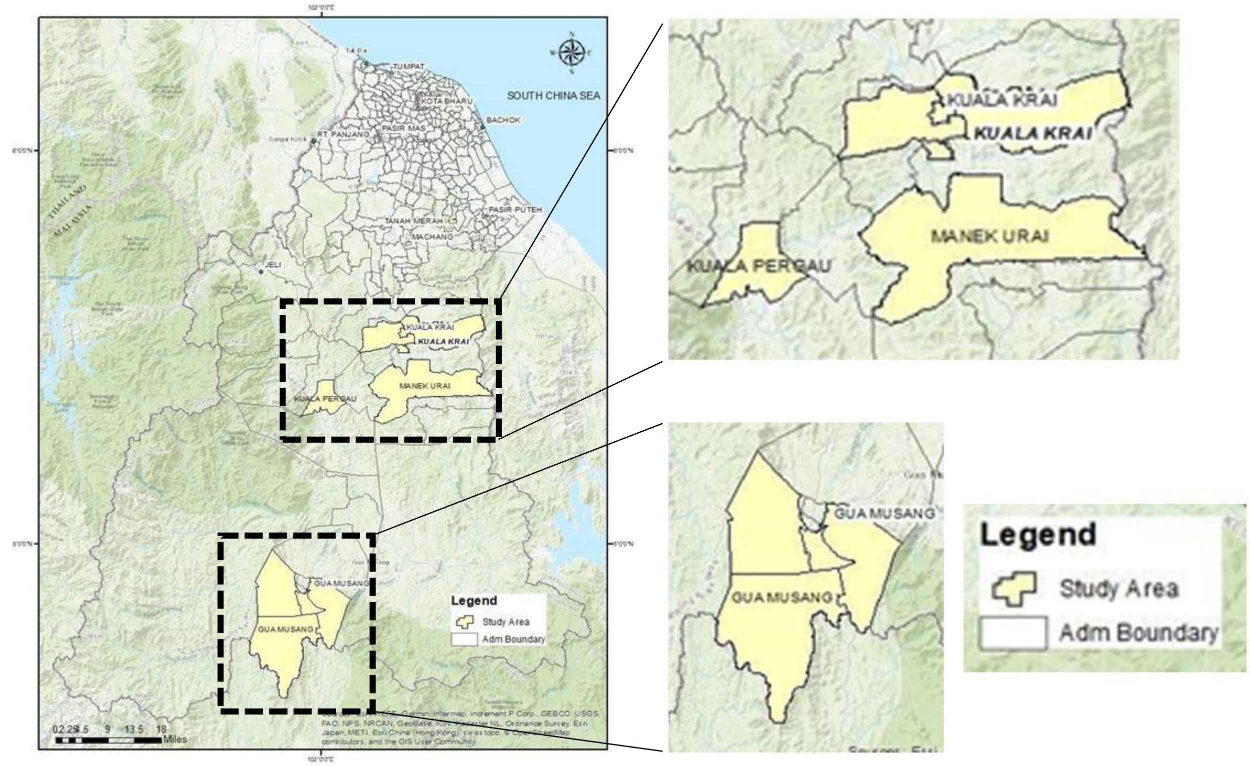

Fig. 1: Location of the study area.

exposure, and vulnerability is required for priority action in overcoming flood problems. Flood damage can be reduced by identifying flood-prone areas and applying proper mitigation measures (Lee & Choi 2018). Therefore, the objectives of the study are to identify vulnerable flood zones using flood vulnerability and risk indices and to minimize flood damage by suggesting mitigation measures.

MATERIALS AND METHODS

Location and Details of the Study Area

This work was conducted in the Kelantan state of Peninsular Malaysia. The area of the state is approximately 15000 km^2 (Anees et al. 2019). The highest elevation is 2187 m above mean sea level. The northern part of the state is surrounded by the South China Sea. Gua Musang Town of the district Gua Musang, Kuala Krai Town of the district Kuala Krai, and its two sub-districts such as Manik Urai and Kuala Pergau were selected based on administrative similarities in status and flooding exposure among locations (Fig. 1).

The area has a tropical and humid climate with mean variation in temperature as 20 to 30°C. High precipitation is generally recorded from November to January, while low precipitation is in June and July. The mean annual precipitation is 3020 mm while the mean daily annual wind speed is 1.50 m.s^{-1} (Anees et al. 2018).

