Site-Suitability Analysis on Seismic Stations using Geographic Information Systems

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Abstract

The Ranau Earthquake which took place on 5 June 2015 was captured as among the worst ever disasters in Malaysia, par with the tsunami tragedy in 2004. Apart from 18 casualties and physical damage to infrastructure, the earthquake also caused landslides, rockfalls and debris flow around Mount Kinabalu. It also caused liquefaction in the Poring Hot Spring area. Although Malaysia has seismic stations to assess local and international earthquakes, academic researchers still find the distribution of seismic stations as insufficiently dense to provide accurate information where blind spots still exist in many places, particularly in earthquake prone areas. A strategic suggestion to address these existing gaps is by installing more sensitive seismic stations in strategic areas to enhance the precision, timeliness and content of earthquake information. Therefore, this study is primarily aimed to identify the criteria used in a site-suitability analysis on seismic stations as well as to suggest strategic locations for subsequent seismic stations to be included in the local seismic monitoring network.

This study employed a GIS-based MCDA tool to create a suitability map for the placement of seismic stations in one of Malaysia's earthquake-prone locations, specifically the district of Niah Suai in Sarawak. The study's findings demonstrate GIS' capacity to combine multiple data layers with varied criteria to generate an acceptable suitability map. The acquired results were thoroughly discussed using descriptive analysis in order to meet the study objectives. The findings of this study may be used to enhance the existing technique employed by MET Malaysia in identifying suitable sites for seismic station placement. An improved seismic station network would aid MET Malaysia in delivering effective and reliable information to the National Disaster Agency for mitigation and preparation against disasters.

Keywords: GIS, MCDA, Seismic Stations, Site Suitability, Niah, Sarawak.

Introduction

An earthquake is a sudden shaking of the earth's surface caused by the movement of rocks along fault lines or above tectonic plate boundaries. Earthquakes may lead to building damage, landslides and liquefaction, destruction of roads and bridges, loss of life and if they happen near the ocean, they will generate tsunamis such as the one in Aceh, Indonesia on 26 December 2004. According to studies from the Centre for Research on the Epidemiology of Disasters (CRED) and the United Nations Office for Disaster Risk Reduction (UNDRR), earthquakes and tsunamis were the cause of the deadliest disasters in the last two decades accounting for 58 percent of total deaths[15].

Many parts of the world are vulnerable to numerous natural hazards, so successful risk reduction is only possible by recognizing and assessing all related risks[10]. Disaster risk assessment is a method of determining the existence and scope of a threat by examining risks and assessing existing vulnerabilities that when combined, might endanger people, property, services, livelihoods and the environment on which they rely. Understanding disaster risk is a priority that is emphasized on from the aspect of prevention. It is also the first priority for action in the Sendai Framework for Disaster Risk Reduction 2015-2030. By understanding disaster risk, preventive measures can be better implemented[19].

Earthquakes and Seismicity in Malaysia

Malaysia is surrounded by tectonic crusts and the occurrence of earthquakes is driven by the movement of these earth plates. Peninsular Malaysia is located on the stable Sunda Trench with low to moderate levels of seismic activity. However, some of the tremors felt on the west coast of Peninsular Malaysia are produced by large earthquakes centred in Sumatra and the Andaman Sea[1,5].

As indicated in fig.1, peninsular Malaysia also experiences few local earthquakes centred in Bukit Tinggi, Kuala Pilah, Manjung, Temenggor and Kenyir. With the exception of causing mild tremors and shaking of high-rise structures, these earthquakes which were typically less than 4 Mw in magnitude, have caused no serious damage[25].

On the other hand, Sarawak experiences quite a number of seismic events which are mainly induced by local earthquakes. The Kelawit fault and the Bukit Mersing fault, both 500 kilometres from the capital city of Kuching, provide a distant seismic risk to Sarawak, though the ground motions predicted from these fault sources have been extremely minor[11]. Between 1874 and 2011, Sarawak had 21 seismic events with a maximum Modified Mercalli Intensity (MMI) rating of VI and magnitudes ranging from 3.5 to 5.3 Mb. This data shows a prediction that an earthquake with a magnitude of up to 5.3 may occur in the said area every 6-7 years[2].

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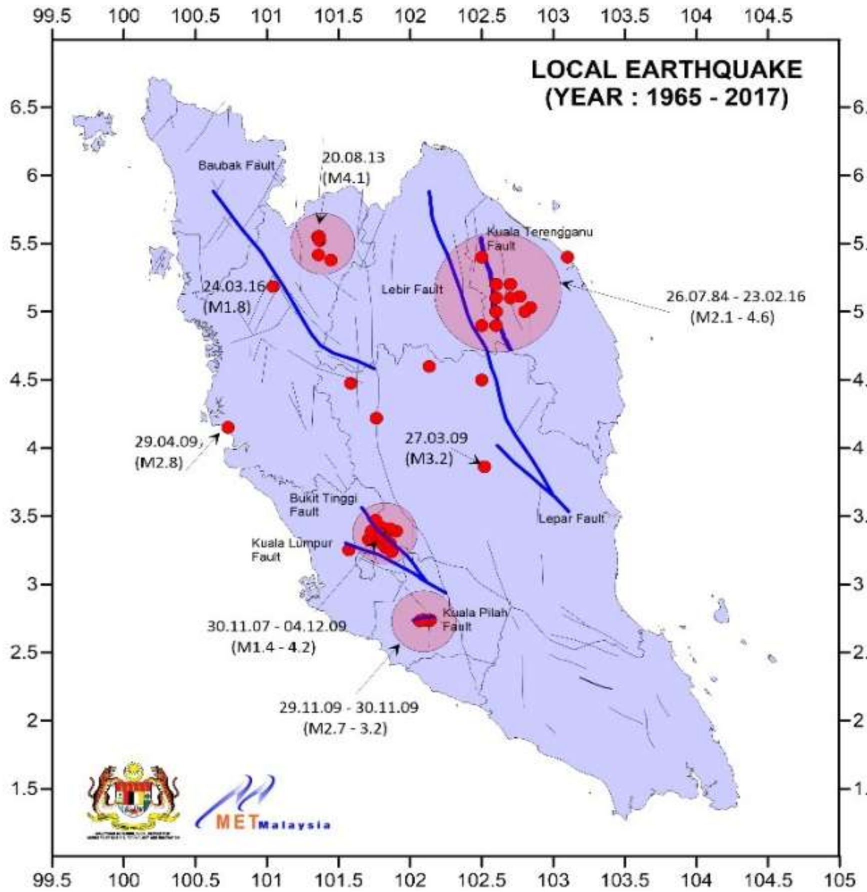

Fig. 1: History of Earthquakes in Peninsular Malaysia[4]

In addition to earthquakes of local origin, Sarawak has also been hit by long-distance earthquakes originating from the southern Philippines, Straits of Macassar, Sulu Sea and Celebes Sea. These distant earthquakes had a maximum strength of V on the MMI scale in Sarawak[5]. The distribution of local earthquakes in Sarawak is shown in fig. 2 where most of them had occurred between Niah and Selangau[25].

Sabah has a dynamic seismotectonic setting with local major fault lines including the Jerudong Fault, Belait Fault, Mulu Fault, Mensaban Fault, Crocker Fault and Pegasus Tectonic Line as well as proximity to active regional faults in the Sulu Sea and Celebes Sea. In terms of area, Kundasang and Ranau are most prone to seismic activities in Sabah as they lay on the active Mensaban and Lobou-Lobou fault zones (Fig. 2). Earthquakes emanating from these faults have caused minor infrastructure damage thus far[17]. To date, there were about 65 weak to moderate local earthquakes recorded in Sabah from 1973 to December 2015 based on the United States' Geological Survey (USGS) database. From these, the 1976 Lahad Datu Earthquake (magnitude of 5.8 Mb), 1991 Ranau Earthquake (magnitude of 5.4 Mw), 2008 Kunak Earthquake (magnitude of 5.0 Mw) and 2015 Ranau Earthquake (magnitude of 6.0 Mw) had caused heavy damage to buildings[25].

