

# Flood Risk Estimation of Paddy Production Considering Plants' Age and Flood Durations



Balqis M. Rehan, Ainun M. Yusuf and Iffah L. Idham

**Abstract** Floods pose serious threats worldwide. During this disaster, civil engineering structures, such as buildings, bridges, dams, water supply, coastal structures, infrastructure facilities are severely affected, causing immense inconvenience to people and disrupting routine life. In the context of water-food security, floods have been a major source of natural disturbance to rice productivity in Malaysia. The consequences of floods will bring losses to the rice production and cause instability. The damage of paddy production due to floods needs to be handled seriously as the negative impact could lead to insufficient food supplies in the country. The purpose of this paper is to estimate flood risk in paddy production considering different flood inundation durations and plant's ages. The calculation of risk considers the probability of extreme flood levels and fine cell resolution of paddy field in the total loss estimation. The location used for this study is in Kedah, where rice production is among the most prominent in Malaysia. Flood risk is expected mounting to nearly half a million ringgits for the 330 ha plots considering the current condition. This emphasize on an effective long-term flood risk management in order to reduce flood risk to paddy production.

**Keywords** Civil engineering · Flood risk assessment · Sensitivity of risk · Paddy

## 1 Introduction

Flooding is among the most environmental hazard and severe from all natural disasters because of the widespread distribution of river, urbanization process, unmanaged drainage system that causing serious damage as loss of lives, loss of properties and loss of livelihoods. The impact of floods is becoming wider due to their increasing frequency and scale, concentration of population and economic

---

B. M. Rehan (✉) · A. M. Yusuf · I. L. Idham  
Department of Civil Engineering, University Putra Malaysia (UPM),  
43400 Serdang, Selangor, Malaysia  
e-mail: [balqis@upm.edu.my](mailto:balqis@upm.edu.my)

activities around river basins and economic inter-dependency due to globalization. The annual occurrences of flood in Muda area have caused damage to the paddy crop production worth millions of Ringgits every year. The Muda area has been facing flood crisis every year especially during the exchange of Monsoon season [1].

Flood risk assessment is used to assess the risk of flooding from various flooding mechanism. Flood risk assessment is essential to evaluate the potential consequences of flood events and can provide information to authorities in planning on actions to be taken before and during flood events [2]. To execute flood risk assessment, it is important to first define what is meant by flooding. Flood is an accumulation of water over normally dry areas and can become hazardous to people and properties and also cause severe losses to crops when severe flooding occurs [3].

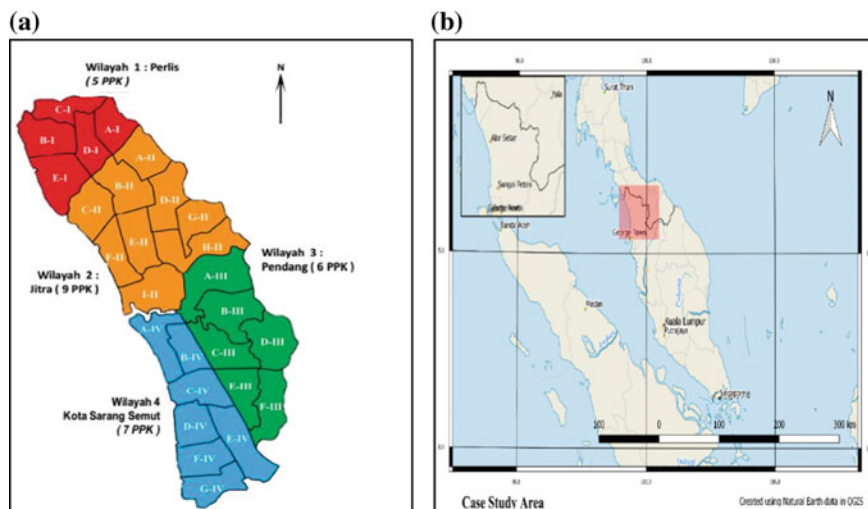
Paddy planted in the Peninsular Malaysia contributes approximately 85.5% of Malaysia's total paddy production and there are approximately 296,000 paddy farmers in Malaysia. The Muda area with areas around 96,558 ha is the largest rice granary area in Malaysia contributing to 40% of the national rice production [1]. Rice is the main staple food in Malaysia and around 74 kg milled rice is consumed per person per year. This indicates that paddy is an important crop granary in Malaysia, where it is the most important food supplies and provides income to farmers.