Data Used

Primary data was collected directly from main sources through interviews, surveys, and questionnaires. Whereas, secondary data was collected from the literature. Secondary data is accessible through different public and government records and online sources. The summary of the data is given in Table 1.

Methodology

Primary Data Collection

Primary data include field surveys, field photographs, interviews with regional government offices, and household surveys with GPS locations. The survey was conducted within flood-prone areas. Factors considered for sampling were the vicinity of the flood-prone area, past flood records, and tenancy by infrastructure, land properties, and settlements in collaboration with community leaders.

- Interviews were conducted with representatives of stakeholders consisting of experts relating to floods, local government, and communities in various circles. Interviews were conducted with 200 respondents.

Table 1: Summary of data used in this study.

Data Type	Parameter/Variable	Frequency	Duration	Source/Remark
Demographic data	Population Size	Study Area	2014, 2015	Questionnaire Survey
Social Data	• Household size • Gender of household • Educational level • Health status • Age • Occupation	Household-level	N/A	Questionnaire Survey
Economy	Household income	Household	N/A	Questionnaire Survey
Flood events	Flood, flood extreme, flood hazard, exposure, and vulnerability.	Flood events in Kelantan and Malaysia	Various periods and time	Previous researcher, publication, and government records
Data Type	Parameter/Variable	Frequency	Duration	Source/Remark
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Economy	Household income	Household	N/A	Questionnaire Survey
Flood events	Flood, flood extreme, flood hazard, exposure, and vulnerability.	Flood events in Kelantan and Malaysia	Various periods and time	Previous researcher, publication, and government records

- Documentation study, which is to collect and study data or documents that support research, at least several relevant agencies such as the Malaysian Meteorological and Public work
- The questionnaire was given to 200 residents who experienced this disaster to find out their condition and response to the flood. The questions given in the questionnaire are important variables in analyzing flood risk. The components of the question are Flood hazard experience, related to depth, duration, and other flood characteristics such as distance from rivers and physical impressions. All questions are expected to become significant data in discussing flood hazards. Flood exposure, about the elements at risk that are affected around the respondent, especially those of vital value to the respondent, and flood vulnerability, which relates to the economic and social impacts of the respondent due to the flood, either directly or indirectly while flood risk, concerning vigilance and action in anticipation of floods.

Development of Flood Risk Classification

Flood Risk is analyzed and grouped into four parameters, namely flood hazard, exposure, and vulnerability. The analysis was carried out with 2 analytical methods, namely spatial analysis, and scoring analysis. These results are then converted spatially using the Weighted Linear Combination (WLC) method to ensure that the weighted translations of different variables derived from the Analytic Hierarchy Process (AHP) equation can be converted into maps in a relevant way. The WLC is the most common methodology in multi-scale evaluation analysis.

Development of spatial risk index using spatial layer overlay for all areal units (Census Tract) of each flood hazard region. The operation was between the hazard and the spatial layers of flood impact. Based on the spatial vulnerability intersection and exposed layers, the impact layers were formed. The Raster multiplication technique was used for the spatial intersection. The calculation of index value and map ranking for all raster grid cells were based on created index values (Rucinska 2014). Therefore, "the flood risk (RF) map" is the "spatial intersection of flood hazard, social (population) and exposure vulnerability" (Equation 1).

$$RF = HF_i \cap_n VP_i \cap VE_i \quad \ldots(1)$$

where HF is a spatial layer of flood hazard which is equal to $\cap$n HFi, HFi is the several flood hazards related to areal components, VP is a spatial layer of social vulnerability which is equal to $\cap$n VPi, VPi is different population vulnerabilities related to the areal components, VE is a spatial layer of vulnerability due to infrastructure exposure which is equal to $\cap$n VEi, VEi is different infrastructure related to the areal components.

Scoring is a decision-making technique in a process that involves factors together by assigning a value to each factor. In determining the scoring assessment can subjective scoring is carried out, namely by setting a score based on certain considerations and based on an understanding of the process, or objective scoring is by statistical calculations.

The scoring process is useful for assigning a score to each score parameter that affects flooding. The greater the influence, the higher the score. For scoring, a score of 1 is given to parameters that have a minor effect and a score of 5 is given to the parameter which has a major effect on flooding.