Among these four, the 2015 Ranau Earthquake was captured as among the worst ever disasters hitting Malaysia after the tsunami tragedy in 2004. Apart from the 18 casualties and physical damage caused to infrastructure, the earthquake also caused landslides, rock falls and debris flow around Mount Kinabalu and liquefaction in the Poring Hot Spring area[24].

The combination of seismological data and geological conditions in Malaysia has resulted in the production of the National Seismic Hazard Map in 2017 by the Department of Mineral and Geoscience Malaysia (JMG). According to the research done, Sabah has the widest range in projected peak ground acceleration (PGA) value (within 1 – 16.5 percent) in Malaysia. In Sabah, the places with PGA values more than 12% g (0.12g) include Lahad Datu, Ranau and Kudat. The highest projected PGA value in Sarawak is 9 -10 percent g (0.09 – 0.1 g) which was found for the Niah region.

Meanwhile, the highest projected PGA Value in Peninsular Malaysia is 9 percent g (0.09g) which was found for Bukit Tinggi, Pahang and Manjung, Perak (JMG). The geological features (fault lines) and seismic hazard areas found in Malaysia are shown in fig. 3.

Malaysian Tsunami Early Warning System (MNTEWS)

MNTEWS was established in 2005 by the Malaysian Meteorological Department (MET Malaysia) with the support of the Ministry of Science, Technology and

Innovation (MOSTI). Its establishment was triggered by the devastating Indian Ocean earthquake-tsunami which occurred on 26 December 2004 and had claimed 68 lives in addition to a RM100 million loss and damage of property in Malaysia.

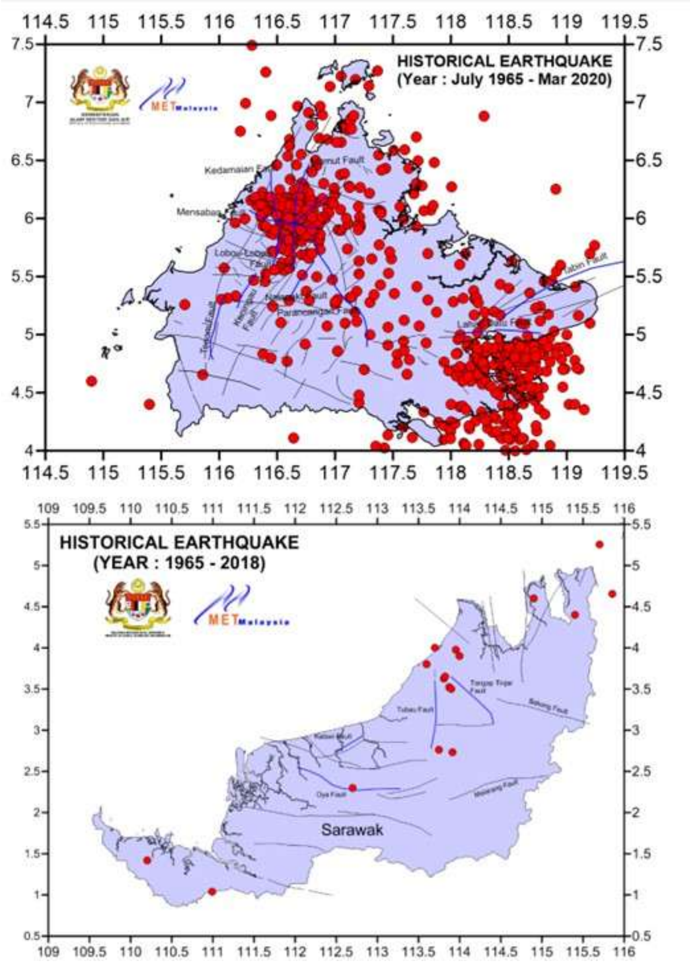

Fig. 2: History of Earthquakes in Sabah and Sarawak[4]

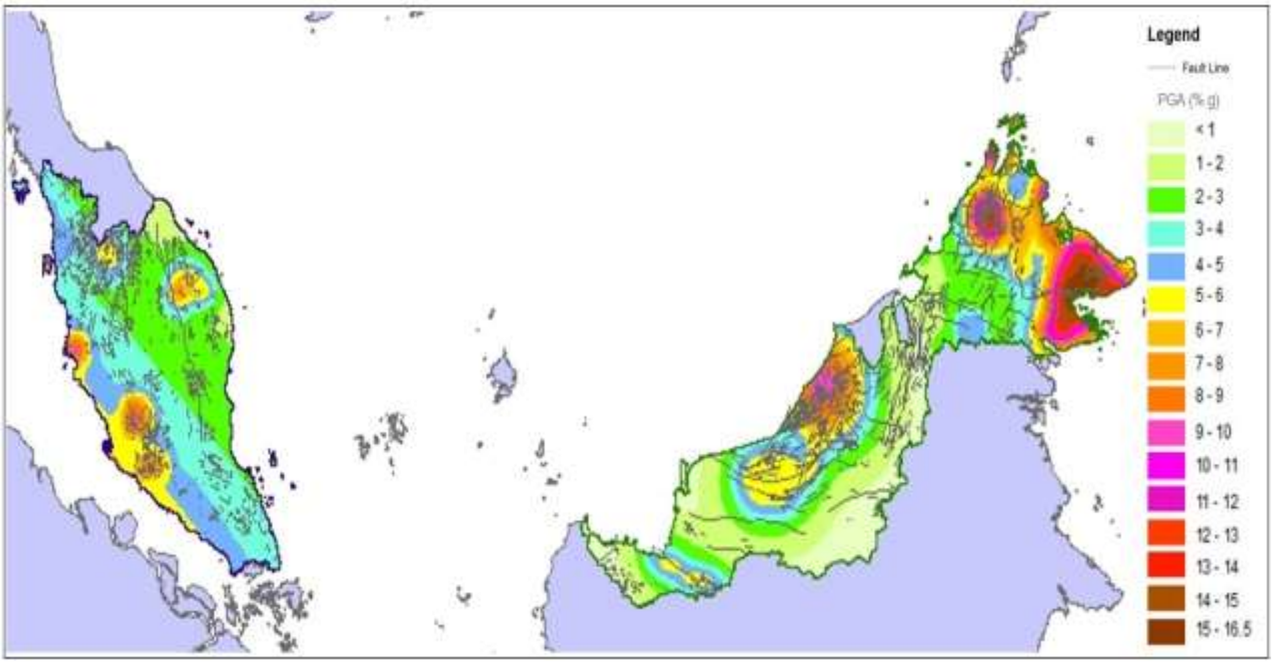

Fig. 3: Geological Features (Fault Lines) and Seismic Hazard Areas in Malaysia (Modified from the Seismic Hazard Map of Malaysia and the Geological Map of Sabah, Sarawak and Peninsular Malaysia by JMG)