The limiting flow carrying capacity of an existing river system is one of the major factor that causes flood [4]. This happens due to an increase in river water level due to heavy rains. The water level will exceed a dangerous height and expose the paddy field to flood damage. The flood extent to the granary area will bring losses to the rice production and cause instability to the rice production in Malaysia. The damage of paddy production due to flood needs to be handled seriously as the negative impact could lead to insufficient food supplies in the country.

Since 2005, flood event in Muda area are becoming an annual phenomenon as a natural disaster [4–6]. This being the case, an understanding of the flood risk in needed for future flood risk mitigation measures. This study is done to provide information on the estimation economic losses of paddy production due to flooding in the Muda area in term of annual average damage (RM). Thus, will allow the authorities to make an effective decision, making an intervention and reduced the impact of flood.

## 2 Study Area and Data

This study has been carried out at the paddy granary in Muda area. Muda area covers two states, Kedah and Perlis at which 96,558 ha of a paddy cultivation area are managed by the Muda Agricultural Development Authority (MADA). As the MADA area is the largest granary in Malaysia, it is divided into four regions to ensure smooth management and administration namely, Region I (Kangar), Region II (Jitra), Region III (Pendang) and Region IV (City of Sarang Semut).



**Fig. 1** Geographical location of the Muda area. **a** Four main regions managed by MADA, **b** location of study area

Figure 1a shows the four main regions managed by MADA and Fig. 1b shows the location of study area located by Muda area.

The main river catchment area that is situated in the MADA area are Sungai Arau, Sungai Bata, Sungai Padang Terap and Sungai Pendang. The river catchment water level is supervised and recorded to reduce flooding by releasing the excess water to the sea. Furthermore, MADA also manages three dam units namely Pedu, Muda and Ahning Dam. The dam is used to supply water for irrigation in the Muda area, in which the Pedu dam is the main source of irrigation supply. To study on a local scale level, a 330 ha plot of paddy field nearby Matang Paku River is chosen to calculate flood risk. Section 2.1 describes the data used in this study.

## 2.1 Data

Flood risk is the product of flood hazard and the consequences. Flood hazard can be represented by an extreme value distribution while flood consequences can be captured by the relationship of flood indicator and flood damage. In this study, the flood hazard is taken as the maximum water level and the flood indicator is the flood stage. The data needed to establish both the flood hazard and the flood consequences are explained below.

### 2.1.1 Spatial Data and Non-spatial Data

Generally, the estimation of flood damage on paddy requires two types of data; spatial data and non-spatial data. The non-spatial data includes extreme events from hydrometeorological variables and the yield costs of paddy production. In this study, the former is represented by the seasonal maximum water level taken from MADA. The latter was obtained from the Department of Irrigation and Drainage (DID) [7], in which an extensive research using past flood losses have recommend a regression function to estimate paddy production losses per hectare. The seasonal maximum water level is required to determine the probability density function for the risk estimates whilst the proposed method of DID was used to obtain the stage-damage curve. The spatial data includes topographic data and land use, which are required to determine flood depth given the flooded areas and their ground elevation. Satellite imagery is used to identify the heterogenous ground elevation of the study area.

The data collection of the water level located at the river around the paddy field was retrieved using MADA telemetry system, from which the daily water levels recorded are from 2012. The daily water level retrieved for this study was until 2017. From the data retrieved, the maximum daily water levels were identified. The average ground elevation of each one square meter cell of the whole study area were recorded from Google earth.

## 3 Methodology

### 3.1 Computation of Probability of Flood Hazard (PDF)

Generalized Extreme Value (GEV) distribution is one of the most prominent probability distributions used to model extreme events. GEV has three parameters, which are the location, scale and shape parameter. The frequency analysis using the GEV distribution can be undertaken by determining the block maxima flood hazard variable of around 20 years of records. The GEV distribution is fitted using L-moments and the parameters are then used to estimate the maximum water level for a given return period.

### 3.2 Establishment of Stage-Damage Curve

Stage-damage curves are the first essential stage in flood loss assessment. A stage-damage curve is needed to establish a damage function and is one of the steps used to estimate flood risk. This study adopts the local scale assessment approach, where the average ground elevation of each cell in a study area used to

determine the individual cell's flood depth for a given maximum inundation stage over the entire study area (i.e. meter above mean sea level). The maximum inundation stage is chosen as the flood indicator under the static assumption, since the most damaging flood consequences of a flood event generally happens when the flood level reaches its maximum.

