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Preliminary Evaluation of Traffic Resilience against Potential Earthquake in Penang Island

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ABSTRACT

When an earthquake occurs in a neighboring country close to Malaysia, such as Indonesia, the tremor can be felt by Malaysians, especially states located along the Straits of Malacca. The epicenter of an active earthquake in the Indian Ocean near northwestern Sumatra, Indonesia triggered a tsunami in December 2004 that hit Penang Island and killed dozens of people and caused minor property damage especially the transportation system. A Quantum Geographic Information System (QGIS), Open Street Maps (OSM), Online Questionnaire Survey, and Literature Review were used to evaluate the preliminary traffic resilience in Penang Island. The presence of fault lines and traffic networks from the secondary data were identified and integrated using GGIS and OSM. The contour results showed that the red zone (most affected) and yellow zone (less affected) were mostly located in the northeast district and the upper half in the southwest district while only a small part was covered with the green zone (not affected) in the southwest district of Penang Island. The factors influencing humans in responding during an earthquake were panic and fear from the point of view of history and general knowledge, as well as announcements and evacuations by the government as the highest votes by online questionnaire survey. Preliminary, the traffic networks with higher probability being affected in the events of earthquake are identified so that further study for the traffic resilience can be carried out.

Keywords: Traffic resilience; Earthquake; Penang; QGIS, Human factors

INTRODUCTION

Major disasters and catastrophes can give a major impact on traffic and transportation systems, there is also recognition that small disruptions in traffic and transportation networks can also have a significant impact on their effectiveness (Calvert & Snelder 2018). Studies and reports have shown congestion, low traffic performance, delaying travel time, accidents, bad weather, construction, and special events (for example, a marathon race) have all been shown to cause costly delays and inefficiencies, resulting in fuel waste, infrastructure deterioration, and increased pollution (Ganin et al. 2017). Often, strong earthquakes cause serious damage to road furniture and affect traffic resilience in the impacted area.

History of earthquake events in Sichuan 2008, Chile 2010, and Tohoku 2011 proved that damages to a road network impede emergency response, rescue, and recovery as well as cause spatially and temporarily extensive traffic interruptions (Kilanitis & Sextos 2019). Minor damage was also found to have a disproportionately large impact on network operation and the total amount of earthquake-induced monetary loss. The road was confirmed to be damaged and the associated road partially or entirely closed after a major earthquake.

Aside from that, other countries are also affected by earthquakes. This is evident in Los Angeles, where the Northridge earthquake on 17 January 1994, severely damaged the city's transportation infrastructure. According to Giuliano & Golob (1998), after the earthquake, the region's transportation, public safety, and utility agencies established detours, a reconstruction plan, and a transportation plan to utilize current system capacity during the recovery phase. It went on to say that traffic conditions changed from day to day in the weeks following the

earthquake as roads were fixed, more transit service was deployed, and detour routes were fine-tuned.

Earthquakes in Medan and Sumatra, Indonesia are always felt by Malaysians, especially Penang and Kedah (Adnan and Masyhur 2002). The worst was in 2004 with a magnitude of 9.3 Mw which caused a tsunami along the coastal areas bordering the Indian Ocean (Avar et al. 2019). Earthquakes give a huge impact on the highway system malfunction, not only blocking the affected road but also reducing the level of services at certain roads since users are searching and choosing a newly available road for their activities. Roads that are able to withstand disasters, maintain their operation and function, and also be able to recover quickly from disruptions are known as resilience.

Earthquakes occur at fault lines where the faults suddenly slip against each other and release energy in the form of waves that move through the earth's crust and generate tremors. Fault lines can be anywhere and everywhere, but the difference is, how active the fault line is or not. This includes Penang Island which is unmissed from the existing fault lines. Penang Island consists of one granitic rock and has naturally occurring fault lines or cracks (Avar et al. 2019). However, the fault lines in Penang are not active to trigger an earthquake event, but the long-term tremors from the nearby earthquakes can cause the rapid ground structure movement of the existing fault in Penang Island.

