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Developing a Household Flood Vulnerability Index: A Case Study of Kelantan

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Abstract: The objectives of this study are to construct a household flood vulnerability index (FVI) and measure vulnerability to floods among affected Kelantanese households. By applying Balica and Wright (2010)'s FVI methodology in this study, the FVI is constructed via integrating the primary and secondary data. While the primary data were collected from the submission of households' questionnaires, the secondary data were obtained from authoritative organizations. The FVI was then applied to evaluate flood vulnerability levels of households in Kota Bharu and Kuala Krai, respectively. Among others, Kota Bharu is found to be economically susceptible to floods evidenced from prevailing income disparities among the households whereas Kuala Krai is physically susceptible to floods mainly due to the conditions of low-lying areas and extreme rainfall pattern. Serving as a reliable system of vulnerability indicators, the FVI enables wider evaluation of an area from multi-faceted perspectives, thus strategically benefitting the decision and policy makers, public and populations at risk.
Keywords: flood vulnerability; household FVI; Kota Bharu; Kuala Krai.

INTRODUCTION

Flood disaster represents the most significant natural hazard in Malaysia. There are two main types of extreme floods; flash flood and monsoon flood that normally occur in this country. While the flash floods are sudden and short-lived, the monsoon floods are generally originated from the Northeast Monsoon (i.e. from November to March) with heavy rains are potentially brought to the East Coast states of Malaysia; Kelantan, Terengganu and Pahang, southern part of Sarawak and northern part of Sabah. As a consequence, various segments of the population are severely affected especially in many flood plain and flood prone areas in Malaysia. Statistically, the annual flooding affects more than 4.82 million (i.e. 22 percent) of the total population and about 29,000 km^2 (i.e. nine percent) of the total land area with an average of RM915 million is inevitably lost in Malaysia every year [1].

Throughout the nation's history, a series of major flood events have been unavoidably experienced since 1926 that affected various locations across many states in Malaysia. To date, several other major flood incidences in the country took place notably in the years of 1931, 1947, 1954, 1965, 1967, 1971, 1979, 1981, 1983, 1988, 1993, 1995, 2001, 2006, 2010 and 2014 [2, 3]. In recent years, the worst flood in decades swamped many states across the Peninsular Malaysia; Johor, Kedah, Kelantan, Melaka, Negeri Sembilan, Pahang, Perak, Perlis and Terengganu that prolonged for two weeks i.e. from 15 December 2014 to 3 January 2015[41]. As a result, the tragic event rendered in the death of 21 people as well as the evacuation of more than 200,000 people [4, 3, 5. Noticeably, it was recorded for Kelantan, Pahang and Terengganu that the continuous heavy rainfall saturated the catchment areas, thus resulting in extremely large run off and causing the rivers to overflow and subsequently inundated surrounding settlements within the low-lying areas such as villages and towns along the river banks [6].

Due to the unprecedented scale of the 2014's major flood events nationwide, the consequences surpassed our expectations and contingent upon, among others, the magnitude and duration of the events. Notwithstanding, there remains a low perception among the public at-large on the important interplay between flood risk, flood hazard and flood vulnerability in determining the severity levels of their living areas being exposed to floods. Yet, many of them are seen to have the belief that the mitigation and management of natural disasters including floods are largely monitored by the government [7, 8].

This paper is structured as follows. A number of literatures on the flood vulnerability or risk assessment are reviewed in Section 2. While Section 3 describes the methodology that is used in this study, the results are reported and discussed in Section 4. Finally, Section 5 wraps up with the policy implication and conclusion of this study.

LITERATURE REVIEW

Balica and Wright [9] launched a study on the use of FVI model to assess the vulnerability levels to floods for three different spatial scales; river basin, sub-catchment and urban within the physical, social, economic and environmental dimensions. They attempted to cover certain river basins; Rhine, Danube, Mekong, Loire, Amazon, Nile and Limpopo, sub-catchments; Bega River, Mun River, Neckar River, Timis River, Tisza River and and 18 sub-catchments of the Philippines archipelago as well as urban areas; Mannheim, Phnom Penh, Timisoara, Delft, Drobeta Turnu Severin, Tours and Dordrecht. In the analysis, mathematical tools (e.g. derivative and correlation methods) and questionnaires were jointly employed. Eventually, this led to producing the simplified version of FVI models for each geographical scale (i.e. out of 80 possible indicators) to contain only 20 finalized indicators for river basins, 22 finalized indicators for sub-catchments and 30 finalized indicators for urban cities, respectively. Based on the findings of Balica and Wright [9], river basin and sub-catchment scales were found to be the most environmentally vulnerable to floods when using the simplified FVI models. Of the indicators, land use and water condition turned out to be the most statistically significant to define the vulnerability levels to floods for river basin and sub-catchment scales, accordingly. Overall, the simplified FVI models for different geographical scales can be potentially used as an educational tool to raise the awareness on the topic of flood vulnerability albeit the models are less physically rigorous.

In the context of Malaysia, Ibrahim, Zardani, Shirazi *et al.* [10] undertook a study in Kelantan on the use of FVI model in which the adopted methodologies were found to be different than those of in Balica and Wright [9]. In particular, the study of Ibrahim *et al.* [10] highlighted the use of FV indices to identify the flood-prone areas within the Kelantan River sub-basins. The FV indices, which were developed by the Geographic Information System (GIS) technique, were comprised of significant indicators such as flood depth-inundation area, market infrastructure vulnerability, population vulnerability, road infrastructure vulnerability, soil erosion potential and soil potential for agricultural activities. Overall, the findings of Ibrahim *et al.* [10] unveiled that the FV indices of Kelantan River sub-basins were ranked to be at high values notably in major metropolitan areas with high concentration of economic activities, populations and infrastructures. In another occasion, Jiang, Deng, Chen *et al.* [11] embarked a study in Kelantan to estimate the risk of flood event. The state's seven flood-prone districts namely Bachok, Kota Bharu, Machang, Pasir Mas, Pasir Puteh, Tanah Merah and Tumpat were chosen as the areas of study. Three techniques; fuzzy comprehensive assessment (FCA), fuzzy similarity method (FSM) and simple fuzzy classification (SFC), which are feasible in the flood risk evaluation, were employed in the study, respectively. From the findings of Jiang *et al.* [11], it is disclosed that the flooded areas, i.e. ranging from 70 to 75 percent, are located within the higher and highest risk zones. Also, the findings of Jiang *et al.* [11] showed that the FCA technique is more effective to evaluate flood risk based on its higher precision in the estimated risk level of flooded areas as compared to the latter FSM and SFC techniques.