Since 2005, DID [7] flood damage regression function has come out with damage factors for different depth, durations and ages of rice crops (Table 1). Flood damage for a given area flooded under a certain flood depth can be determined by multiplying the damage factor with an estimated unit value of paddy and the determined flooded area associated with the flood depth. The total damage (RM) was calculated following Eq. (1). The calculation of the damage can be done by using the unit value of paddy in Kedah multiply by the damage factor for every stage to estimate the monetary loss occur per hectare when flooding.

$$\text{Total Damage} = \text{Unit value of paddy production} \times \text{damage factor} \times \text{flooded area} \quad (1)$$

The flood depth is categorized into three; 0.9 m, 0.9–1.2 m or more than 1.2 m. Flood damage can be calculated for each cells of different ground elevation levels within the study area using the depth of damaging flood of the respective cell. In particular, the

**Table 1** The DID report from previous study

Rice plant age	Flood duration	Flood depth (m)	Damage factor (%)
Rice plant—under 80 days old	Case 1: <2 days old	0.9	30
		1.2	33
		>1.2	60
	Case 2: 3–4 days old	0.9	37
		1.2	40
		>1.2	80
	Case 3: 5–6 days old	0.9	40
		1.2	43
		>1.2	86
	Case 4: >7 days old	0.9	45
		1.2	49
		>1.2	96
Rice plant—above 80 days old	Case 5: <2 days old	0.9	30
		>1.2	60
	Case 6: 3–4 days old	0.9	37
		>1.2	100
	Case 7: 5–6 days old	0.9	40
		>1.2	100
	Case 8: >7 days old	0.9	45
		>1.2	100

number of cells under three categories of flood depth, 0.9 m, 0.9–1.2 m or more than 1.2 m, would need to be identified given a maximum flood inundation level. This gives the total flood damage for that study area given the maximum flood level.

Calculation of flood damage for the study area can be repeated for different maximum flood stage to construct a stage-damage relationship curve. To ease the repeated computation, this study adopts the methodology proposed by [8]. Also, stage-damage relationship can be associated with different scenarios of paddy growth stage, i.e. plant age. Based on this method, a realistic damage curve of flood impacts to rice production can be constructed for the study area.

### 3.3 Calculation of Flood Risk as Expected Annual Damage (EAD)

The calculation of expected annual damage can be obtained by interpolating the fitted GEV probability distribution and using the stage-damage function to come out with a probability-damage relationship [9]. The stage-damage curve can be obtained by multiplying the area of flood for each stage with the damage. The probability-damage curve specifically relates between the exceedance probability and the consequential damage. A few basic relationships were constructed to get the probability-damage relationship, which are area-ground elevation, probability density function, and stage-damage curve. By determining the area under the probability-damage curve, the EAD can be determined in terms of monetary loss.

The area under this curve, which represent the expected annual damage, can then be computed by using the Trapezoidal Rule. Trapezoidal Rule was calculated on a following Eq. (2).

$$EAD = \rho_0 D_0 + \sum_{i=1}^n (\rho_i - \rho_{i-1}) \frac{(D_i + D_{i-1})}{2} \quad (2)$$

where  $\rho_i$  is the probability of exceedance  $i$ -year return period computed from the fitted GEV model and  $D_i$  is the probable flood damage value of  $i$ -year return period obtained from a pre-processing total damage estimation for a range of maximum flood stage associated with probability of exceedance.

## 4 Results and Discussion

### 4.1 Maximum Water Level

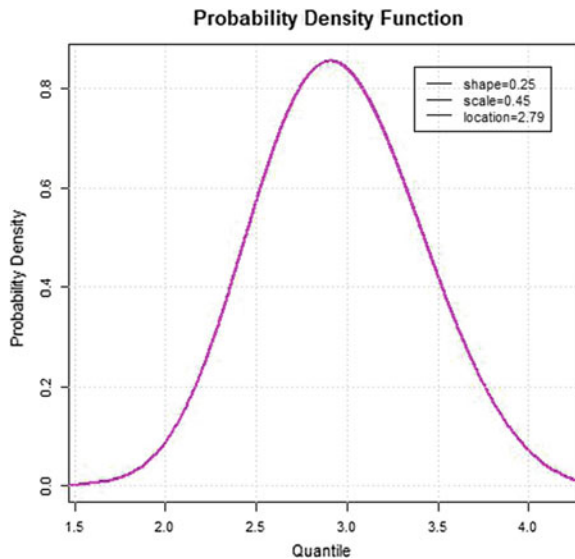
The water level is selected as the hazard parameter, since the historical records of water level is available from MADA telemetry system near to the study area. The

data from the water level station in Matang Paku was retrieved. The water level of the river is recorded for every 1 h interval every day of that year and the maximum daily water level is determined from the 24 h daily water level record. The maximum monthly water level is then determined from the daily maximum water level. Thus, there will be 12 maximum water level a year for every month starting from January till December. As the paddy plantation is divided into two seasons, the seasonal maximum water level will be determined rather than annual maximum water level. The season for the paddy plantation is from March to August for season 1 and September to February for season 2.