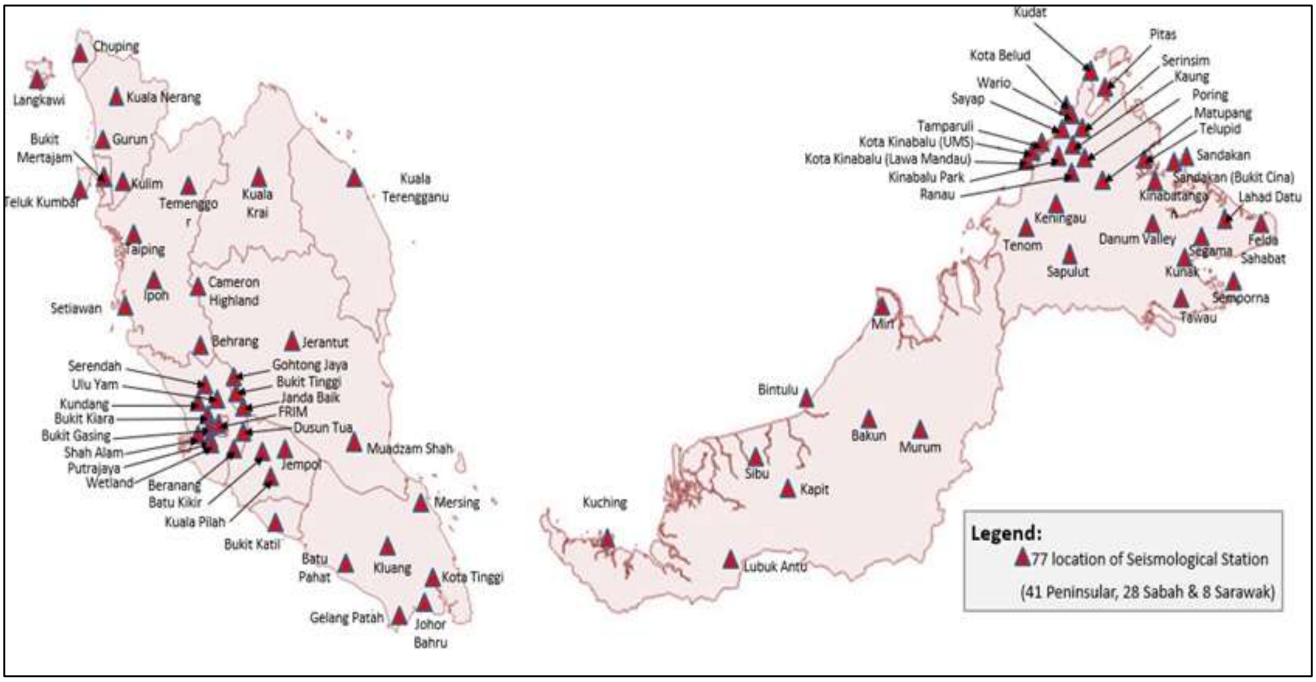

Fig. 4: Malaysian National Seismic Network (MET Malaysia)

Table 1
Offsite Studies On Site Selection Process[20,26]

Site Selection - Offsite Studies	
Criteria	**Preliminary Site Evaluation**
Definition of geographic region of interest	- Use of geological maps to examine major tectonic faults and seismotectonic maps in order to determine seismotectonic characteristics.
Seismo-geological considerations	- Both seismic signal and noise level at stations are affected by underground conditions. - The greater the bedrock's acoustic impedance, the lower the seismic noise and the higher the station's maximum potential gain.
Topographical considerations	- Seismic waveforms and signal amplitudes may be influenced unexpectedly by incredibly steep mountain slopes or deep valleys. - Wind-generated seismic noise, lightning strikes and icing of communications equipment are all common hazards on mountain peaks. As a result, this site should be avoided.
Station access considerations	- Seismic stations are often situated in remote places, as far away from human activities as feasible. - Find a suitable balance between remoteness and accessibility. If the location is too difficult to reach, it will be costly to set up and maintain.
Evaluation of seismic noise sources	- Evaluate the site's actual distance from significant seismic noise sources.
Seismic data transmission and power considerations	- Look for a topography that allows for dependable direct radio frequency communication between the remote station and the central recording location. - Determine line availability and the lengths across which additional lines must be placed. - If main power is not accessible on site, the distance and cost of additional power lines must be calculated.
Land ownership and future land use	- The land's long-term development strategy must be assessed.
Climate considerations	- Data such as precipitation, wind, solar and temperature levels of a site must be collected from a meteorological institution.

The MNTEWS is comprised of three major components: (i) Data and Information Collection Component, (ii) Processing and Analysis Component and (iii) Dissemination Component. The seismic network is a sub-system of data and information collection in MNTEWS[3]. MNTEWS currently has a broad seismic network used to assess local or international earthquakes. This network relies on a total distribution of 77 seismic stations throughout Malaysia[12] (Fig. 4).

However, this distribution of seismic stations is insufficiently dense to provide accurate information, as blind spots still exist in many places, particularly in earthquake prone areas. A strategic suggestion for addressing the existing gaps is by installing more sensitive and accurate seismic stations in strategic areas to enhance the precision, timeliness and content of earthquake information[25].

Site Selection for Seismic Stations

Considering the risk of local earthquakes in Malaysia and far-field sources of earthquake risk from neighbouring countries such as Indonesia and Philippines, research and development on better earthquake monitoring has always remained a priority. The first way to ensure that the seismic monitoring system operates at its most optimum efficiency is to choose the best location for seismic sensor installations. The ability of modern seismic network technologies to detect earthquake events and record incident waveforms is affected by signal characteristics and noise frequency in the region. If the noise level in the region where the seismic network is installed is too high, the benefits of high-tech infrastructure would be missed.

A high trigger threshold would be expected if the noise produces extreme spikes or other transitions, or if there is man-made seismic noise, resulting in low network detection[26]. Therefore, appropriate site selection procedures need to be performed to ensure the effectiveness of new earthquake stations or network. Several criteria for the selection of suitable locations for seismic stations[20,26] are depicted in table 1. Meanwhile, the following criteria were presented in certain publications for the assessment of seismic station site suitability[21,22]:

i. Land Use/Land Cover: Land near to sources of noise is deemed less suitable.
ii. Topographic Characteristics: Locations with varying topography are more suitable.
iii. Slope Map and Slope Aspect: Lower slope locations are ideal for station placement.
iv. Geological Characteristics: The placement of seismic stations near fault lines is seen to be most suitable.
v. Geophysical Data:
- Gravity Data: Seismic stations are considered more suitable to be situated in areas with shallower basement depths.
- Seismic Data: Locations with higher magnitude earthquakes of deeper hypocentral depths are considered as suitable sites for seismic stations.

The use of geospatial technology for site-suitability analysis: Land-use suitability mapping and analysis are the most valuable uses of GIS in planning and management. The purpose of the site search study is to define the site's optimal boundaries. Both the site search problem and land suitability analysis imply that the research region is split into a set of fundamental units of observations such as polygons (areal units) or rasters.

The challenge of land suitability analysis entails categorising units of data based on their appropriateness for certain activities. The explicit site search analysis not only evaluates the appropriateness of the site, but also its spatial qualities such as its form, contiguity and compactness by adding the fundamental observational units in accordance with certain criteria[13]. GIS technology delivers bigger and better data for decision-making scenarios. With the overlay process, it allows decision-makers to select a list that meets a predetermined set of criteria and the multi-criteria decision analysis (MCDA) inside GIS is used to design and assess alternative plans that may facilitate compromise amongst interested parties[16].

The site selection process for the development of seismic stations is a complicated process and its complexity necessitates a site selection method by specialists involving the simultaneous examination of numerous variables. An example of the use of GIS-based site-suitability modelling for seismic stations' employment (Fig. 5) was portrayed in a study on seismic site selection approach conducted in northern Rahat, a volcanic zone of Saudi Arabia. The GIS was utilised in conjunction with the MCDA to create a suitability map for seismic station installations. The findings demonstrated GIS' capacity to combine several data layers with numerous criteria to generate a realistic suitability map[22].

Study Area

The aim of this study is to suggest strategic locations for future seismic stations to be included in the seismic monitoring network. A case-study approach was chosen to provide rounded and detailed illustrations of the research in order to achieve the study objectives. Therefore, in the preliminary study conducted to identify the study area, the researchers used the ArcGIS 10.8 application to integrate all information regarding the epicenter of historical earthquakes (Fig. 1 and Fig. 2), fault line regions and seismic hazard maps (Fig. 3), as well as current seismic station locations (Fig.4) into a single map of Malaysia.