The number of private vehicles in Penang has increased since 1980, as evidenced by a Local Government study conducted in 1996. Penang Island's increased car ownership has resulted in car dependency. During weekday peak hours, Penang suffers from traffic congestion on a specific main road as people commute to work or return home, particularly in the inter-urban road and central business district (CDB) area. As a result, congestion, delays, and travel times were increased in the city (Wei Loon and Jacqueline 2013). Thus, with current traffic loads, in the event of earthquake, will the traffic networks resilience enough to support through, is a big question.

Currently, there is no earthquake study and research on traffic resilience for the island of Penang although there is little earthquake-related history and events that took place. Therefore, this study was conducted with the intention to evaluate the traffic resilience in Penang in the event of earthquake. However, this study only covers the preliminary study of traffic resilience by determining the likelihood of areas affected by earthquake events. The objective of this paper is to identify and integrate the traffic network closest to fault lines underneath Penang Island in a software called Quantum Geographic Information System (QGIS) and to evaluate the influence of human factors in earthquake response.

METHODOLOGY

The traffic network is obtained from the Open Street Map (OSM) software and sorted into QGIS. OSM is a piece of software that can be plugged into QGIS to create an editable map of the entire world. Meanwhile, fault lines were identified from secondary data, georeferenced, and marked on a map of Penang in OSM. Fault lines were identified from a research study conducted by Avar et al. (2019). Both the traffic network and fault lines were integrated into QGIS and demonstrate the possibility of the areas affected by the probability occurrence of earthquake. The Penang Island was then classified into different colors indicating different levels of hazardous areas such as red, yellow, and green zones.

As mentioned above, although the fault lines in Penang are not active to trigger an earthquake event, but the long-term tremors from the nearby earthquakes can cause the rapid ground structure movement of the existing fault in Penang Island. Therefore, it is necessary to explore how ready the community in facing such emergency events. Human factors learnt from previous earthquakes incidents in other countries were reviewed and compared to a questionnaire survey conducted locally in this study.

In the current study, human factors from the historical views of earthquakes from countries that have experienced these events such as Japan, Indonesia, China, and others are studied. This type of natural disaster has occurred in these countries because they are all situated in seismically active areas along subduction zones. However, the scope of this study only covers the preliminary literature review of earthquake cases in various countries around the world. From the review, the similarities and differences in human factor responses for each country were compared. Different countries with different cultures and backgrounds may have influenced citizens to react differently. This might be contrary to the situation in Malaysia where most people might have no idea what to do if the catastrophe occurs.

A questionnaire survey was then conducted to support the review of the literature and analyse human factors that may influence decision-making during an earthquake event. Precisely, Malaysia is one of the countries that are in a ring of inactive earthquakes, and the citizens are rarely or never exposed to this natural disaster. Nevertheless, the survey aimed to find out the extent of the public's understanding of the earthquake events and what their actions would be if they are facing the events.

RESULT AND DISCUSSION

INTEGRATING FAULT LINES AND TRAFFIC NETWORKS IN QGIS

The location of fault lines was identified using secondary data and was marked on the OSM in the QGIS. Figure 1 shows the position of fault lines in Penang Island in OSM/QGIS, based on Avar et al. (2019). Existing fault lines in Penang Island, as shown in Figure 1, are more to the Northwest, Southwest, and West of the centre of Georgetown. Most of the fault lines are located at tourist areas such as Teluk Bahang, Batu Ferringhi, Tanjung Bungah, Bukit Bendera, Kek Lok Si Temple, Balik Pulau, Bukit Ayer Itam, and some in Jelutong and Georgetown. Another traffic network layer was digitised onto the QGIS software, which after integrated with the fault line layer, shows the closest possibility of the affected areas. The traffic network in the current study only covers the Northeast District, which contains the majority of the commercial, industrial, tourist, and residential areas. Figure 2 depicts the traffic network in QGIS software in the Northeast District. Traffic network in the QGIS displayed the main road networks such as Lebuhraya Bukit Jambul, Lebuh Chulia, Lebuhraya Thean Tek, Jalan Cantonment, Jalan Burma, Jalan Doktor Lim Chwee Leong, Jalan Free School, Jalan Batu Ferringhi, Jalan Ayer Itam, Jalan Jelutong and other main roads in the district.