In the southern part of Malaysia, Mohd Saudi, Juahir, Azid *et al.* [12] commenced a study in Johor on developing the flood risk index of the Johor River basin. As such, three statistical methods; factor analysis (FA), statistical process control (SPC) and artificial neural network (ANN) were employed in the study, accordingly. Under the FA procedure, the results indicated that water level, which registered with a correlation coefficient of 0.738, can be practically used for the flood warning alert system. With the ANN method, the accuracy of prediction and the accuracy of the test result with R^2 were evaluated to be at 0.96 and the root mean squared error (RMSE) equals to 2.57. Thus, the flood risk index of the Johor River basin is expected to facilitate the local authorities in terms of managing the state's flood control and prevention.

From the past studies that were reviewed, it is observed that there is an inevitable gap in the literature for the case of Malaysia per se notably with regard to the applicability of FVI methodology that follows the works of Balica and Wright [13]. Further, most existing studies in Malaysia such as Jiang *et al.* [11], Mohd Saudi *et al.* [12] and Ibrahim *et al.* [10] (i.e. with varying techniques and different sets of methodologies) tend to focus on the macro issues of flood hazard within various locations in Malaysia for establishing the models of flood vulnerability and flood risk, respectively. Thus, the motivations to undertake this study are to fill this gap in the literature and contribute to the new knowledge via constructing a household FVI and to measure vulnerability to floods notably among affected households of Kelantan.

METHODOLOGY

Study Area

This study was carried out in Kelantan, which represents one of the states in Malaysia, covers an area of 15,022 km^2 and 10 administrative districts; Bachok, Gua Musang, Jeli, Kota Bharu, Kuala Krai, Machang, Pasir Mas, Pasir Puteh, Tanah Merah and Tumpat. Geographically bound by the latitude 6°7'31.43"N and the longitude 102°14'17.04"E, the state as shown in Figure 1 is located in the Northeast Peninsular Malaysia, thereby facing the South China Sea and bordered with Thailand in the north, Terengganu in the east, Pahang in the south and Perak in the west.

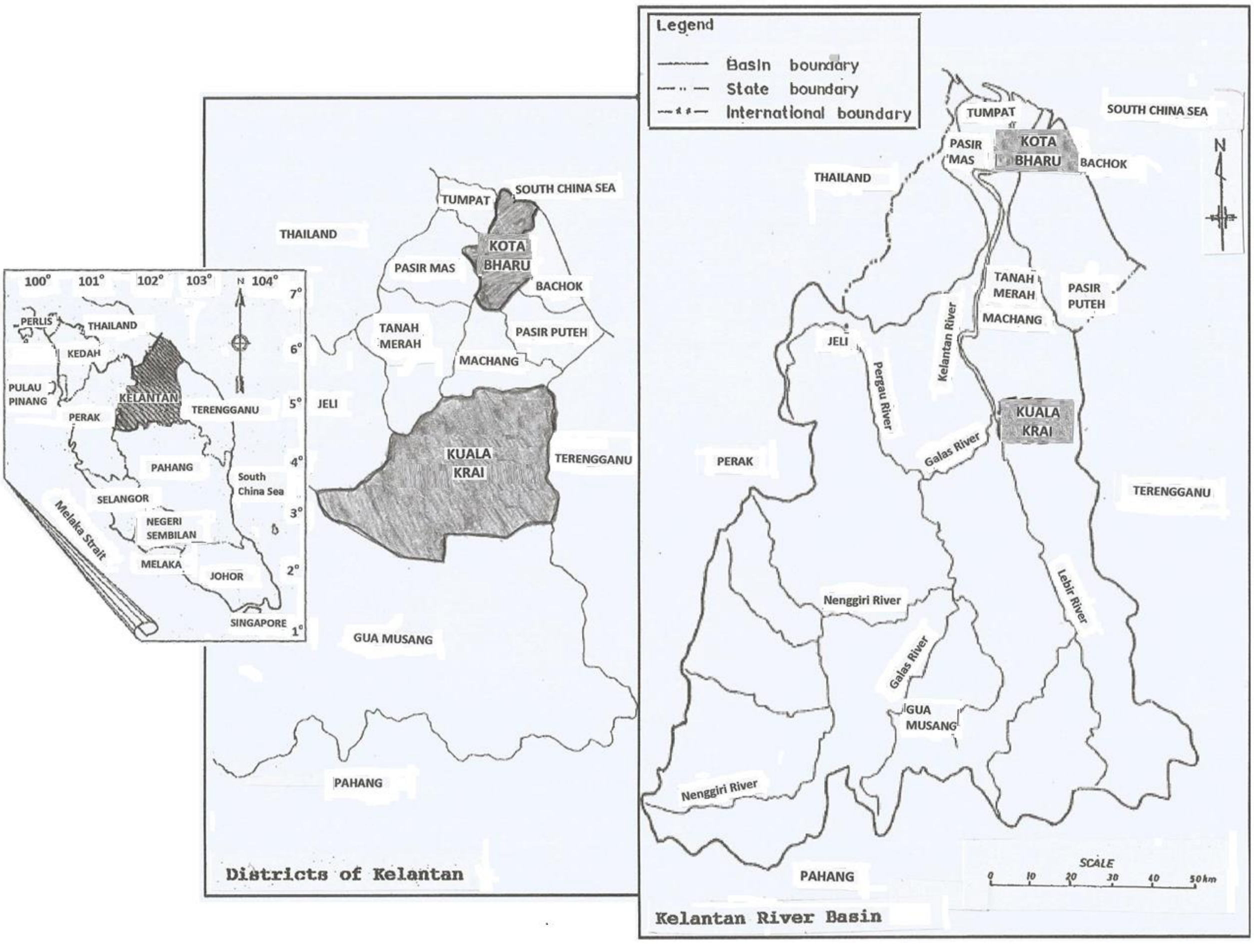

Fig-1: Geographical location of the study area
Source: Department of Town and County Planning Kelantan [14]