The procedure of the decision-making method using AHP analysis for the appropriate site selection zone is as follows:

- Hierarchy building at several levels. Hierarchy designing for all parameters of flood hazard, exposure, and vulnerability.
- Based on the couple, element comparison of the decision to reduce the decision-making concept.
- Determination of parameters by the normalization of the Eigenvector associated with the maximum Eigen matrix ratio. Comparison matrix couples are shown in Table 2.
- Calculation of each parameter weight using pair ratio with an assumption. If the consistency ratio (CR) value is 0.10, then the judgment is inconsistent or bad sensitivity value.

Spatial analysis is the aggregation weights relative that has been produced in the previous stage to produce composite weight as the final score of spatial decision making.

Statistical Analysis

In general, the analysis used in this research is quantitative analysis techniques based on statistical analysis. This analysis is divided into two groups, namely:

- Use descriptive statistics to analyze collected data to avoid general conclusions or generalizations. The analysis is only in the form of an accumulation of basic data and descriptions, in the sense that it does not seek or explain relationships, test hypotheses, make predictions, or draw conclusions. For example, in analyzing questionnaire data, field measurement data, and secondary data from Hyetograph and Hydrographs.
- Inferential statistics It is concerned with drawing conclusions and making assumptions based on observations, such as correlational analysis and comparative analysis, that have been carried out. Correlational research is to find an association or effect between the Independent Variables and the Dependent Variables. Comparative Analysis Comparative analysis is a method of mathematical analysis aimed at comparing the circumstances between two or more types. The measurement methodology used is often quite varied, depending on the type of data size and the number of categories, and the application of these analysis techniques. For example, the relationship between facets of floods, such as flood risk, exposure, and vulnerability, is studied.

Table 2. Comparison matrix couples (Imanda & Andono 2015).

Value	Definition
1	Equally important
3	Quite important
5	High importance
7	Very high importance
9	Extremely high interests
2,4,6,8 Values between each criterion	

RESULTS AND DISCUSSION

In this study, flood vulnerability has been defined as a combination of three types of distinctive vulnerabilities such as economic, infrastructure, and social. Each of these three types can further be categorized in Table 3. To determine Infrastructure, a social and economic vulnerability that was impacted by the flood in 2014, a survey using a questionnaire and interviews with 200 respondents, as illustrated in figure (Fig. 2), was undertaken. The questionnaire containing seventeen questions was provided to the community of Gua Musang, Kuala Krai, Kuala Pergau, and Manik Urai to those who experienced the flood occurrence in 2014. The Analytic Hierarchy Process (AHP), a quantitative analysis technique, is used to compare flood vulnerability index components like the social vulnerability index, economic vulnerability index, and infrastructure vulnerability index, especially in determining the weight of all associated parameters.

Economic Vulnerability

Economic vulnerability (EV) is represented by total loss data including losses in transportation, buildings, household, shop, and farms. For this study, economic vulnerability is classified into 3 classes based on the below calculation:

$$\text{Total loss (RM)} = \frac{(\text{high total loss}) - (\text{low total loss})}{3\ (\text{classes})} \quad \ldots(2)$$

Based on data survey in the study areas (Gua Musang, Kuala Krai, Kuala Pergau dan Manik Urai), three classes of economic vulnerability can be determined - High total loss (H), Medium loss, and Low loss. Where, H > RM 100 000, M < RM 100 000 and > RM 50 000, and Low (L) < RM 50 000.