### 4.2 Probability of Hazard

GEV parameters were estimated from the seasonal maximum water level and six return periods, i.e. 5, 10, 15, 20, 25, and 30 years, were then selected to represent a range of possible flood events. Water levels of each return period can be determined based on the exceedance probability. The water level for the return period 5 years is 3.34 m and shows the lowest water level and the highest water level is for the return period of 30 years at 3.8 m. By using the GEV parameters, the probability density function can also be plotted, as in Fig. 2.

Fig. 2 The probability density function graph for flood in MADA



### 4.3 Area-Ground Elevation

Next, the area-ground elevation relationship was established using Google Earth that provides information on the elevation of the paddy field. The area-ground elevation shows the ground elevation of the paddy field for each 1 ha cell. There is a total of 330 cells representing 330 ha of the Muda area. The minimum elevation considered for flood impact in the study area is 2 m and the highest is 6.5 m considering the normal water level for paddy plantation. The number of cells was counted based on a 0.5 m incremental elevation. Figure 3 shows the area-ground elevation in Muda area where the numbers in the cells and the different colours represent the minimum elevation, respectively.

A maximum flood level can be introduced using a hypothetical horizontal plane with a specified height above datum over the study area. Since flood damage is categorised into three different flood depth condition, which is 0.9 m, 0.9–1.2 m and more than 1.2 m, flooded area is distinguished according to these categories. For example, when the flood level reaches 3.2 m AD, the total affected area is 74 ha but the number of cells with 0.9 m flood depth and 1.2 flood depth would be

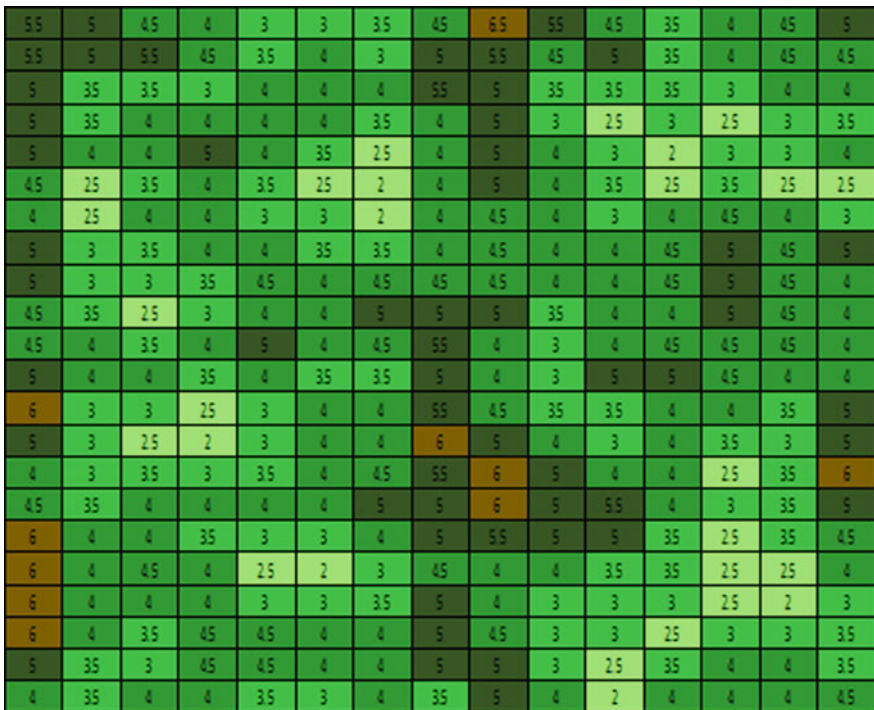


Fig. 3 The area-ground elevation in Muda area



different. Due to the inconsistency in the cell's threshold level for damage and the DID's flood damage-depth, the cells are grouped according to their nearest value to the DID's flood damage-depth.