Specifically, the two districts of Kelantan that were severely hit from the 2014's major flood event were chosen in this study to be Kota Bharu and Kuala Krai. With the coordinates of 6^{o}8'23.54"N and 102^{o}14'31.93"E, Kota Bharu is the capital city of Kelantan and the city is adjacent to the Kelantan River. Covering a 115.64 km^2 land area, the city has a total population of 314,964 people in 2010 [15]. From the 2014's flood event, Kota Bharu was among the hardest-hit districts with 45,953 evacuees officially registered at various relief centres [16]. Meanwhile, the other district of Kelantan is Kuala Krai. With the coordinates of 5^{o}31'59.99"N and 102^{o}11'60.00"E, the city contains the Lebir and Galas Rivers that jointly flow into the greater Kelantan River. Given a 2,329 km^2 land area, the city covered a total population of 40,659 people in 2010 [15]. From the 2014's flood event, Kuala Krai was among the hardest-hit districts with entire houses and villages were wholly submerged. As a result, 40,490 evacuees officially registered at various relief centres [16].

Theoretical Framework

In Figure 2, the focus of Turner, Kasperson, Matson *et al.* [17] is on the local setting whereby a village or district constitutes as a unit of analysis.

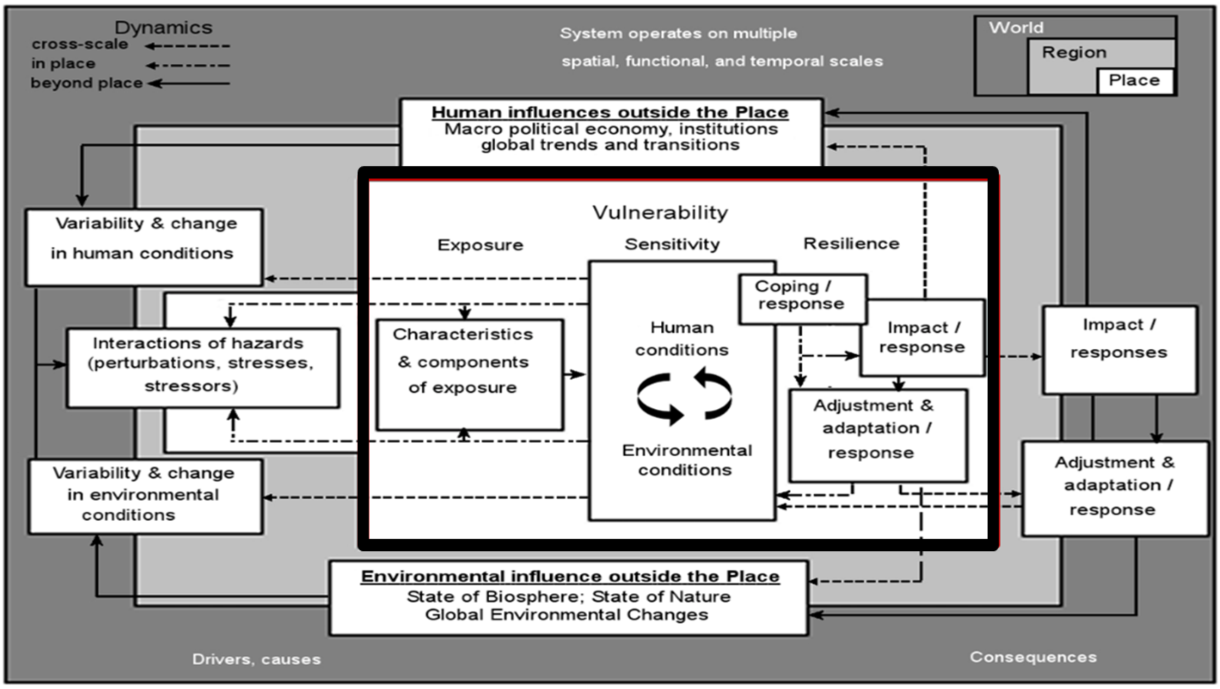

Fig-2: Interaction among available factors within the expanded vulnerability framework
Source: Turner *et al.* [17]

It is applicable for the use of both qualitative and quantitative data variables. In the context of vulnerability, it does exist in a multifaceted coupled human – environment system at different spatial, functional and temporal scales. In particular, the works of Turner *et al.* [17] in Figure 3 depicts the prevailing interactions among exposure, sensitivity and resilience factors that potentially affect the existing system, thus providing an insight on the vulnerability of an area.

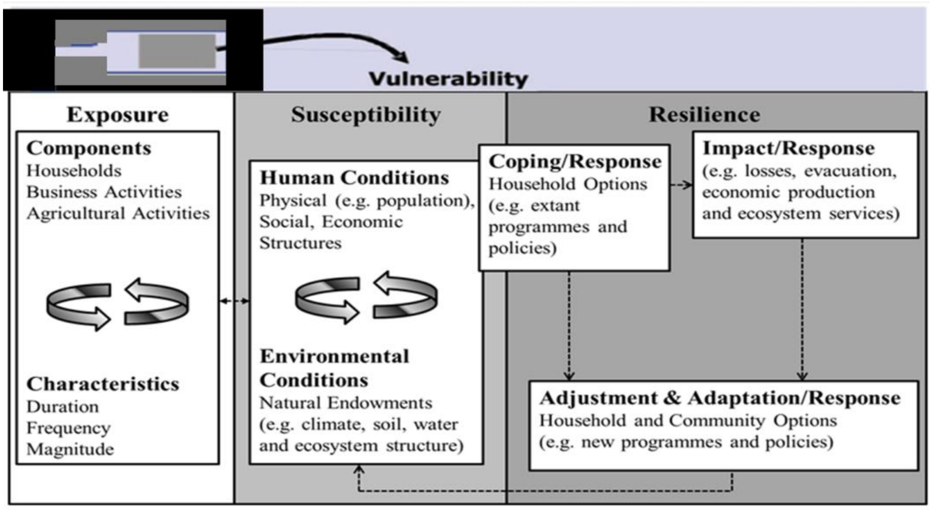

Fig-3: Details of vulnerability factors in the vulnerability framework
Source: Turner *et al.* [17]