In regards to the analysis, it was determined that Sarawak has a lower density of seismic stations than Peninsular Malaysia and Sabah and thus, is a suitable location for the establishment of additional seismic stations.

In order to determine the suitability of a seismic station site, the Niah Suai sub district was chosen as the study area (Fig. 6) for this research due to the frequency of earthquakes in the area as well as high PGA values ranging from 8 to 10 in the Niah region.

Material and Methods

The selection criteria were established based on a review of literature on seismic station site selection. The criteria for selecting seismic station locations are divided into three categories[22]: (i) general which includes network geometry and seismic data transmission; (ii) natural resources which include seismic-geological conditions, seismic noise, topography and climatic condition; and (iii) realisation resources which include the ability to realise the project. The main criteria influencing the site selection process are described in table 2 based only on the data provided in this study.

Data analysis for this study was performed using ArcGIS Version 10.8. Seven site suitability criteria for seismic stations were used to analyse the chosen sites and these sites were classified into different classes which are Class 1: Most Suitable, Class 2: Suitable, Class 3: Moderately Suitable, Class 4: Less Suitable and Class 5: Extremely Less Suitable. The Natural Breaks (Jenks) classes were utilised in this study based on natural groups found in the data according to slope, elevation, earthquake magnitude and epicentral depth criteria, while manual classification methods were used to set the buffer distance for fault line and land use data.

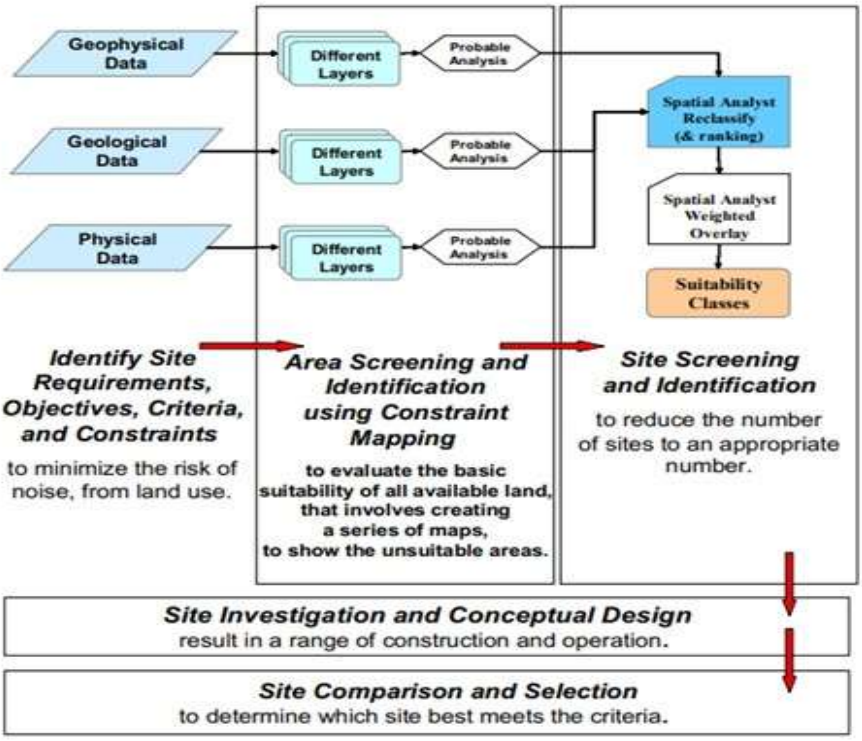

Fig. 5: Flow process of the GIS-MCDA method for seismic station site suitability[22]

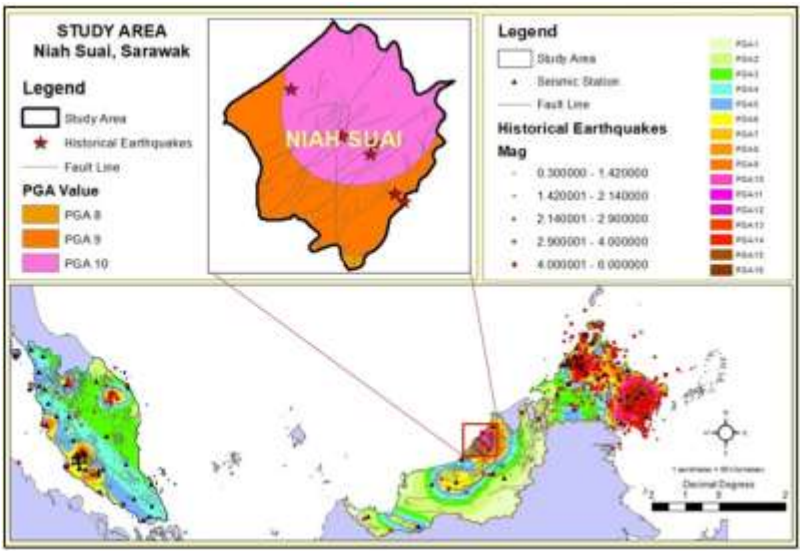

Fig. 6: Study Area

Table 2
Criteria for the site-suitability analysis of seismic stations.

S.N.	Criterion	Description
1	Slope (degree)	Lower-slope locations are ideal for station placement. Slopes facing towards the sun are preferable since the seismic station placed can be powered by solar panels.
2.	Elevation (m)	The highest mountains and deepest valleys are classified as poor suitability classes, while the second highest and second lowest elevation values are classified as other classes and so on, until reaching a moderately changing topography which is the most suitable class for seismic station installation.
3.	Earthquake Magnitude	Locations with higher-magnitude earthquakes are considered as suitable sites for the placement of seismic stations.
4.	Epicentral Depth (km)	Locations with deeper hypocentral depths are considered as suitable sites for the placement of seismic stations.
5.	Sediment	Based on the geological map of Sarawak, the sediment in the Niah Suai area is mostly of shale and sandstone types. Therefore, classification of the sediment was based on their acoustic impedance or bedrock quality grade.
6.	Fault (buffer km)	The placement of seismic station(s) near fault lines (a possible source of earthquakes) is seen to be the most suitable. Therefore, it is proposed that a buffer zone be constructed within the fault region.
7.	Land Use	- Areas close to main roads and land use features are deemed permanently unsuitable, while those further away are deemed the most acceptable. - Proposed buffer zone: 1 km for roads, rivers, residential areas, villages and towns and industrial and retail areas. Subsequent buffer zones are assigned consecutively at 1 km intervals.