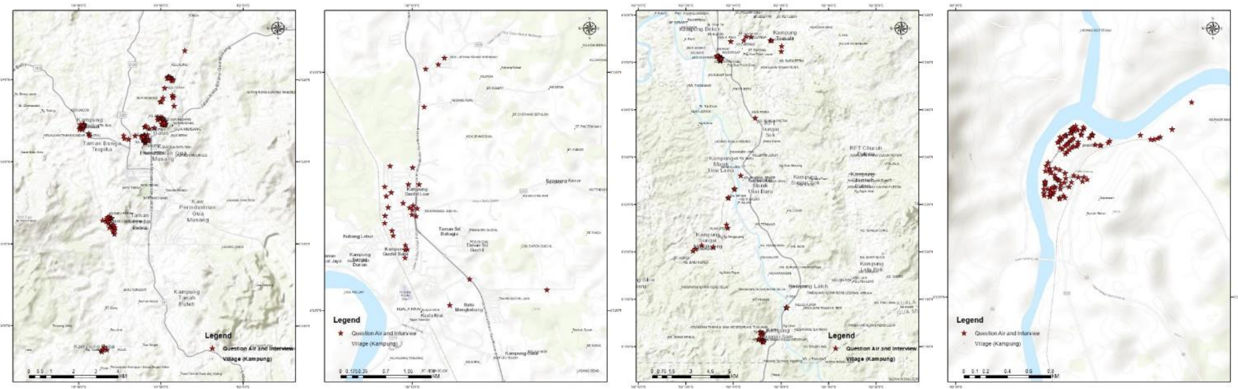

Fig. 2: Respondents' location of Gua Musang, Kuala Krai, Manik Urai, and Kuala Pergau for questionnaire and interview.

The results of the classification study Economic vulnerability in the 4 study areas can be seen in the graph (Fig. 3):

Based on the data above, economic vulnerability by area is calculated in Table 4:

Social Vulnerability

The focus of social vulnerability on occupation, gender, and age is shown in Fig. 4. These factors have important physical or mental characteristics which affect a person's ability to take preventive measures against flooding.

Table 3: Categorization of distinctive vulnerabilities.

Category	Theme	Types
Economics	Total loss	1. Transportation
		2. Household
		3. house,
		4. shop business
		5. farm
Social	Age	6. 19 years and below
		7. 20 years-39 years
		8. 40 years-60 years
		9. 61 years an above
	Occupation	10. Business
		11. Farmer
		12. Government
		13. Housewife
		14. Labor
		15. Pensioner
		16. Private
		17. self-employed, unemployed
		18. student
	Gender	19. Male
		20. Female
Physical	Facilities	21. Roads
		22. Railways
		23. Bridges
		24. schools and
		25. hospitals

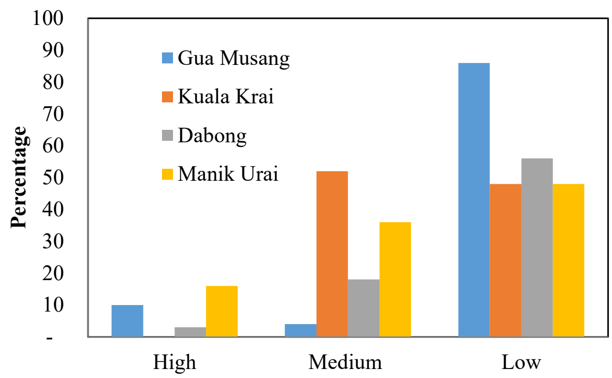

Fig. 3. Percentage of total loos by area.

Fig. 4 shows that, in December 2014 Kelantan flood, people below the age of 20 years are exposed more. It also showed that young people are more vulnerable to flooding than older people. In Fig. 4, fewer gender differences mean no effect in identifying the flood-level social vulnerability during the flood.

Fig. 5 shows the Respondents' classification based on their occupation. Based on collected data, most people are involved in the business which affects more during the flood. Additionally, unemployed people experienced the same. Overall results showed that flood vulnerability can be determined based on the impact experienced by the type of

Table 4. Economic vulnerability by area.

Area	Total Lost	EV Level
Gua Musang	2,600,000.00	Medium
Kuala Krai	5,100,000.00	High
Dabong	2,795,000.00	Medium
Manik Urai	4,140,000.00	High