Data and Sampling Method

In this study, the construction of a household FVI model is sourced from the primary and secondary data. While the primary data were collected through the households' submission of questionnaire sets, the secondary data were obtained from authoritative organizations such as Malaysia's Department of Irrigation and Drainage, Meteorological Department of Malaysia and Department of Statistics, Malaysia. Accordingly, the details of 40 identified indicators are shown in Table 1.

Pertaining to the collection of primary data, a series of survey were administered to a sample of 80 affected households within the surrounding communities of each district in which the respondents are selected under a cluster sampling method. The data as per Table 1 are collected thereafter via using the questionnaires being distributed among the respondents following the surveys.

Table-1: Selected Indicators of Flood Vulnerability

No.	Defined Indicator	Unit	Type of Data	Vulnerability Factor	Vulnerability Component
1	Flood Frequency	#/year	Primary	Exposure	Physical
2	Flood Duration	day	Primary	Exposure	Physical
3	Cultural Heritage	1 or 0	Primary	Exposure	Social
4	Proximity to River	m	Primary	Exposure	Economic
5	Business Owners	%	Primary	Exposure	Economic
6	Housing Type	%	Primary	Susceptibility	Physical
7	Household Size	%	Primary	Susceptibility	Social
8	Education	%	Primary	Susceptibility	Social
9	Farmers	%	Primary	Susceptibility	Social
10	Disabled Persons	%	Primary	Susceptibility	Social
11	Female	%	Primary	Susceptibility	Social
12	Income Inequality	%	Primary	Susceptibility	Economic
13	Emergency Services	%	Primary	Resilience	Social
14	Shelters	%	Primary	Resilience	Social
15	Awareness / Preparedness	%	Primary	Resilience	Social
16	Communication Rate	%	Primary	Resilience	Social
17	Past Experience	%	Primary	Resilience	Social
18	Evacuation Routes	%	Primary	Resilience	Social
19	Coping Mechanisms	%	Primary	Resilience	Social
20	Warning System	1 or 0	Primary	Resilience	Social
21	Long Term Resident	%	Primary	Resilience	Social
22	Flood Insurance	%	Primary	Resilience	Economic
23	Economic Recovery	%	Primary	Resilience	Economic
24	Recovery Time	%	Primary	Resilience	Environmental
25	Drainage System	%	Primary	Resilience	Environmental
26	Altitude	m	Secondary	Exposure	Physical
27	Temperature	^{o}C	Secondary	Exposure	Physical
28	Raining Days	#	Secondary	Exposure	Physical
29	Affected Population	%	Secondary	Exposure	Social
30	Population Density	#/km^2	Secondary	Exposure	Social
31	Heavy Rainfall	mm	Secondary	Exposure	Economic
32	Urbanized Area	%	Secondary	Exposure	Economic
33	Land Use: Agriculture	%	Secondary	Exposure	Economic
34	Rainfall	mm	Secondary	Exposure	Environmental
35	Population Growth	%	Secondary	Susceptibility	Social
36	Urban Growth	%	Secondary	Susceptibility	Economic
37	River Level Rise	m	Secondary	Susceptibility	Environmental
38	Dikes and Levees	km	Secondary	Resilience	Physical
39	Flood Investments	%	Secondary	Resilience	Economic
40	Land Use: Forest	%	Secondary	Resilience	Environmental

Method of Analysis

The data are analyzed using the following methods; Deductive and Inductive Approaches, Computation and Application of the Flood Vulnerability Index.

Deductive and Inductive Approaches

Both theory-based (deductive) and data-based (inductive) approaches were employed in this study for selecting statistically significant indicators to develop the FVI model of affected households across the two districts of Kelantan; Kota Bharu and Kuala Krai. The deductive approach focuses on the theoretical framework in selecting significant indicators and taking into consideration on the relationship among indicators whereas the inductive approach i.e. through the parametric method e.g. conducting a household's survey, determines those indicators based on the statistical linkages with observed vulnerability consequences [18,19].

As far as the survey methodology is concerned, it is covered under a quantitative method. In the questionnaires, the line-up of questions was structured to use the type of "close-ended approach." In other words, the close-ended questions are directly posed to the respondents and they only respond by marking the answers being provided in the questionnaires. To elaborate, the first section is on the demographic profile of the respondents in which the information such as gender, age, education level, occupation and duration of stay to be potentially obtained. Also, the remaining four sections are meant to be key inputs for the flood vulnerability assessment as measured from the physical, social, economic and environmental dimensions based on the perspectives of respondents. In these sections, some questions in the form of 'agree' and 'disagree' expressions, which can be categorized into a-five scale ratings (i.e. 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree and 5 – strongly agree) are included as well.