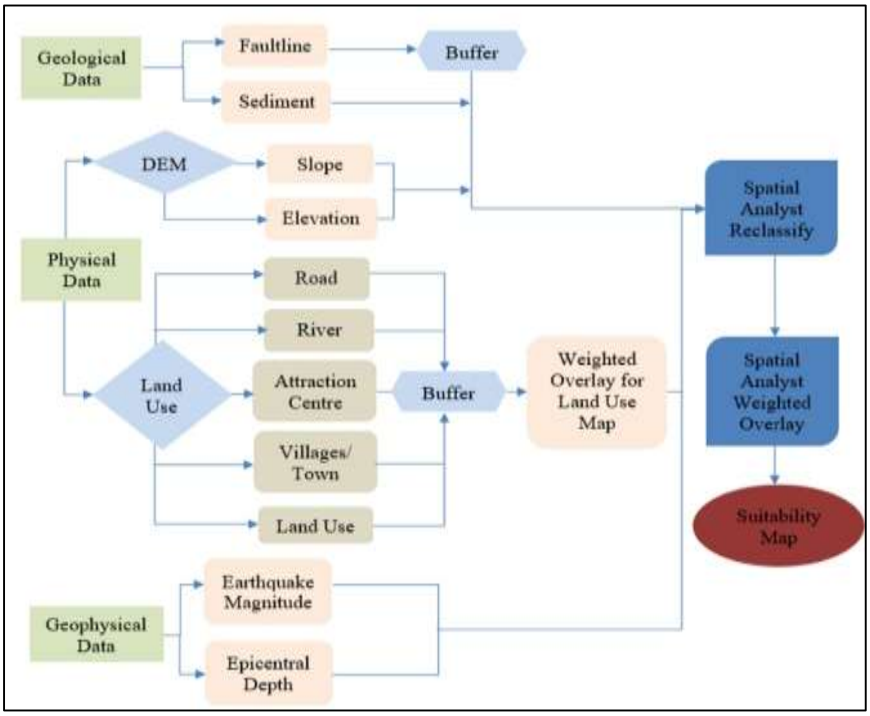

Fig.7: Flow chart of the MCDA processes for seismic station site suitability

The suitability map for this study was created using the GIS-based MCDA technique. Integrating GIS into the MCDA is another effective method for assessing land suitability as the GIS application allows for the determination of criteria while MCDA combines them into a suitability index. The flow chart of the MCDA processes for seismic station site suitability is shown in the fig. 7. The weight of each criterion was calculated based on its relative relevance and the preferences of decision-makers or professionals in determining which site best meets their requirements. The degree of effectiveness function for each suitability class is denoted by the following equation:

$$E = W_f \,.\, R_f \quad (1)$$

Results and Discussion

Results of Data Analysis: The main findings of this study are depicted in the form of maps. Seven maps were created as a result of the data analysis. The findings for each of the criterion considered in selecting a suitable location for the establishment of seismic stations are listed and shown on the derived maps below.

i. Slope: The slope criterion is important in seismic station site selection. According to earlier research, lower slope areas are preferable for station installations. From the findings (Fig. 8), 43 percent of the research region has a gradient degree of less than 3.84°, indicating the best level of seismic station site suitability.

ii. Elevation: For the elevation criterion, site locations with sufficiently variable topography are more suitable as locations of seismic stations. From the analysis (Fig. 9), 42 percent of the study area is located in moderately changing topography, with 9 percent in the most suitable region, 12 percent in the suitable region and 21 percent in the moderately suitable region.

iii. Earthquake Magnitude: Locations of earthquakes with higher magnitudes are considered the most suitable areas to build seismic stations. From the analysis (Fig. 10), 11 percent of the study region is located in most suitable areas, 18 percent in suitable areas and 51 percent is located in moderately suitable areas.

iv. Epicentral Depth: Deep hypocentral depth is considered best for seismic station placement. The analysis (Fig. 11) showed that 27 percent of the study area is located in the most suitable region, 28 percent in the suitable region and 26 percent in the moderately suitable region.

v. Fault Lines: The placement of seismic stations near fault lines is seen to be most suitable. Hence, to determine the site suitability class for the fault line criterion, fault buffers (using Euclidean Distance tools) were delineated with an interval of 1km for each class, with class 1 representing the most suitable area and class 5 as the least suitable area. From the data analysis (Fig. 12), it was found that 41 percent of the study area is located within less than 1 km from the fault line.