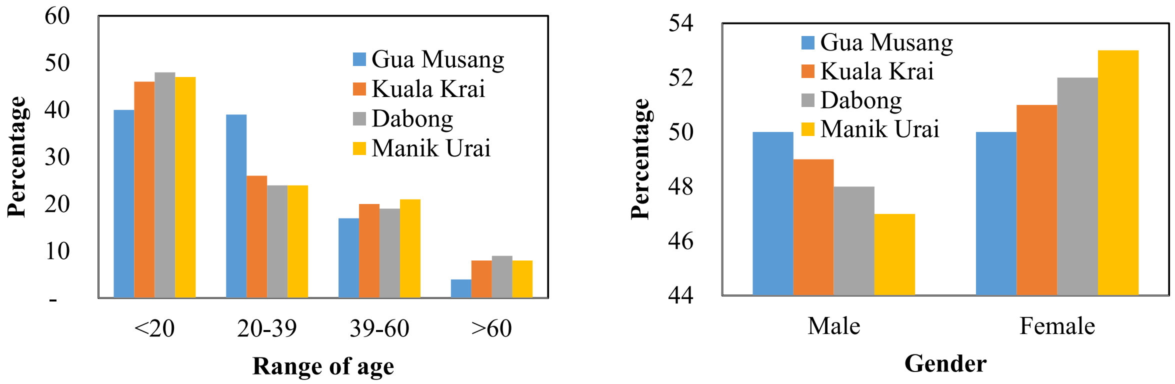

Fig. 4: Percentage of age and gender composition by area.

work. Furthermore, high flood vulnerability was experienced by business occupational people.

Calculation of the Social Vulnerability Index (SVI) is the result of accumulating all vulnerability parameters into the following equation:

$$SVI = \left(weight \times ratio\,\frac{F}{M}\right) + (weight \times range\ of\ age) + (weight \times occupation) \quad ...(3)$$

Through calculations using AHP, the weight of each SVI parameter is shown in Table 5.

$$SVI = (0.24 \times ratio\ gender) + (0.54 \times range\ of\ age) + (0.21 \times occupation) \quad ...(4)$$

By combining all elements of social risk, including multipliers, the overall score results are obtained as shown in Table 6.

Physical Vulnerability

The final category is infrastructure vulnerability, which includes road networks, railways, bridges, hospitals, and schools. Infrastructure is one of the basic requirements for population, communication, and safety which can be affected by floods. Schools can be used as evacuation places or centers of aid during a flood. Hospitals require special protection during floods. If hospitals get affected by flooding, it could worsen the treatments. As to be concluded, critical facilities tend to give special attention to vulnerability analysis to provide a more accurate estimate of the flood.

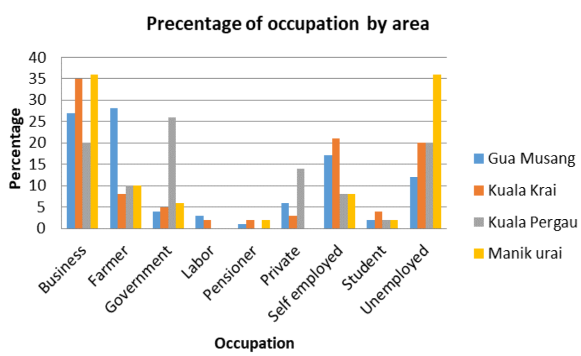

Fig. 5: Percentage of occupation composition by area.

Table 5: Weight of elements of social vulnerability.

Parameters	Gua Musang	Kuala Krai	Kuala Pergau	Manik Urai	Weight
Age	40.00	46.00	48.00	47.00	0,54
Gender	1.00	1.04	1.08	1.13	0,24
Occupation	2.25	1.75	1.00	1.00	0,21

Table 6: Social vulnerability score, classification of social vulnerability, and social vulnerability class.

	Age	Gender	Occupation	SV Score
Gua Musang	22	0.24	0.47	22
Kuala Krai	25	0.25	0.37	26
Dabong	26	0.26	0.21	26
Manik Urai	25	0.27	0.21	26

Class score	SV Level
<8	Low
>8 and < 17	Medium
>17	High

Area	Score	SV
Gua Musang	22	High
Kuala Krai	26	High
Dabong	26	High
Manik Urai	26	High