Computation of the Flood Vulnerability Index

On the conceptual descriptions of disaster (e.g. flood) risk, Smith [20] considers disaster risk as the product of two components i.e. probability and consequence. Meanwhile, Blaikie, Cannon, Davis *et al.* [21] treat disaster risk as the combination of hazard and vulnerability that is expressed in Equation [1] in the works of the Pressure and Release (PAR) model:

$$Risk = Hazard \; x \; Vulnerability \qquad [1]$$

Therefore, in the context of a flood event, Equation [2] is duly adjusted from Equation [1]:

$$Flood \; Risk = Flood \; Hazard \; x \; Flood \; Vulnerability \qquad [2]$$

Separately, a vulnerability assessment is performed to determine the conditions of physical, social, economic and environmental vulnerabilities to the flood effect at a particular time. Subsequently, the indicators of flood vulnerability are combined together into a set of indicators in order to compute the FVI model using Equation [3]:

$$FVI_i = \left(\frac{E*S}{R}\right)_i \; ; \; i = PV, SV, EcV \text{ and } EnV \qquad [3]$$

where E is Exposure, S is Susceptibility, R is Resilience, PV is Physical Vulnerability, SV is Social Vulnerability, EcV is Economic Vulnerability and EnV is Environmental Vulnerability. Additionally, the mean of total FVI (i.e. between zero and one) is computed as per Equation [4]:

$$The \; Mean \; of \; Total \; FVI = \frac{\left(\frac{E*S}{R}\right)_{PV} + \left(\frac{E*S}{R}\right)_{SV} + \left(\frac{E*S}{R}\right)_{EcV} + \left(\frac{E*S}{R}\right)_{EnV}}{4} \qquad [4]$$

Prior to that, all datasets were normalized by using the normalization formula as expressed in Equation [5] in order to convert them into non-dimensional units by interpolating the maximum and minimum of obtained data variables [22]:

$$Z_{\text{ij}} = \frac{X_{\text{ij}} - Min\left(X_{\text{ij}}\right)}{Max\left(X_{\text{ij}}\right) - Min\left(X_{\text{ij}}\right)} \qquad [5]$$

where X_{ij} denotes as the value of j indicator $(j = 1,2,...,40)$ in the i district $(i = 1,2)$, Z_{ij} is the matrix that corresponds to the normalized score in which its scaled value ranges between zero and one. While the value of one refers to the maximum value, the value of zero represents the minimum value. In Equation [5], the normalized score for each indicator will be produced via the use of Microsoft Excel Max ( ) and Min ( ) functions.

Application of the Flood Vulnerability Index

The produced results generally adhere to the value designations of FVI model that were developed in Balica [23] and Balica *et al.* [23]. As such, Table 2 assists to interpret values of the FVI model signifying from very low to very high vulnerability to floods for a given area.

Table-2: The Household FVI's Value Interpretation

Index Value	Description
0.75 – 1.00	Very high vulnerability to floods An area has a very high vulnerability to floods. Either the physical, social, economic, environmental or all aspects are very high vulnerable to floods.
0.50 – 0.75	High vulnerability to floods An area has a high vulnerability level to floods. Either the physical, social, economic, environmental or all aspects tend to be highly vulnerable to floods.
0.25 – 0.50	Vulnerable to floods An area has a moderate vulnerability level to floods. Either the physical, social, economic, environmental or all aspects are moderately vulnerable to floods.
0.01 – 0.25	Low vulnerability to floods An area has a low vulnerability level to floods. Either the physical, social, economic, environmental or all aspects are lowly vulnerable to floods.
< 0.01	Very low vulnerability to floods An area has a very low vulnerability level to floods. Either the physical, social, economic, environmental or all aspects are very low vulnerable to floods.

Source: Balica [23]; Balica *et al.* [22]

Hence, the designations of FVI model are useful in providing a broad overview of flood vulnerability levels that would suggest for more appropriate measures to be potentially designed and implemented.

RESULTS

Kota Bharu, Kelantan

Computation and Application of Flood Vulnerability Index

A survey was administered to a total sample of 80 flood-hit household respondents from the surrounding communities that live within the Kelantan River basin in the district of Kota Bharu. Several communities were covered including Kampung Baung, Kampung Pasir Hor, Kampung Pintu Gang, Kampung Surau Kota and Kampung Tanjung Chat. Subsequently, the FVI methodology was computed and applied to the total sample. The results are reported in Table 3.

Table-3: The FVI Results on the Household Respondents of Kota Bharu

Kota Bharu's Flood Vulnerability Index		
FVI Component	FVI Value	FVI Designation
$FVI_{Physical}$	0.491	Vulnerable to floods
FVI_{Social}	0.501	High vulnerability to floods
$FVI_{Economic}$	0.736	High vulnerability to floods
$FVI_{Environmen\ tal}$	0.564	High vulnerability to floods
FVI_{Total}	0.573	High vulnerability to floods

When analysing the physical vulnerability, the households and settlement areas are unveiled to be vulnerable to floods. Geographically, the areas are located within the Kelantan River basin that is characterized by very low slope and vastly low-lying lands. While there are considerably high levels of frequency and duration that reinforce the areas' exposure to flood vulnerability, the prolonged raining days also provide a positive indication of continuous heavy rainfall that eventually renders to increasing the areas' vulnerability to floods. To a certain extent, the finding of prolonged raining days to foster the creation of extreme floods in this study is parallel with the works of the IEM [6], the Sky News Australia [24] and Basri, Ismail, Khairolannuar *et al.* [25]. As far as the housing type is concerned, the likelihood of the areas' vulnerability to floods to be reasonably high as evidenced by exceeding numbers of traditional and single-storey houses relative to modern and several storey houses in the sample. More importantly, such highly vulnerable areas to floods are moderated by a tolerable level of resilience underpinned by existing levees that are built with the relative length of 131 km against the Kelantan River's total length of 248 km. However, given the unprecedented scale of 2014's major flood event, almost the entire districts of Kota Bharu were flooded as stemmed from the incapability of those levees to cease the rise in water level of Kelantan River from overflowing and spreading to nearby areas thereafter [26].