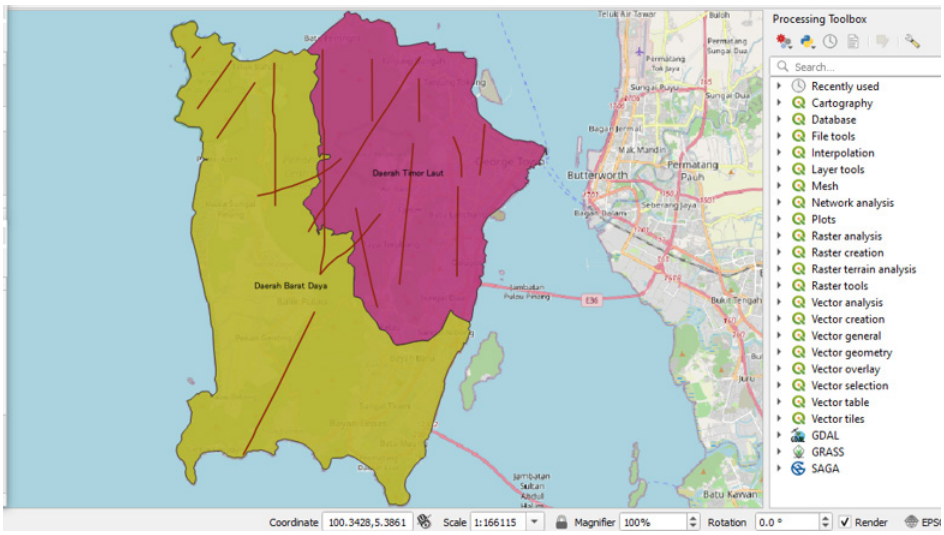

FIGURE 1. Location of Fault Lines in OSM-QGIS

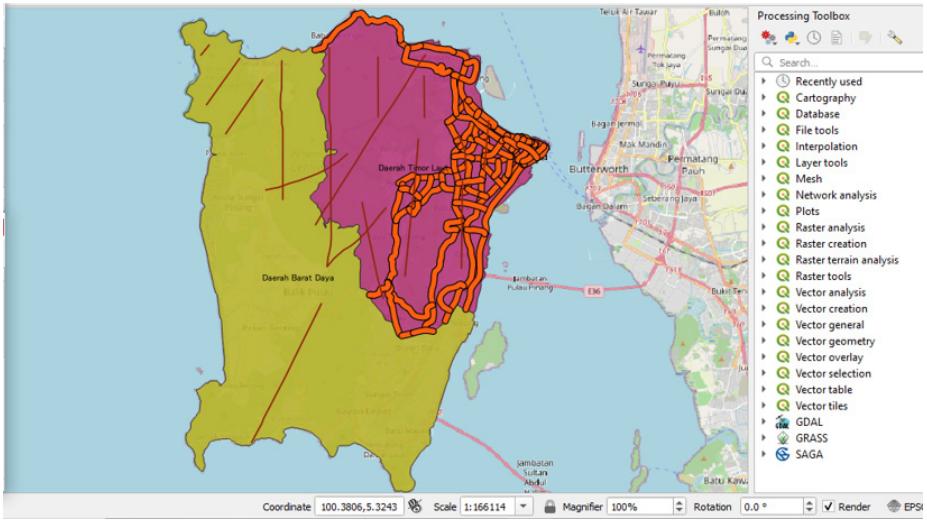

FIGURE 2. Traffic Networks in Northeast District

The colour zones indicating different levels of hazardous in the QGIS was tabulated in Table 1 and the traffic networks in those zones is also shown in Figure 3. Based on Figure 3, most of the areas in the Northeast region of Penang Island are in the red zone and yellow zone which is Georgetown, Tanjung Bungah, Batu Lanchang, Paya Terubong, and Air Itam. These areas are filled with residential areas, tourist attractions, and dense traffic networks. The worst is that some of them are sitting on fault lines. This could be a serious problem if earthquakes strike. The traffic in the areas may suffer severely damaged since it is in a dangerous zone.