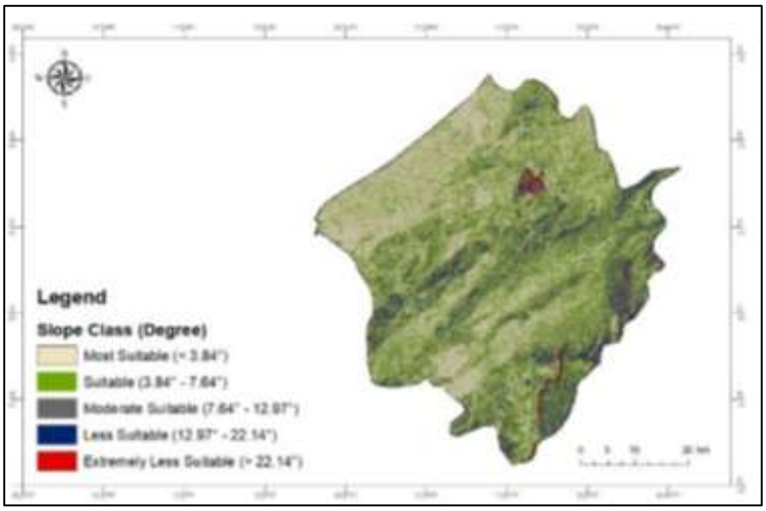

Fig. 8: Slope Class Map of the Study Area

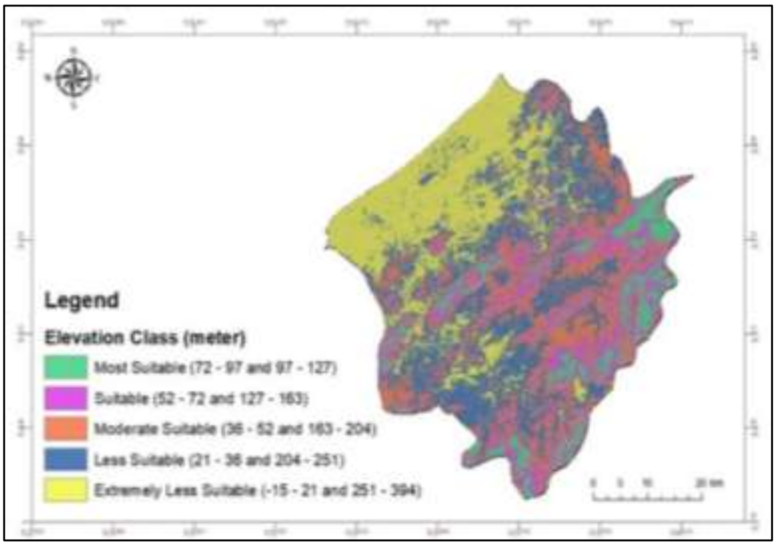

Fig. 9: Elevation Class Map of the Study Area

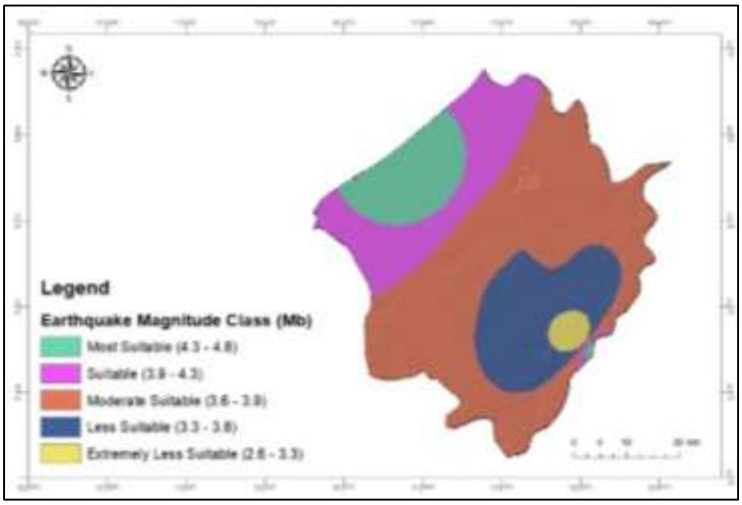

Fig. 10: Earthquake Magnitude Class Map of the Study Area

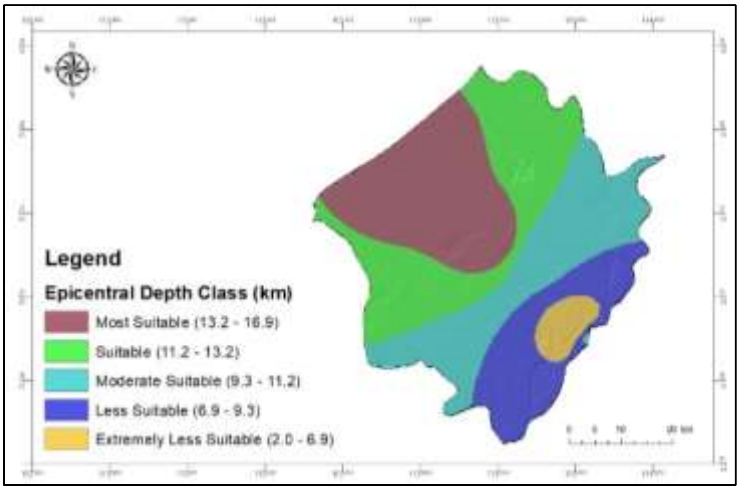

Fig. 11: Epicentral Depth Class Map of the Study Area

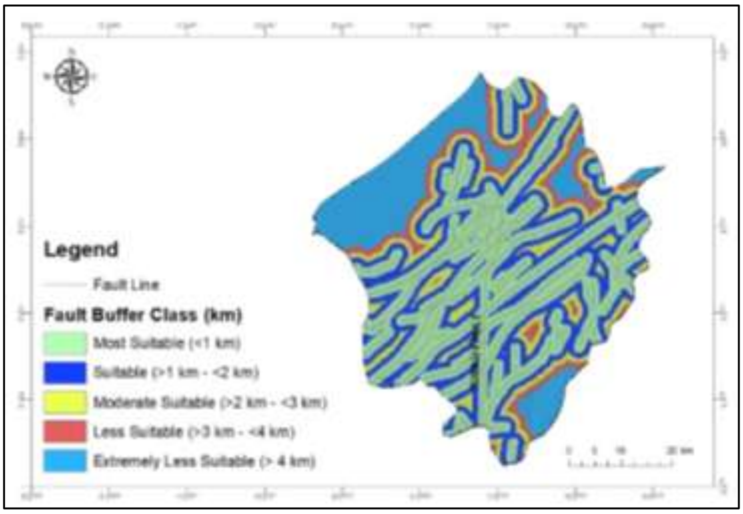

Fig. 12: Fault Buffer Class Map of the Study Area

vi. Sediment: The classification of different types of sediments is made by referring to the New Manual of Seismological Observatory Practice 2 (NMSOP-2). From the analysis made (Fig.13), only 1 percent of the area is made of limestone or calcareous types of sediment. This type of sediment is located in the area of the Niah National Park and considered as the most suitable site for seismic station placement.

vii. Land Use: The land use criterion considers locations away from noise sources as these might interfere with seismic sensor readings. As a result of the data analysis

(Fig.14), it was discovered that 50 percent of the region surrounding Niah Suai is classified as a restricted area and 0 percent is classified as extremely less suitable.

viii. Site Suitability Map for Seismic Station Placement: Each of the criterion has been allocated with different weights (W_f) based on its influence, degrees of effectiveness (E) and average rates (R_f), as indicated in table 3. The weights for the seven criteria considered were defined and calculated based on previous research and professional recommendations. To create a site suitability map for the placement of seismic stations, the seven criterion layers were converted into a same size map with a dimension of 30 metre × 30 metre pixels before been integrated using a weighted overlay tool.

The final result in the form of a seismic station site suitability map is displayed in fig. 15. From the analysis, six suitability classifications for seismic station placement were included as shown in table 4. Approximately 50 percent of the study area is considered restricted, while the rest of the area is classified as follows: most suitable areas (21%), suitable areas (16%), moderately suitable areas (8%), less suitable areas (3%) and extremely less suitable areas (1%).

ix. Optimum Sites for Seismic Station Placement: The researchers utilized ArcToolbox> Spatial Analyst Tool> Conditional> Con to highlight the areas that are most suitable for seismic station placement [areas assigned a Class 1 value (21%) on the Site Suitability Analysis and Classification table] (Table 4). The output map for optimal sites is shown in fig. 16.

Sites in the optimum areas (Fig. 16) are considered as the most suitable locations for seismic station placement. However, many criteria must be considered in this study including accessibility (roads), electrical facilities which enable the seismic monitoring system operations, telephone line facility (Streamyx) to enable seismic data transmission, a flat surface to build the seismic station(s), good satellite and solar panel exposure, safety and land ownership. This is to ensure that the transmission of seismic data can go smoothly without difficulties or interruptions.

The map of the optimal location (Fig. 16) was then overlaid with a Google Earth base map to clearly indicate the land use characteristics around the study area. The results of the analysis (Fig. 17) show that agricultural regions make up the majority of areas designated as optimum. Thus, the researchers propose the region highlighted with a red box be chosen as the location for the placement of a seismic station since it is adjacent to an area with infrastructural facilities as it is located near the Sepupok and Batu Niah Towns.

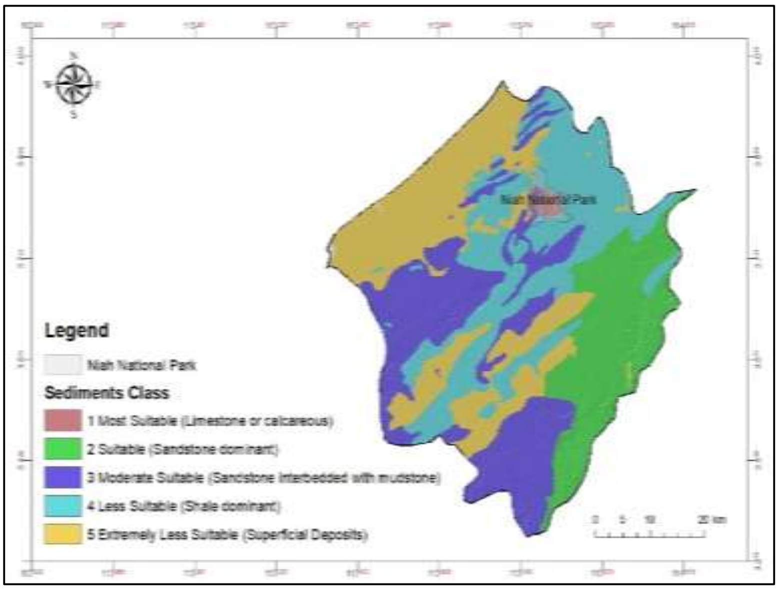

Fig. 13: Sediment Class Map of the Study Area

Table 4
Site Suitability Analysis and Classification

Class	Suitability	Percentage (%)
Class 0	Restricted	50
Class 1	Most Suitable	21
Class 2	Suitable	16
Class 3	Moderately Suitable	8
Class 4	Less Suitable	3
Class 5	Extremely Less Suitable	1