On the social aspect, the households and settlement areas are disclosed to have high vulnerability to floods. As a consequence of the 2014's major flood event, many living areas and cultural heritage locations such as religious places (e.g. mosque, church and temple) and graveyards were heavily affected within the communities, respectively. To some extent, an area tends to be vulnerable to floods due to a greater concentration of individuals and families that reside within the area, so does it apply to the communities of Kota Bharu as well. Despite relatively small ratio of affected people against the total population of Kota Bharu from the 2014's major floods, the areas were considered to be vulnerable to floods due to the inclusion of considerably large evacuees that are attributable to socially-disadvantaged groups; women, disabled individuals (i.e. elderly people at aged 60 and above, children under-15 years old and disabled persons) and farmers. Apart from that, the availability of other factors; increasing levels of education, expanding household sizes (i.e. more than four persons in a family) and reasonably high population growth rates, contributes to elevating the vulnerability degrees to floods among the communities in Kota Bharu. To fully recover in the pre-, during and post-floods, such vulnerable areas are revealed to face several challenges in the process notably in terms of inadequate flood warning system being implemented in-place, ineffective coping mechanisms and unapplied past experience to floods by affected households. Notwithstanding, affected households within the communities are seen to be well-prepared against the extreme floods through various modes of communication and there were commendable availability of operational emergency services and temporary shelters (e.g. school and community centre) especially during the events.

Pertaining to the economic aspect, the households and settlement areas in Kota Bharu are found to have high vulnerability to floods. In particular, small business owners and farmers represent the hardest-hit group being economically suffered from the floods as compared to other professions. Unimaginably, they experienced tremendous losses of assets, marketable and agriculture commodities due to the relative closeness of their business and agriculture activities to the water structure of greater Kelantan River as well as nearby rivers. Further, as the city of Kota Bharu is increasingly urbanized with rapid paces of development exacerbated by active encroachments on lands for new settlements and agriculture activities due to rising city dwellers, this contributes to putting the residential, business and commercial areas in a jeopardy when the floods strike. Also, the economic vulnerability of households to floods is considerably high due to the prevalence of income disparities among them. As such, it is disclosed that many of respondents, i.e. about 68 percent of the total sample, yield the incomes of above RM1,000 level on a monthly basis. In view of the areas were only insured by fewer rational respondents, the areas would likely to become severely affected when the extreme floods hit and an economic recovery process may take reasonably long to fully recover from the flood events.

With regard to the environmental dimension, the households and settlement areas are proven to be highly vulnerable to floods. This is mainly due to excessive developments, thus overusing the lands can cause the environmental degradations within Kota Bharu. Also, this study discovers that the rising volume of rainfall on average has considerably significant role to lead to producing the possibility of the areas to be environmentally vulnerable to floods. While the areas' environmental vulnerability to floods are observed to be moderately high as augmented by the continued rise in Kelantan river level, the areas are environmentally resilient to floods backed by sufficient forest area reservations and drainage system, albeit improperly maintained, throughout the city. Accordingly, the reserved forest areas act as a sponge mechanism to avert floods and the existing drainage system removes foul and surface water as well as avoids sewer flooding within the city. Yet, there is a challenge for the areas to undergo a moderate pace of environmental recovery phase in order to fully recover from the floods just like the environmental conditions in the pre-flood events.

Following the FVI designations in Table 3, the households and settlement areas in Kota Bharu are manifested to be vulnerable to floods on average across the physical, social, economic and environmental components of vulnerability.

Kuala Krai, Kelantan

Computation and Application of Flood Vulnerability Index

A survey was also conducted among 80 flood-hit household respondents in total from the surrounding communities that live within the Kelantan River basin in the district of Kuala Krai. Several communities were covered including Kampung Laloh, Kampung Lata Rek, Kampung Cheneh, Kampung Manek Urai and Kampung Batu Jong. Then, the FVI methodology was computed and applied to the total sample. As such, associated results are shown in Table 4.

Table-4: The FVI Results on the Household Respondents of Kuala Krai

Kuala Krai's Flood Vulnerability Index		
FVI Component	FVI Value	FVI Designation
$FVI_{Physical}$	0.677	High vulnerability to floods
FVI_{Social}	0.706	High vulnerability to floods
$FVI_{Economic}$	0.552	High vulnerability to floods
$FVI_{Environmen\ tal}$	0.588	High vulnerability to floods
FVI_{Total}	0.631	High vulnerability to floods

On the physical vulnerability, the households and settlement areas in the district of Kuala Krai are found to have high vulnerability to floods as mainly due to the combined physical factors of lower elevation or altitude and extreme rainfall pattern. Accordingly, this is consistent with the findings of Sidek, Nazirul, Jajarmizadeh *et al.* [25] and Irwan, Mat Amin, Wan Kamaruddin *et al.* [27]. To elaborate, lower altitude reflects the topographical features of Kuala Krai that directly sits on the confluence of Galas and Lebir Rivers. Of which, both Galas and Lebir Rivers are positioned to jointly flow into the greater Kelantan River. Although the occurrence of floods in Kuala Krai is expected to be within moderate durations and not frequent on a yearly basis, the non-stoppable raining days constitutes as a positive indication of continuous heavy rainfall especially during the Northeast Monsoon period that eventually leads to increasing the physical vulnerability of the areas to floods. Further, the rise in the local temperature on average would foster the rain-producing mechanisms to generate the medium-to-large sized downpours. Also, the greater prevalence of traditional and single-storey houses contributes to increasing the areas' vulnerability to floods physically. With the built levees of 33 km length against the Galas and Lebir Rivers' length of 269 km to avert floods, the communities have some resilience capacity waiting to be capitalised especially when the extreme floods strike.

Socially, the households and settlement areas are disclosed to be high vulnerability to floods. By the rule of thumb, high vulnerability is associated with high exposure, high susceptibility and low resilience. In this respect, high exposure is represented by considerable numbers of cultural heritage buildings or religious places within the communities to be heavily inflicted from the 2014's major floods. Additionally, the inclusion of statistically significant indicators such as larger household sizes (i.e. more than four persons in a family), higher education levels and population growth levels, i.e. with over 0.5 into the FVI model, reinforces the areas' condition to be highly susceptible to vulnerability. Therefore, this leads to increasing the areas' vulnerability to floods notably within the social aspect. Still, the areas are considered as highly vulnerable to floods given the areas have low resilience in term of inadequate flood warning systems that are operational within the communities. Further, the remaining indicators under the exposure, susceptibility and resilience factors of vulnerability are consolidated in the FVI model as part of the attempt to moderate the potential effects among those indicators, thereby eventually weighing the areas to retain as highly vulnerable to floods.