#### **4.4 Total Damage**

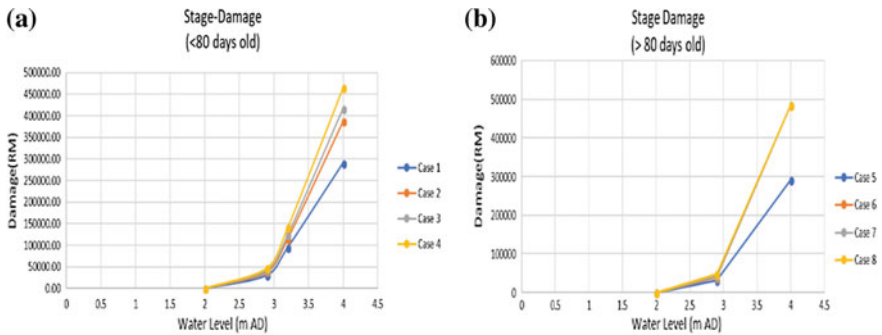
In order to plot the stage-damage curve, the total damage for the paddy production due to flood need to be calculate first. The total damage will vary according to the different scenarios as the damage factor will be different for every flood depth, flood duration and rice crop age. The total damage will be divided into two categories, which are rice crop age less than 80 days old and rice crop age more than 80 days old. The total damage for each category will be further divided into four different scenarios in which the duration of the flood will be different. For the first scenario the duration of flood is less than 2 days, followed by 3–4 days, 5–6 days and more than 7 days for the following scenarios.

Based on the calculation, the total damage for each scenario for rice crop age less than 80 days increases as the flood duration increases, with the highest flood damage for flood duration more than 7 days and the flood depth is more than 1.2 m, i.e. RM 465,702. Moreover, the total damage for the different flood duration for rice crops age more than 80 days old increases for depth 0.9 m but the total damage will be the same when flood is more than 1.2 m and flood duration more than 2 days as the damage factors is 100% which indicate that all the paddy in the flooded area will be damaged and causes the highest damage of RM 485,107.

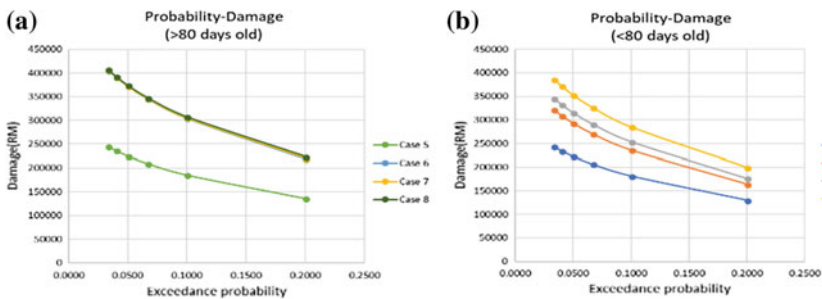
Then, after calculated the total damage for paddy production, the stage-damage curve for rice crops age less than 80 days old indicates that when the water level is at 2 m there will be no damage and the damage will increase when the water level increase. Case 4 has the highest damage while case 1 has the lowest damage. This shows that the longer the flood duration the higher the damage. For the stage-damage curve for rice crops age more than 80 days old shows when the water level is at 2 m there will be no damage and the damage will increase when the water level increase. Case 5 has the lowest damage while cases 5–7 have similar high damage. This indicate that when the age of rice crops is more than 80 days old, it will receive the highest damage if the flood duration is more than 2 days and flood depth more than 1.2 m. Thus, this shows that the critical age of rice plant is 80 days old. Figure 4a shows the stage-damage curve for rice crop age less than 80 days old and Fig. 4b shows the stage-damage curve for rice crop age more than 80 days old.

#### **4.5 Probability-Damage Curve**

The damage for every water level based on the exceedance probability can be determined from the stage-damage curve. The damage for every flood level is first



**Fig. 4** The stage-damage curve for **a** rice crop age less than 80 days old and **b** rice crop age more than 80 days old



**Fig. 5** The probability-damage curve of, **a** rice crop age less than 80 days old and **b** rice crop age more than 80 days old

determined to plot the probability-damage curve. The probability-damage for rice crop age less than 80 days old shows that the higher the probability, the lower the damage. Based on the different scenarios, when the flood duration increases the damage will also increase. Furthermore, the probability-damage for rice crop age more than 80 days old shows that the higher the probability, the lower the damage. Based on the different scenarios, when the flood duration increases the damage will also increase but the damage will be similar when the flood duration is more than 2 days for rice crop age more than 80 days old. Figure 5a shows the probability-damage of rice crop for age less than 80 days old and Fig. 5b shows the probability-damage of rice crop for age more than 80 days old.