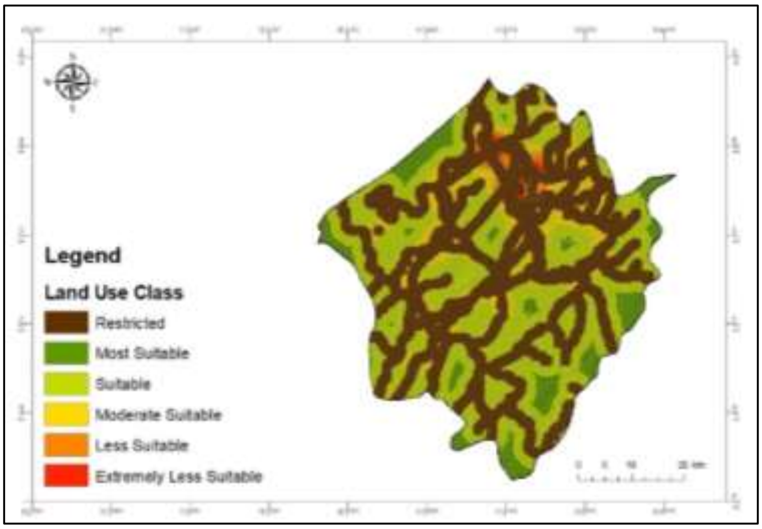

Fig. 14: Land Use Class Map of the Study Area

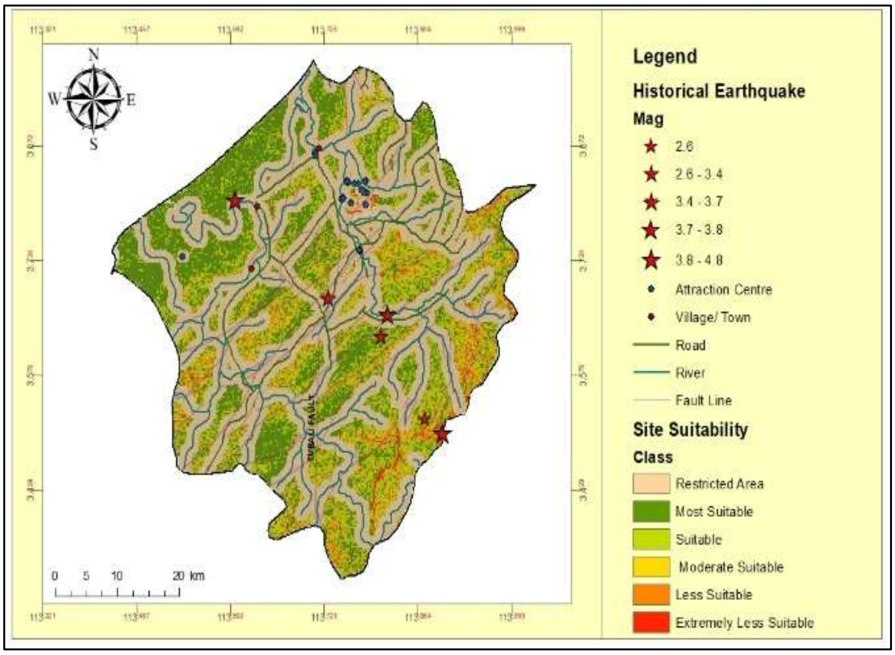

Fig. 15: Site Suitability Map for Seismic Station Placement

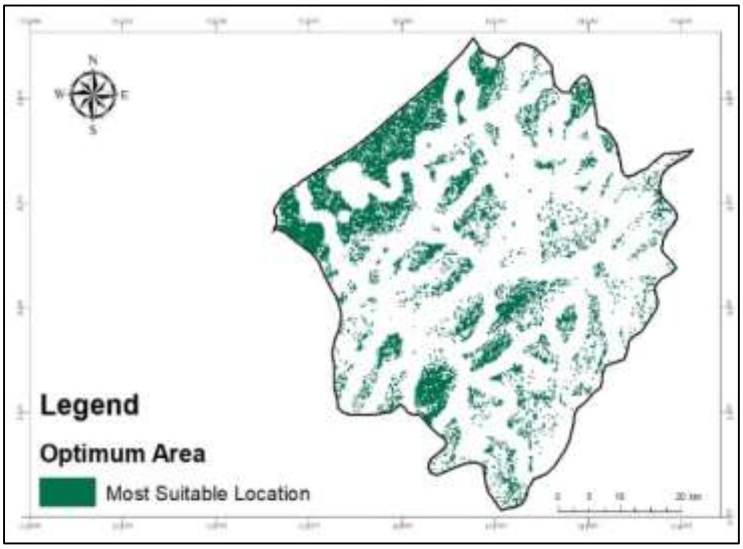

Fig. 16: Output map for the optimal location of seismic station(s)

Table 5
Class ranks and assigned weights for each criterion layer

S.N.	Criterion	Class Weightage	Class	Class value range	Average Rank (R_f)	Weight (W_f)	Degree of Effectiveness (E) $E = R_f \times W_f$	Rank (Reclassify)
1	Slope (degree)	20%	Most Suitable	< 3.837531°	90	0.2	18	1
			Suitable	3.837531° - 7.635612°	70	0.2	14	2
			Moderately Suitable	7.635612° - 12.967572°	50	0.2	10	3
			Less Suitable	12.967572° - 22.137568°	30	0.2	6	4
			Extremely Less Suitable	22.137568° - 71.547112°	10	0.2	2	5
2	Elevation (m)	18%	Most Suitable	72 - 97 and 97 - 127	90	0.18	16.2	1
			Suitable	52 - 72 and 127 - 163	70	0.18	12.6	2
			Moderately Suitable	36 - 52 and 163 - 204	50	0.18	9	3
			Less Suitable	21 - 36 and 204 - 251	30	0.18	5.4	4
			Extremely Less Suitable	-15 - 21 and 251 - 394	10	0.18	1.8	5
3	Earthquake Magnitude	15%	Most Suitable	4.3342 - 4.799881	90	0.15	13.5	1
			Suitable	3.937509 - 4.3342	70	0.15	10.5	2
			Moderately Suitable	3.670174 - 3.937509	50	0.15	7.5	3
			Less Suitable	3.351096 - 3.670174	30	0.15	4.5	4
			Extremely Less Suitable	2.600833 - 3.351096	10	0.15	1.5	5
4	Epicentral Depth (km)	15%	Most Suitable	> 13.160208 - 16.898649	90	0.15	13.5	1
			Suitable	11.232575 - 13.160208	70	0.15	10.5	2
			Moderately Suitable	9.304942 - 11.232575	50	0.15	7.5	3
			Less Suitable	6.910003 - 9.304942	30	0.15	4.5	4
			Extremely Less Suitable	2.003299 - 6.910003	10	0.15	1.5	5
5	Fault (buffer km)	12%	Most Suitable	< 1	90	0.12	10.8	1
			Suitable	> 1 - < 2	70	0.12	8.4	2
			Moderately Suitable	>2 - < 3	50	0.12	6	3
			Less Suitable	> 3 - < 4	30	0.12	3.6	4
			Extremely Less Suitable	> 4	10	0.12	1.2	5
6	Sediments	12%	Most Suitable	Limestone or calcerous	90	0.12	10.8	1
			Suitable	Sandstone dominant	70	0.12	8.4	2
			Moderately Suitable	Sandstone interbedded with mudstone	50	0.12	6	3
			Less Suitable	Shale dominant	30	0.12	3.6	4
			Extremely Less Suitable	Superficial Deposits	10	0.12	1.2	5
7	Land Use	8%	Most Suitable	6th Buffer (1km)	90	0.08	7.2	1
			Suitable	5th Buffer (1km)	70	0.08	5.6	2
			Moderately Suitable	4th Buffer (1km)	50	0.08	4	3
			Less Suitable	3rd Buffer (1km)	30	0.08	2.4	4
			Extremely Less Suitable	2nd Buffer (1km)	10	0.08	0.8	5
			Restricted	1st Buffer area: 1km for residential, industrial and retail areas, roads, rivers, attraction areas, villages and towns.				0

Fig. 17: Site suggestion for seismic station placement in Niah Suai, Sarawak

The Niah Suai District[14] has a total area of 2887.2 km^2 with 57.3 percent of it comprising of agricultural regions such as oil palm (1545.08 km^2), swamp paddy (60.70 km^2), hill paddy (38.13 km^2) and pepper (9.68 km^2). So, despite the fact that 21 percent of the area included in the Site Suitability Map for Seismic Station Placement (Fig. 15), it is classified as most suitable. Only a few areas around major towns in the Niah Suai district were considered due to their strategic location and proximity to facilities that meet the criteria for seismic station installation. This research is the initial stage in determining the suitability of location for the establishment of seismic stations after taking into account key criteria in site selection such as geological features of the region, earthquake risk and land use impact factors around the study area.