Economically, the households and settlement areas are discovered to have high vulnerability to floods. Among others, the areas are seen to be in proximity to the three main river structures; Kelantan, Lebir and Galas Rivers. Therefore, the exposure of the areas to the water structures is considerably higher. In term of the land use, the emphasis is more on ramping up the development of agriculture activities (e.g. paddy, rubber and oil palm) rather than transforming the city of Kuala Krai to be increasingly urbanized. Hence, the exposure of the areas to vulnerability within the system with respect to the land use management for agriculture and business activities is moderately vulnerable to floods. Furthermore, the significance of the data on heavy rainfall in the city was analysed and turns out to be moderately significant. Hence, heavy rainfall has the potential to affect flooding as the areas are highly vulnerable to floods [27]. Moreover, the economic vulnerability of households to floods in term of the income disparities is relatively lower than those of Kota Bharu's respondents. Just like the case of Kota Bharu's households, the areas tend to be severely affected when the extreme floods hit since the areas were only insured by fewer respondents. Plus, an economic recovery phase may take place at slower pace than in Kota Bharu to recover from the flood events.

When analysing the environmental vulnerability, the households and settlement areas are verified to be highly vulnerable to floods. While rising rainfall volume on average has incremental role to cause the areas to be environmentally vulnerable to floods, the areas' considerably high environmental vulnerability to floods were augmented by the continued rise in Kelantan river level. Yet, the areas serve as environmentally resilient to floods underpinned by ample reservations of forest areas and built drainage system in-place, albeit improperly maintained, throughout the city. However, a slower pace of environmental recovery phase needs to be undergone by the areas towards fully recovering from the floods to become just like the environmental conditions in the pre-flood events.

Based on the FVI designations in Table 4, on an average basis, the households and settlement areas in Kuala Krai are unveiled to have high vulnerability to floods across the multiple components of vulnerability.

Overall, the list of used indicators is duly tabulated in Table 5 for a clear understanding. Of which, the indicators are adopted in the assessment of households in the districts of Kota Bharu and Kuala Krai, respectively, in order to measure the vulnerability levels to floods.

Table-5: Vulnerability Indicators Used in the Development of Household FVI

Component	Vulnerability Factors		
	Exposure *(E)*	Susceptibility *(S)*	Resilience *(R)*
Physical	Altitude	Housing Type	Dikes and Levees
Vulnerability	Flood Frequency		
(PV)	Flood Duration		
	Raining Days		
	Temperature		
Social	Cultural Heritage	Education	Communication Rate
Vulnerability	Population Density	Household Size	Past Experience
(SV)	Affected Population	Female	Evacuation Routes
		Disabled Persons	Coping Mechanisms
		Population Growth	Flood Warning Systems
		Farmers	Long Term Resident
			Emergency Services
			Shelters
			Awareness/Preparedness
Economic	Proximity to River	Income Inequality	Flood Investments
Vulnerability	Heavy Rainfall	Urban Growth	Flood Insurance
(EcV)	Business Owners		Economic Recovery
	Land Use: Urban		
	Land Use: Agriculture		
Environmental	Rainfall	River Level Rise	Drainage System
Vulnerability			Recovery Time
(EcV)			Land Use: Forest

Additionally, the descriptions on used variables are included in Table A.1 in the Appendix section for clearer perspective. In describing the used indicators, some descriptions are aptly modified from past studies in order to fit in within the local context notably in the Kelantan's case while the remaining descriptions are selectively adopted from various past studies.

CONCLUSION

In this paper, the assessment on a sample of households within the Kelantan River basin particularly in both districts of Kota Bharu and Kuala Krai on vulnerability to floods is presented. This study is based on the Turner *et al.* [17]'s framework and integrates quantitative data, i.e. covering both primary and secondary sources, on human – environmental dimensions of vulnerability. With that, this enables the consideration on a broad set of vulnerability elements that come into play in evaluating the vulnerability levels of flood-hit households in Kota Bharu and Kuala Krai across the physical, social, economic and environmental dimensions. From the findings of this study, one notable difference is the households and settlement areas in Kota Bharu are economically susceptible since the district has high vulnerability to floods mainly due to greater prevalence of income disparities among the respondents. As for Kuala Krai, the district is physically susceptible to floods underpinned by the conditions of low-lying areas and extreme rainfall pattern.

With the construction of FVI model for a particular area, this constitutes as a strategic attempt to develop reliable systems of indicators on flood vulnerability and risk at the local, regional and national settings. In turn, this leads to enabling the decision makers to assess the impact of floods on the physical, social, economic and environmental conditions and disseminate the results to the policy makers, public at-large and populations at risk. As echoed in Nasiri and Shahmohammadi-Kalalagh [19], the use of FVI model can be combined with other decision making tools including participatory methods with vulnerable people in affected areas. Concerning on the early warning of floods, it is important to develop the early warning systems that are people-centred. Particularly, it is suggested that the newly improved systems whose warnings are timely and understandable to those at risk that take into consideration on the demographic, livelihood, gender and cultural attributes of the targeted audiences. Also, the systems necessarily include the general procedure on how to act upon warnings and that support effective operations by disaster managers and other decision makers.

In term of reducing main risk factors related to the environmental conditions and natural resource management, it is proposed that the decision makers and policy makers alike to continuously promote for the sustainable use and management of ecosystems through proper land-use planning and development activities to reduce vulnerabilities and risks associated with the flood events. Apart from that, there is a need to protect and reinforce critical public amenities and infrastructures notably clinics, communication modes, disaster management centres, hospitals, schools, transport lifelines and culturally important lands and structures through proper design and retrofitting as means to strengthen them for being sufficiently resilient to floods.