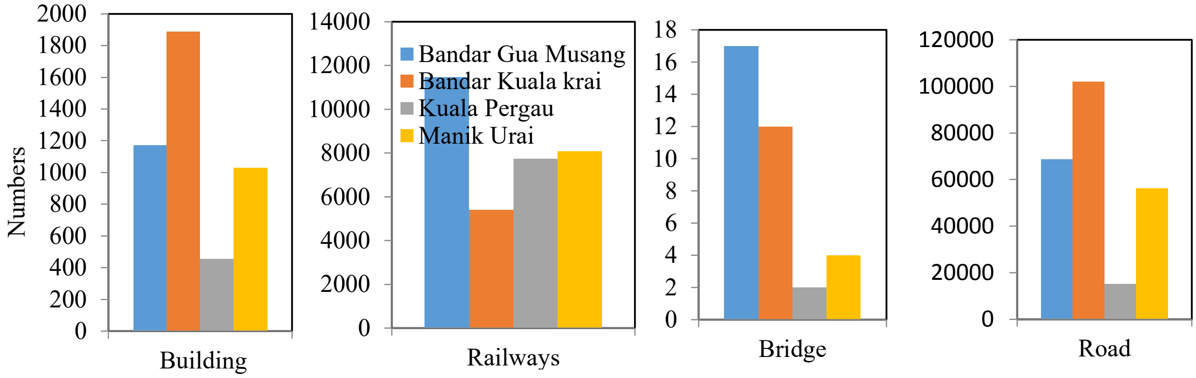

Fig. 6: Numbers of vulnerable buildings, railways, roads, and bridges.

The results of data processing related to physical vulnerability are shown in graphic images that represent each component (Fig. 6)

The physical vulnerability weight or index calculated by using the AHP method can be seen in Table 7.

The following method is used to calculate physical vulnerability across the entire study region. It adds up all components of physical risk, in this example, generally referred to as physical infrastructure, such as buildings, roads, railroads, and bridges, and multiplies them by their weights,

$$PV = (0.411 \times building) + (0.288 \times road) + (0.185 \times railways) + (0.411 \times bridges) \quad ...(5)$$

The results of calculations using Eq. 5 produce a total score as shown in Table 8.

Table 8 shows the physical vulnerability score from all areas based on their weight. Physical vulnerability is classified as Low (<8333), Medium (>8333 and <16666), and High (>16666). Based on the classification, Bandar Kuala Krai obtain the biggest score followed by Gua Musang, Manik Urai, and Kuala Perga. The results of the analysis shown in Table 8 also conclude that urban areas, Kuala Krai and Gua Musang Town are more vulnerable in terms of physical aspects than rural areas in Manik Urai and Kuala Pergau areas. By using the classification method in the table above, the level of Physical vulnerability can be determined as in Table 9.

Table 7: Physical vulnerability weight.

Parameters	Gua Musang	Kuala Krai	Kuala Pergau	Manik Urai	PV weight
Building	1.171	1.890	455	1.031	0.411
Road	68.629	101.984	15.047	56.192	0.288
Railways	11.445	5.407	7.742	8.074	0.185
Bridge	17	12	2	4	0.170

Flood Vulnerability Classification

To determine the vulnerability index for the entire study area, the method used is in principle the same as the method used in calculating vulnerability in the portion of the study area. Based on calculations made, a comparison of the overall vulnerability class area can be seen in the following Table 10.

While the Total Vulnerability Index in the study area is shown in Table 11. Total vulnerability is obtained by adding up all the vulnerability component indexes throughout the blood of the study.

Since the index value is known, then the vulnerability index classification is determined from the entire study area. The vulnerability was classified as Low (<33), Medium (>33 and <66), and High (>66). Based on the classification, it is

Table 8: Physical vulnerability score.

Sub-district	Building	Railways	Road	Bridge	PV Score
Gua Musang Town	481	1.945	15.647	3	18,076
Bandar Kuala krai	776	920	23,252	2	24,950
Kuala Pergau	187	1,316	3,430	0.3	4,933.3
Manik Urai	423	1,372	12,811	0.7	14,606

Table 9: Physical vulnerability class

Area	PVScore	PVLevel
Gua Musang	18.076	High
Kuala Krai	24.950	High
Dabong	4.933	Low
Manik Urai	14.606	Medium

Table 10: Vulnerability scores and vulnerability index of areas.

Parameters	Gua Musang	Kuala Krai	Kuala Pergau	Manik Urai	Weight
Social	22	26	26	26	0,541
Economy	1.00	1.04	1.08	1.13	0,241
Physical	2.25	1.75	1.00	1.00	0,211

Table 11: Total Vulnerability scores in all study areas

Parameters	Gua Musang	Kuala Krai	Kuala Pergau	Manik Urai
Social	22	26	26	26
Economy	16	51	28	41
Physical	18	24	5	14
Total	56	101	59	81

known that the Kuala Krai and Manik Urai areas are in the classification of areas with a high-level classification, while Dabong and Gua Musang are in the middle of the face in the Kelantan flooding event in 2014 (Table 12).

In terms of the economic impact at the community level, in remote rural areas, the loss of service facilities and shops can have a major impact on the community's economy. Urban areas typically see less of an economic impact than rural areas, in part because there are more options for amenities that can boost the local economy there.