**Table 2** Risk as expected annual damage for different rice plant age

Rice plant age	Risk in expected annual damage (RM)			
	<2 days	3–4 days	5–6 days	>7 days
Under 80 days old	89,580	111,696	119,425	133,521
Over 80 days old	92,473	144,166	145,133	146,746

#### 4.6 Expected Annual Damage

The EAD was calculated based on the area under the probability-damage curve. By determining the probability increment and the mean damage increment, the weighted damage can be obtained. The EAD is the total of the weighted damage. The EAD for every scenario shows different values due to the different conditions of flooding and rice age. It can be seen that the longer flood duration causes higher damage to the paddy production. There is a big difference of damage when compared by the rice plant age affected by flooding. Flood damage towards paddy under 80 days old is lower than the paddy age over 80 days old. Table 2 shows the risk in EAD for all scenarios.

## 5 Conclusions

In Muda area, the flood risks were estimated for different flood scenarios, namely different flood area, flood depth, flood duration and rice plant age. The findings of this study show that paddy is more prone to damage during the critical age of 80 days old and when flood duration is longer. Flood risk is expected mounting to nearly half a million ringgits for the 330 ha plots considering the current condition. This emphasise on an effective long-term flood risk management in order to reduce flood risk to paddy production. Estimated flood risk is also useful in cost-benefit analysis involving flood mitigation efforts.

Albeit the successful of the study to estimate flood risk to paddy, effort to enhance the valuation of risk is needed. The three critical parameters in determining flood damage, i.e. flood depth, duration and plant age comes from the characterizations of flood hazard, exposure and economic losses. These can be unwrapped and investigated at individual level to improve our understanding of the flood risk components focusing on paddy production. The improved understanding and estimation of flood risk in terms of EAD can help decision makers prioritize investment allocations for flood mitigation projects involving paddy production.

**Acknowledgements** The authors would like to thank the Muda Agricultural Development Authority (MADA), Department of Agriculture and the Department of Irrigation and Drainage especially Tuan Haji Ir Mukhlis Zainal Abidin for supporting the study and providing data and information about the Muda area.

## References

1. Mada.gov.my (2017) Rice industry development program. Official Website Muda Agricultural Development Authority [online]. Available at <http://www.mada.gov.my/en/corporate-information/reports-by-program/rice-industry-development-program/>. Accessed 27 Aug 2017
2. Olesen L, Lowe R, Ambjerg-Nielsen K (2017) Flood damage assessment—literature review and recommended procedure. Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia
3. Kuzminski L, Szalata L, Zwodziazk J (2016) The reality of life during floods. *J Civ Environ Eng* 6(5)
4. Muda Agricultural Department Authority (2008) Senario Kejadian Banjir di Kawasan Muda
5. Firdaus R, Latiff LA, Borkotoky (2013) The impact of climate change towards Malaysian paddy farmers. *J Dev Agric Econ* 5(2):57–66
6. Muda Agricultural Department Authority (2017) Laporan Kejadian banjir dari 20–25 September 2017 di Kawasan Muda
7. Department of Irrigation and Drainage Malaysia (2012) Updating of condition of flooding and flood damage assessment in Malaysia, vol 1. Final report
8. Rehan BM (2018) An innovative micro-scale approach for vulnerability and flood risk assessment with the application to property-level protection adoptions. *Nat Hazards* 91 (3):1039–1057
9. Federal Emergency Management Agency (FEMA) (2001) Understanding your risks; identifying hazards and estimating losses. FEMA 386-2. Washington, DC, Aug 2001
10. Muhadi NA, Abdullah AF (2015) Flood damage assessment in agricultural area in Selangor river basin. *J Teknol (Sci Eng)* 76(15):111–117
11. Olsen A, Zhou Q, Linde J, Ambjerg-Nielsen K (2015) Comparing methods of calculating expected annual damage in urban pluvial flood risk assessments. *Water* 7(1):255–270
12. Chau VN (2014) Assessing the impact of extreme floods on agricultural in Vietnam: Quang Nam case study. Master thesis, Massey University, Manawatu, New Zealand
13. Akasah ZA, Doraisamy SV (2015) 2014 Malaysia flood: impacts & factors contributing towards the restoration of damages. *J Sci Res Dev* 2(14):53–59