The results of this study can be used by relevant agencies, especially MET Malaysia to conduct comprehensive investigation on the selected areas such as conducting ambient noise measurements in the proposed locations to determine the source of seismic noise in the area and ensure that the chosen location has adequate infrastructural facilities for effective seismic data transmission.

Conclusion

This study employed a GIS-based MCDA tool to create a suitability map for the placement of seismic stations in one of Malaysia's earthquake-prone locations, specifically the district of Niah Suai in Sarawak. The study's findings demonstrate GIS' capacity to combine multiple data layers with varied criteria to generate an acceptable suitability map. GIS is a valuable tool for resolving such challenges since it provides an unbiased technique as well as the capacity to optimize and modify relevant variables.

According to the findings, 45 percent of the studied region are classified as suitable locations for seismic station installation (most suitable, suitable and moderately suitable classes), while 50 percent were identified as restricted areas and the remaining 5% are less suitable locations. This research is intended to meet the goals of the Sendai Framework Disaster Risk Reduction Priorities 1 and 2 which are to better understand disaster risk and enhance disaster risk governance in the country. By knowing the risks of earthquakes in our region, we can further develop and enhance the existing system of seismic monitoring with the main purpose of reducing the risk of earthquake disasters, property damage and earthquake mortality. The enhancement of seismic monitoring network would provide major benefits to the emergency response and recovery team in dealing with earthquake disasters. With appropriate information, decision-makers can develop successful mitigation plans to reduce the impact of earthquakes as well as strengthen the country's resilience.

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References

1. Adnan A., Marto A. and Irsyam M., Seismic hazard assessment for peninsular Malaysia using Gumbel distribution method, *Jurnal Teknologi*, **42(B)**, 57-73 **(2005)**

2. Adnan A., Ramli M.Z. and Abd Razak S.M., Disaster Management and Mitigation for Earthquakes: Are We Ready?, In 9th Asia Pacific Structural Engineering and Construction Conference, 34-44 **(2015)**

3. Chai M.F., Abdul Wahab A., Mohd Khalid N., Hashim N.H., Noordin M.N. and Che Abas M.R., Tsunami Databases for the National Tsunami Early Warning Centre of Malaysia: Toward the Implementation Plan of Regional Tsunami Watch Providers (RTWP), In: Malaysian Meteorological Department, MMD and MOSTI **(2009)**

4. Chai M.F., Risiko Dan Sistem Pemantauan Gempa Bumi Di Gunung Kinabalu, Program Memperingati Gempa Bumi Gunung Kinabalu 05 Jun 2015 https://www.facebook.com/SbhParks/videos/636461027755497 **(2021)**

5. Che Abas M.R., Earthquake Monitoring in Malaysia, Seismic Risk Seminar Malaysia **(2001)**

6. JMG, Geological Map of Sarawak, Third Edition **(2013)**

7. JMG, Geological Map of Peninsular Malaysia, 9th Edition **(2014)**

8. JMG, Geological Map of Sabah, 4th Edition **(2015)**

9. JMG, The Seismic Hazard Map of Malaysia, First Edition **(2017)**

10. Kappes M.S., Keiler M., Elverfeldt K. and Glade T., Challenges of Analyzing Multi-Hazard Risk: A Review, *Nat Hazards*, DOI: 10.1007/s11069-012-0294-2 **(2012)**

11. Looi D.T., Tsang H.H., Hee M.C. and Lam N.T., Seismic Hazard and Response Spectrum Modelling For Malaysia and Singapore, *Earthq. Struct*, **15(1)**, 67-79 **(2018)**

12. Malaysian Meteorological Department (MET Malaysia), Ministry of Energy, Science, Technology, Environment & Climate Change, Annual Report **(2017)**

13. Malczewski J., GIS-based Land-Use Suitability Analysis: A Critical Overview, *Progress in Planning*, **62(1)**, 3-65 **(2004)**

14. Miri Division Administration, https://miri.sarawak.gov.my/page-0-0-205-Pejabat-Daerah-Kecil-Niah.html **(2021)**

15. Mizutori M. and Guha-Sapir D., Human Cost of Disasters: An Overview of the Last 20 years (2000-2019), Centre for Research on the Epidemiology of Disasters (CRED) and United Nations Office for Disaster Risk Reduction (UNDRR), Belgium and Switzerland **(2020)**

16. Norhisham M.N. and Roslee R., Geohazard Assessment in the Kota Kinabalu area, Sabah, Malaysia, In Journal of Physics: Conference Series, 13581, 012068, IOP Publishing **(2019)**

17. Harith N.S.H., Adnan A., Tongkul F. and Shoushtari A.V., Analysis on Earthquake Databases of Sabah Region and Its Application for Seismic Design, *International Journal of Civil Engineering and Geo-Environmental*, **8**, 1-5 **(2017)**

18. PLANMalaysia (Jabatan Perancangan Bandar Dan Desa), Kementerian Perumahan Dan Kerajaan Tempatan, Pembangunan Dan Pengurusan Di Kawasan Berisiko Bencana Gempa Bumi **(2018)**

19. PLAN Malaysia (Jabatan Perancangan Bandar Dan Desa), Kementerian Perumahan Dan Kerajaan Tempatan, Garis Panduan Perancangan (GPP) Bandar Berdaya Tahan Bencana di Malaysia (Disaster Resilient City) **(2019)**

20. Plenkers K., Husen S. and Kraft T., A Multi-Step Assessment Scheme For Seismic Network Site Selection In Densely Populated Areas, *Journal of Seismology*, **19(4)**, 861-879 **(2015)**

21. Qaddah A.A. and Abdelwahed M.F., GIS Spatial Modeling in Site Suitability for Seismic Station: Case Study of Harrat Al-Madinah. Vorisa Scientific Meeting, 17–18 **(2013)**

22. Qaddah A.A. and Abdelwahed M.F., GIS-Based Site-Suitability Modeling for Seismic Stations: Case Study of The Northern Rahat Volcanic Field, Saudi Arabia, *Computers and Geosciences*, **83**, 193-208 **(2015)**

23. Stabile T.A., Iannaccone G., Zollo A., Lomax A., Ferulano M.F., Vetri M.L.V. and Barzaghi L.P., A Comprehensive Approach For Evaluating Network Performance, *In Surface And Borehole Seismic Monitoring Geophysical Journal International*, **192(2)**, 793-806 **(2013)**

24. Tongkul F., The 2015 Ranau Earthquake: Cause and impact, *Sabah Society Journal*, **32**, 1–28 **(2016)**

25. Tongkul F., 1960- Earthquake Science in Malaysia: Status, Challenges and Way Forward/ Felix Tongkul, (INAUGURAL LECTURE SERIES; 7) Mode of access: Internet **(2020)**

26. Trnkoczy A., Bormann P., Hanka W., Holcomb L.G. and Nigbor R.L., Site Selection, Preparation and Installation of Seismic Stations, In New Manual of Seismological Observatory Practice, Deutsches Geo Forschungs Zentrum, 1-108 **(2009)**

27. Trnkoczy A., Bormann P., Hanka W., Holcomb L.G., Nigbor R.L., Shinohara M., Shiobara H. and Suyehiro K., Site Selection, Preparation and Installation of Seismic Stations, In: Bormann P., Eds., New Manual of Seismological Observatory Practice 2 (NMSOP-2), Potsdam: Deutsches Geo Forschungs Zentrum, https://doi.org/10.2312/GFZ. NMSOP-2_ch7, 1-139 **(2012)**.

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