TABLE 1. Colour Zones in Penang Island relative to the fault lines

Zones	Level Affected	Radius from Fault lines
Red	Most Affected	1 meter
Yellow	Less Affected	2 meter
Green	Not Affected	3 meter and above

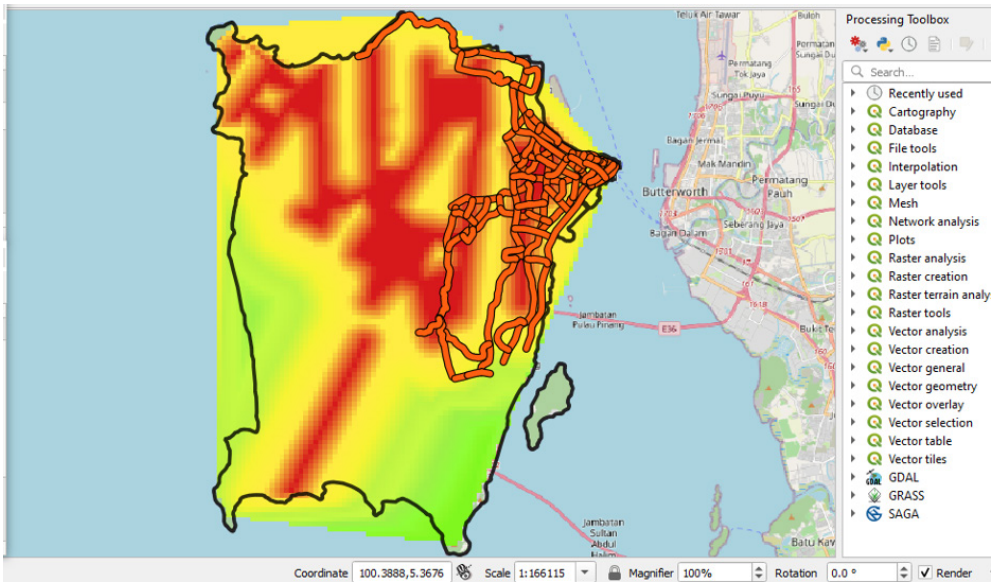

FIGURE 3. Traffic Networks in the Classified Zones

PEOPLES' BEHAVIOURS TOWARDS EARTHQUAKE DISASTER

Analysis of people's behavior towards earthquake disasters was employed to investigate the factors that influence humans in evacuation plans and the possibility of action that may be taken during the emergency earthquake events. It's conducted through online questionnaire survey and literature review from the historical events.

ONLINE QUESTIONNAIRE SURVEY

A short online questionnaire survey was distributed using online platforms such as Whatsapp, Instagram, Facebook, and Telegram. The questionnaire contains demographic section, earthquake-related background knowledge and their opinion towards evacuation actions. The two main parts of questions of interest and discussed herein the current paper are about the contributing factors to their evacuation route and their possible immediate actions in the event of earthquake. The total number of respondents who have answered the online survey is 152 respondents with 53 male and 99 female. Penang citizens were, initially, the main targeted population. However, it was also open to people outside of Penang Island, within Peninsular of Malaysia, assuming that with similar culture and background knowledge of earthquake, their responses are within tolerable variation. Furthermore, since natural disasters and disturbances can strike anywhere and at any time, the survey is assumed to be relevant to all Malaysians. From the 152 respondents, 66 were from Penang, while 86 were from other places in the Peninsular of Malaysia. From the data collected, it shows that the highest percentage from both the young (13 years old to 24 years old) and adult (25 years old to 64 years old) age groups voted that the factor which influences them the most on the evacuation route is

based on their general knowledge, as shown in Figure 4. It is surprising to find that these numbers which based on their own general knowledge (31/152 = 20.39% for Young age and 29/152 = 19.08% for Adults) is even higher than following announcement/evacuation by government (29/152 = 19.08% for Young age and 14/152 = 9.21% for Adults). Besides, as expected, adults show lower fear/panic level than the young group. Also, it's sad to observe that emergency drill is not common among Malaysians. The low panic level is contradicted to the scenario observed in several historical earthquake events as described in the subsequent section.