Table-A.1: Reference Data Sources

Appendix

No.	Indicator	Definition	Unit	Past Studies*
1	Flood Frequency	The likelihood of a flood event to occur in a year.	# / year	Balica and Wright [9]
2	Flood Duration	The expected time of flood impact to prolong.	# of days	Kissi *et al.* [28]
3	Cultural Heritage	The number of historical buildings and religious places were in danger when the recent 2014's major floods hit. If none, take one.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
4	Proximity to River	The average proximity of business and agriculture areas to the water structure.	m	Messner and Meyer [30]
5	Business Owners	The percentage of households who operate the business activities.	%	Karmaoui *et al.* [29]
6	Housing Type	The percentage of traditional and single-storey houses, which are very susceptible to floods, currently inhabited by the respondents.	%	Perdikaris *et al.* [31]; Singh *et al.* [32]
7	Household Size	The percentage of expanding household sizes (i.e. more than 4 persons in a family) in a community.	%	Asube and Garcia [33]; Kissi *et al.* [28]
8	Education	The percentage of households who receive education at the secondary and above levels in the sample.	%	Connor and Hiroki [34]; Villordon [35]
9	Farmers	The percentage of households who are farmers and manage agriculture activities.	%	Mwape [36]; Kissi *et al.* [28]
10	Disabled Persons	The percentage of disabled individuals (i.e. old people aged 60 and above, children under-15 years old and disabled) in a community.	%	Balica and Wright [9]; Balica *et al.* [13]
11	Female	The percentage of female members that belong to a household in the sample.	%	Rashid [37]; Bathi and Das [38]
12	Income Inequality	The percentage of households who earn monthly incomes of RM1,000 and above levels in the sample.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
13	Emergency Services	The percentage of households who seek necessary assistance either from the government or other institutions following the floods.	%	Balica and Wright [29]; Kissi *et al.* [28]
14	Shelters	The percentage of households who come forward to get shelters or refuges at times of floods.	%	Balica and Wright [29]; Balica *et al.* [23]
15	Awareness/Preparedness	The awareness or preparedness level of households on how to respond in the wake of the floods.	%	Balica and Wright [9]; Kissi *et al.* [28]

Note: *#* is number, *%* is percentage and *m* is metre.
*Past author or authors who consolidated the effect of corresponding variable in their flood vulnerability or risk assessments, respectively.

"Continued Table A.1"

No.	Indicator	Definition	Unit	Past Studies*
16	Communication Rate	The rate of communication among households that have access to available sources of information on floods.	%	Connor and Hiroki [34]; Karmaoui *et al.* [29]
17	Past Experience	The usefulness of past floods experience by affected households to deal with the recent 2014's major floods.	%	Balica and Wright [9];

				Kissi *et al.* [28]
18	Evacuation Routes	The probability of households to temporarily evacuate from hit areas to safer and higher places.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
19	Coping Mechanisms	The effectiveness of coping mechanisms in-place by households to withstand the magnitude of floods.	%	Kissi *et al.* [28]
20	Flood Warning Systems	The availability of flood warning systems to indicate the early warning of floods.	1 or 0	Balica and Wright [9]; Karmaoui *et al.* [29]
21	Long Term Resident	The availability of long term residents (i.e. with the staying duration of more than 10 years) in a community.	%	Kissi *et al.* [28]
22	Flood Insurance	The possibility of valuable belongings and properties to be insured by rational households before floods. If none, take one.	%	Balica and Wright [28]; Villordon [35]
23	Economic Recovery	The progress of economic development in affected areas to steadily recover from floods.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
24	Recovery Time	The required time for the overall system to recover from the floods.	%	Balica and Wright [9]
25	Drainage System	The effectiveness of drainage system within an affected area to remove foul and surface water and avoid sewer flooding.	%	Balica *et al.* [23]
26	Altitude	Average slope or elevation of a particular area.	m	Kissi *et al.* [28]
27	Temperature	Average temperature in a month within a year.	^oC	Nguyen [40]
28	Raining Days	Higher number of raining days may likely to produce floods that can cause various damages and losses.	#	Jean-Baptiste *et al.* [39]
29	Affected Population	The ratio of affected population in the district over the total affected population in the entire state from the 2014's floods.	%	Connor and Hiroki [34]; Balica and Wright [9]
30	Population Density	Higher concentration of people at an area implies that higher social vulnerability to floods for the area.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
31	Heavy Rainfall	Excessive rain that potentially cause a severe flooding of an area.	mm	Balica and Wright [12]

Note: *%* is percentage, *m* is metre, ^oC is degree of Celsius, *#* is number and *mm* is milimetre.
*Past author or authors who consolidated the effect of corresponding variable in their flood vulnerability or risk assessments, respectively.

"Continued Table A.1"

No.	**Indicator**	**Definition**	**Unit**	**Past Studies***
32	Land Use: Urban	The ratio of allotted urban areas to the district's total land use over the 2010 – 2014 timeframe.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
33	Land Use: Agriculture	The ratio of allotted agriculture areas to the district's total land use over the 2010 – 2014 timeframe.	%	Kissi *et al.* [28]
34	Flood Investments	The percentage of flood investments over the state's total GDP.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
35	Rainfall	The average volume of rainfall in a year.	mm	Balica & Wright [9]; Karmaoui *et al.* [29]

36	Population Growth	The rates of population growth in an area over the 2010 – 2014 timeframe.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
37	Urban Growth	The ratio of increase in city dwellers in an urban area over the 2010 – 2014 timeframe.	%	Balica and Wright [9]; Karmaoui *et al.* [29]
38	River Level Rise	The rise in water levels at major rivers locally due to non-stoppable heavy rainfall.	m	Balica *et al.* [23]
39	Dikes and Levees	Benefits gained by the communities in term of the reduction in flood affected area over the total flood affected area.	km^2	Balica and Wright [9]; Karmaoui *et al.* [29]
40	Land Use: Forest	The ratio of allotted forest areas to the district's total land use over the 2010 – 2014 timeframe.	%	Balica and Wright [9]; Karmaoui *et al.* [29]

Note: *%* is percentage, *mm* is milimetre and *m* is metre.
*Past author or authors who consolidated the effect of corresponding variable in their flood vulnerability or risk assessments, respectively

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