The social impacts are discussed in two ways. First by direct examination of relationships between scarcity and density. Second particular social impacts indirect relationships between key demographic variables.

The population of old people is large in rural areas. Among them, mostly living alone increases flood vulnerability. Those people who migrate from urban to rural areas have less knowledge of flooding. It will also increase flood vulnerability. Migration, in general, is a key issue for both urban and rural areas.

Risk Assessment

Flood risk is defined in this study as a function of flood hazard, Flood exposure, and Flood vulnerability. The risk assessment was done based on the flood hazard model simulation results, flood exposure data, and the identified vulnerable elements at risk. Two factors were considered while the assessment i.e., the magnitude and the probability of occurrence of the risk. Flood risk assessment is calculated qualitatively according to a certain class level and then spatially presented as a Flood Risk Map.

Table 12: Vulnerability level by areas.

Area	Score	VI Level
Gua Musang	56	Medium
Kuala Krai	101	High
Dabong	59	Medium
Manik Urai	81	High

Quantitative Risk Assessment

Flood risk can be considered as the actual threat. The estimation of flood risk results either in monetary or loss of life units, if the losses are measurable, or in qualitative terms (e.g. allocation in classes) in the case of intangible damages (social, environmental, cultural) to the affected areas. However, not all the values for the quantification of risk were available.

Based on flood hazard and the flood vulnerability for the different study areas using classes the qualitative assessment of risk was performed. The risk classes were weighted according to their level of importance. Follow the equation below:

$$Flood\ Risk = \Sigma FH + \Sigma FV + \Sigma FE \qquad \ldots(6)$$

The Flood Risk value of the data processing results shown in Table 13 shows that the greatest flood risk during the Kelantan extreme floods in 2014 based on the selected study area occurred in the Kuala Krai area, especially in terms of flood vulnerability.

Based on these data, flood risk is classified according to value into 3 classes High, Moderate and Low levels. Based on the classification, the class interval was obtained from Eq. (6):

$$\text{Class Interval} = \frac{273 - 0}{3} = 91 \qquad \ldots(6)$$

The highest flood risk value is 273, the lowest flood risk is 0. Flood risk in extreme flood conditions can be classified into 3 levels Low (0 to 91), Moderate (91 to 182), and High (>182). Based on the data collected, Gua Musang comes under the class Moderate while the rest is in the class High.

Based on Table 13, it can be said that flood risk is relatively higher in the rural area compared to the urban area as shown in Fig. 7. Risk assessment refers to the tolerability estimation based on the local society's acceptability criteria. The estimated risk comparison was based on the

Table 13: Flood Risk value in the study area

	FH	FV	FE	FR
Gua Musang	41	56	69	166
Kuala Krai	68	101	123	292
Manik Urai	63	59	129	251
Kuala Pergau	71	81	121	273