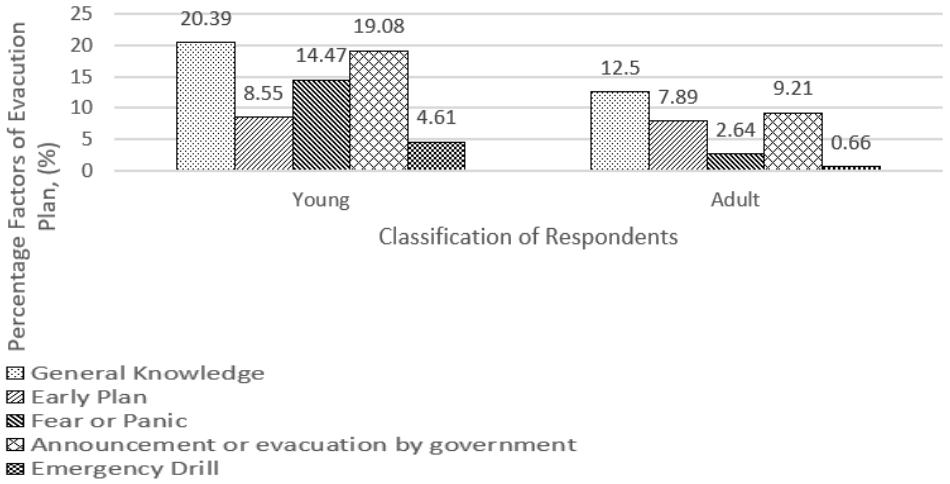

FIGURE 4. Percentage of Factor Influencing the Evacuation Route by different age groups of respondents

The following question is about the possible immediate action that respondents may take in the event of an earthquake. The two highest votes selected by respondents were to 'escape to less affected areas' and 'seek alternative shelters for immediate help', as indicated in Figure 5.

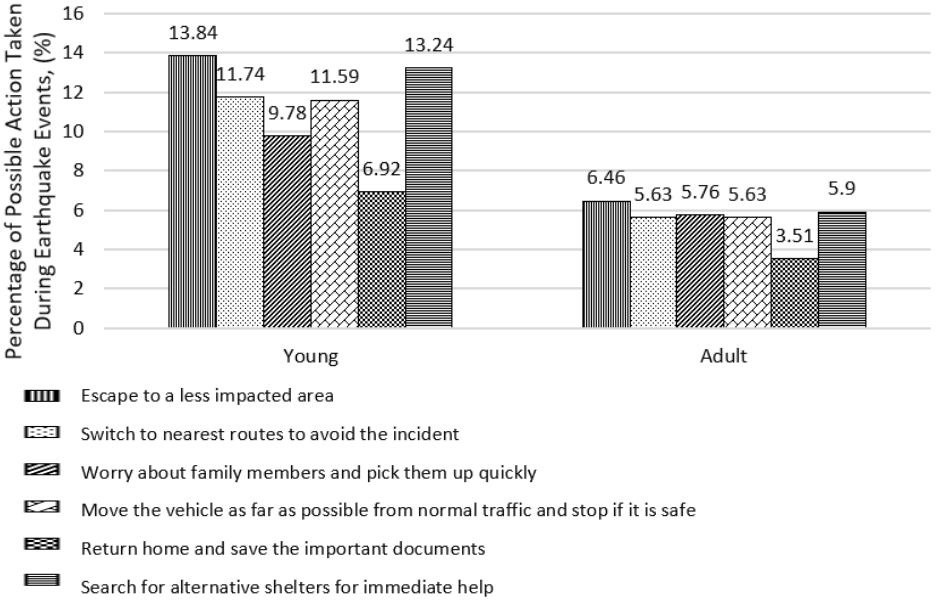

FIGURE 5. Percentage of Possible Action Taken by Young and Adult Groups during Earthquake Events