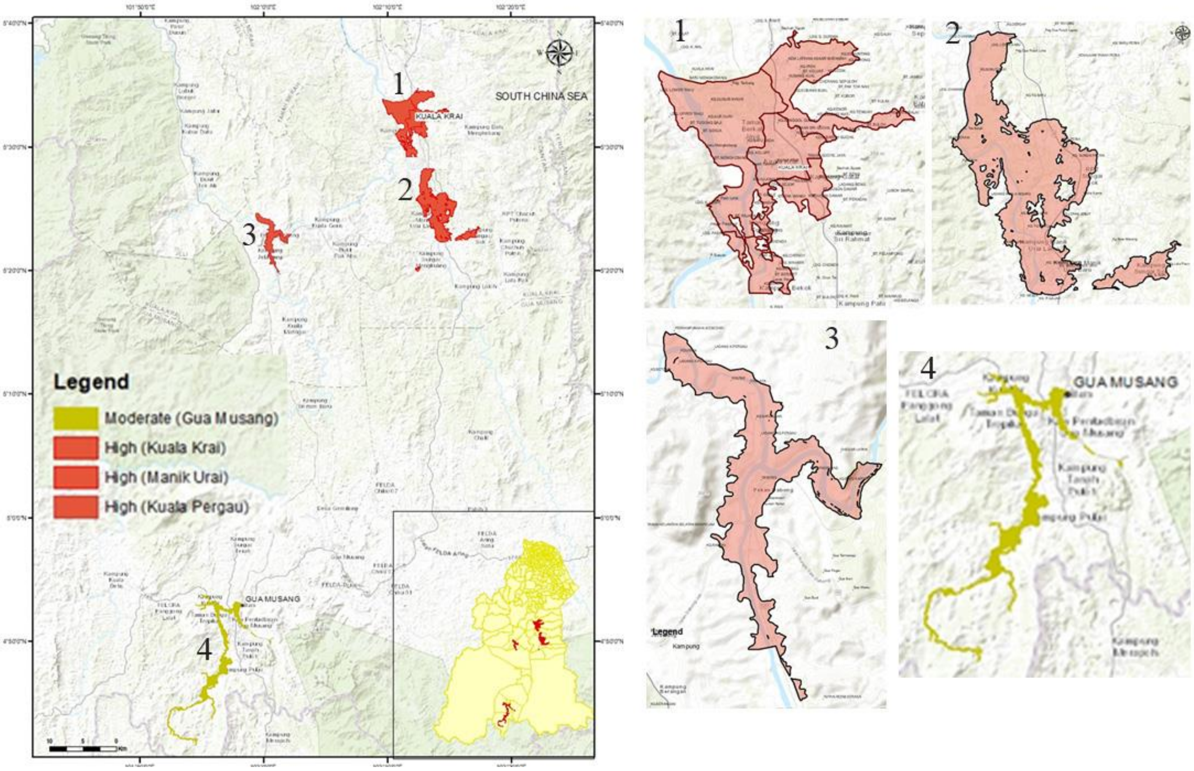

Fig. 7: Flood Risk Classes.

risk of the particular affected system and risk reduction application.

Research on economic flood impacts at the community level is lacking. As was already said, remote rural areas with little amenities and services were anticipated to have suffered greater economic losses. These setbacks further deplete rural residents' motivation to rebuild their businesses. It may also harm people's perceptions of the country as a desirable location for investments.

Before 2014, Kelantan experienced extreme flooding at least three times, in 1886, 1926, and 1967. However, because there was a lack of information at the time, it was unable to adequately prepare for the 2014 floods, which resulted in a loss of life and property. It may also be that the period between flood events is very long. The results of the survey and interviews only included one respondent who experienced severe floods in 1967. When there is extreme flooding, response actions should be expedited based on priority. This project is a methodical approach to addressing the flood issue in the field. It is vital to establish a specific value, whether it be the index, score of the extreme flood formula, or quantity, to ensure that this priority applies equally to all. All aspects of floods, including hazards, exposure, and vulnerability, should be covered by this value.

In the case of extreme flooding, deforestation is not the main factor. It can be ascertained that deforestation in Kelantan in 1967 or earlier was still at a low stage, or not yet significant, and extreme flooding occurred. The results of the analysis show that the main cause of extreme flooding in Kelantan is the high intensity of rainfall. When a flood happened, the intensity of the rainfall in some places was very high. On the slopes of Mount Gagau, rainfall intensity of up to 515 $mm.day^{-1}$ was recorded for 3 days before the flood occurred.

CONCLUSION

Three vulnerability classes such as economic, social, and physical were assessed using a questionnaire that contain 200 respondents' (flood 2014 affected people) interviews . In terms of economic vulnerability, Kuala Krai and Manik Urai are classified as High while Gua Musang and Kuala Pergau are classified as Medium. The social vulnerability which is focused on age, gender, and occupation, for all studies are classified as high. Physical vulnerability score from all areas shows Bandar Kuala Krai obtain the highest score followed by Gua Musang, Manik Urai, Kuala Perga, Kuala Krai and Bandar Gua Musang. Gua Musang Town is more vulnerable in terms of physical aspects than rural areas in this case the Manik Urai and Kuala Pergau areas. Total vulnerability is obtained by adding up all the vulnerability component indexes and the result is Kuala Krai and Manik Urai areas are in the high-level class, while Dabong and Gua Musang are in the medium class.

The risk classes were weighted according to their level of importance. The Flood Risk Value data processing results show that the greatest flood risk during the Kelantan extreme floods in 2014 based on the selected study area occurred in the Kuala Krai area, especially in terms of vulnerability. Flood risk is relatively higher in rural areas as compared to urban areas.

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