LITERATURE REVIEW FROM THE HISTORICAL EARTHQUAKE EVENTS

In an emergency, people tend to act and are less capable of performing adequately. People behave differently depending on their gender, age, socioeconomic status, and level of knowledge. According to Provitolo et al. (2011), a large number of communities, regardless of economic development level, are unwilling to face natural or man-made disasters. Human behaviour in the face of a disaster event varies according to a variety of factors. Some factors influencing people's behaviour have been discovered based on an examination of earthquake events from various studies.

Humans are born with a natural inquisitiveness. Since people tend to seek out information in advance about unusual or unprecedented situations, this personality trait has had a significant influence on decision-making. As a result of this problem, the evacuation process takes longer than expected, which is exacerbated by the panic scenario. People cannot think rationally in a panic situation because the brain needs to process what is going on and what needs to be done. This is demonstrated by the actions of people who were shocked, unable to react, froze due to tremors, and felt loss and fear, especially among women and first responders. All these unforeseen underlying reasons contribute to the delay in the evacuation procedure. Hofinger et al. (2014), discovered that evacuation knowledge is a factor that influences human behaviour in evacuation planning. When a dangerous scenario arises, people who are familiar with evacuation procedures can cope and respond quickly. This is since some people may comply with an alarm before taking any action, assuming that it is the true hazard alarm, or another alarm is ringing. Some might be waiting for instructions or group members before exiting and looking for exit signage. The reason for this scenario is that people under stress are more likely to require and accept leadership because clear instruction combined with action in evacuations can help evacuees focus on their safety.

Several studies, such as the Kobe Earthquake in Japan in 1995, the Loma Prieta earthquake (1989), the Chiba-ken-oki Earthquake (1987), the Nihon-kai-chubu Earthquake (1983), the Nankai through Mega Earthquake, and the Great East Japan Earthquake, have also revealed people's reactions to earthquakes. The majority of people claimed they were completely unaware of the earthquake. They felt like they were in the middle of a tire explosion, a car behind them hit them, and they could not control their vehicle due to the severe vibrations. They realized it was an earthquake after observing trees, roads, and streetlights move up and down. Others claimed that they were too shocked and slammed on the brakes, bringing the vehicle to a halt. Meanwhile, many female respondents stated that they were frozen and unable to react, feeling lost and scared. There were also people who said they ran to the nearest exit to save themselves and were too scared to go any further, asking for help by heading to headquarters, and there were also people who continued their journey as far as they could and returned home.

CONCLUSION

The majority of the Northeast District in Penang Island was classified as a red and yellow zone, based on the fault line information. Therefore, the traffic network in that area also falls in the classified zone and what is more concerning is that some of the traffic networks are located directly on top of the fault lines. As discussed, where earthquakes happen due to the slips of fault lines towards each other, then it will have a huge impact on the traffic network and highway system. However, for a typical epicentral distance between a far-field event and Penang Island being greater than 350 km, likelihood of liquefaction is very small and limited by very large earthquake events. There is uncertainty of probability of occurrence on intraplate earthquakes in the Peninsula with sufficient magnitude to cause liquefaction (Avar et al. 2019). As for the evaluation of factors that influence people in an evacuation plan, most factors that influenced people from their experience in facing earthquake events are panic, seismic motion, evacuation knowledge, shocks, and fear. Meanwhile, from the online questionnaire survey, the two highest votes by young and adult respondents in choosing their evacuation routes are based on their general knowledge and announcement/evacuation by the government. In evaluating people's actions during an earthquake incident, both young and adult respondents strongly agree to seek immediate help and escape to a less impacted area. This finding is in line with the findings from a survey about people's actions in the history of the Great East Japan Earthquake (East 2015).

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DECLARATION OF COMPETING INTEREST

None

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