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Evaluating the cumulative costs of small-scale flash floods in Kuala Lumpur, Malaysia

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ABSTRACT

The cumulative costs associated with frequent small-scale flash floods have been calculated for Kuala Lumpur, Malaysia, to get an insight on damages and losses. There is limited information on the impact of frequently occurring small-scale events compared to large-scale or catastrophic disasters, particularly with respect to its overall implications on the economy at the city level. Such information would support the formulation of effective disaster risk reduction strategies. The study evaluated the direct and indirect damage cost of 204 flash floods in Kuala Lumpur between 2010 and 2016 using a heuristic approach to compensate for data scarcity, and drawing on the market price and restoration cost method. The assessment relied primarily on secondary data from various government departments and relevant authorities. The results revealed that the total flash flood damage was as high as RM48.7 million, which represented 0.04% of the gross domestic product (GDP) of Kuala Lumpur in 2016. Direct costs were associated with damage to roads as well as commercial and residential areas to a lesser extent, while loss of productive time was the leading factor for indirect costs. Indirect damage costs are up to four times higher than direct damages, with disrupted road networks being the highest contributor to both costs. Moving forward, risk reduction strategies should focus the transportation sector. The findings of this study is useful baseline information for future projection of damages and losses due to small-scale flash floods in Kuala Lumpur.

1. Introduction

The frequency and damage due to disasters arising from climate hazards have been increasing over the past decades (Attary et al., 2020; Hallegatte, 2014; Shabnam, 2014). One reason for this is the increase in temperature of the earth's surface, air, and water. The continuation of increasing temperature trends is likely to cause further increases in the frequency and intensity of various climate-related extreme events (Runkle et al., 2018; IPCC, 2021). The risks to densely populated areas are expected to be magnified (IPCC, 2022). While major and catastrophic disasters with casualties are severe enough to attract attention, small-scale climate-related events are often overlooked despite their higher frequency. The cumulative impact of the small-scale events merits further investigation, especially in urban areas, to better understand and implement more efficient risk reduction measures.

Flash floods generally result from intense rainfall, dam or levee failure or rapid snowmelt with less than six hours of duration (Samsuri et al., 2018). They are characterized by sudden rise in the water level, relatively high velocity, large amounts of debris, and short duration with high frequency (Buslima et al., 2018). They are mostly unpredictable and may have a detrimental cumulative impact on the affected community. Flood events with pluvial characteristics have a short duration of about less than six hours with relatively shallow floodwater depths (Nizam et al., 2019). In this study, small-scale flash floods are defined as short duration events of about less than six hours with shallow depths of flood waters, generally less than two meters, with limited spatial extent, and without associated fatalities. The occurrence of flash floods in urban areas are expected to increase with extreme rainfall events due to global warming, making it imperative for such localised events be assessed retrospectively and prospectively.

Malaysia is adversely affected by extreme weather events. Between 1998 and 2018, the country experienced approximately 51 major

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disasters, affecting 3 million people with 281 deaths, with total damages estimated at US$2 billion (Ringgit Malaysia RM 8 billion) (Zurairi, 2018). Floods are the most common disaster in the country (Yusoff et al., 2018). The rapid economic development of Kuala Lumpur has also contributed to uncontrolled structural development and environmental degradation (Pereira et al., 2010; Vaghefi et al., 2017). In conjunction with extreme rainfall events, this has contributed to increased incidences of flash floods. While no fatalities have been reported, flash floods have affected the city centre by causing heavy traffic jams and hindering mobility, which disrupts daily activities in the city (Bhuiyan et al., 2018a, 2018b). In the context of those affected, the flash floods are disaster events. Their livelihood is affected, and there is massive clean-up of impacted areas, including repair or replacement of damaged property such as cars, appliances and houses.

The coverage of the impacts of flash floods has been minimal in the literature. The cumulative economic costs of frequent small-scale events are unknown. Hence, it is largely unclear how these impacts can be evaluated in the future. Climate-related disaster events disrupt various productive activities. Therefore, analysing the costs involved with that disruption and damage is important to build resilience and achieve the goals of a sustainable city. The purpose of this study is to provide baseline information on costs associated with frequent small-scale flash floods in Kuala Lumpur. The damages and losses associated with 204 flash flood events between 2010 and 2016 in the city will be evaluated. The proportionate costs in terms of the city's gross domestic product (GDP), which has never been reported previously, will also be determined. The ensuing section presents a review of the literature, followed by the methodology that was used in the study. This is followed by results and discussion, and a final section on the conclusions of this study.

2. Literature review

2.1. Disaster impact assessment framework

Disaster impacts can be represented by direct and indirect damages, and distinguished further with respect to the tangibility and intangibility of the damage elements. This approach includes economic and non-economic impacts (EMA, 2002; Garcia-Aristizabal and Marzocchi, 2012; Hallegatte, 2014; Hochrainer-Stigler, 2012; Mechler et al., 2010; Meyer et al., 2013; Safaie et al., 2017; UN General Assembly, 2016). Direct and indirect damages are distinguished based on the occurrence time of damage, direct contact of the hazard, and the location (whether in a disaster area or not) of the damage. The tangibility of the damages is decided based on marketability, measurability, and monetary value of the affected items (Hochrainer-Stigler, 2012; Jonkman et al., 2008; McKenzie et al., 2005). In this framework, all physical, stock, monetisable, and priceable elements are denoted as tangible. They are further classified as direct if the elements were caused by direct contact within the hazard area during the hazard event (EMA, 2002; Garcia-Aristizabal and Marzocchi, 2012; Hochrainer-Stigler, 2012; Mechler et al., 2010; Meyer et al., 2013) as well as during the hazard event (Hallegatte, 2014). Similarly, all affected elements that are not physical, not traded in the market, unmeasurable, and not monetisable are categorised as direct intangible damage. The indirect damage elements are those affected due to the consequence of the direct damages of the disaster, not necessarily within the hazard area, and during the time of the hazard. This is supported by the theories that the total direct damage will have a consequential impact, that is, indirect damage (Mechler & Hochrainer, 2010).

This study conceptualises disaster impacts due to flash floods where such events are considered disasters in the local context, specifically for the affected population of Kuala Lumpur. The city's susceptibility refers to its sensitivity to the hazards. Its vulnerability includes the 'damageability' of the physical elements, such as several types of houses (i.e., single-story houses/landed houses, bungalow, and multi-story buildings), with respect to their damage rate, road, and transportation network, clean-up costs, and traffic congestion-related costs including repair and replacement costs. The cost and damage rates can differ across land use classes, and types of houses and assets. For example, the cleaning cost of single-story houses/landed houses in residential areas will differ from the cost for the same type of house in commercial areas (as the rates for basic amenities and services are higher for areas classified as commercial).

Table 1
Flash floods and flood damage evaluation in previous studies.

Impact type	Flood characteristics/level of damage	References
Direct damage	679 properties and 381 content claims	(Spekkers et al., 2011)
	Insurance claims for 195 private buildings	(Grahn and Nyberg, 2014)
	75-ha area of crop land affected	(Vozinaki et al., 2015)
	High number of death and injury by flash flood	(Li et al., 2019; Špitalar et al., 2014; Terti et al., 2017)
Direct and indirect damage	Over 1800 people died and a colossal economic loss of billions of US dollars. Over 20 % of the total area and more than 14 million people were affected.	(Mahmood et al., 2016)
	2 m high flash flood in Kajang city of Malaysia inundating half of the city	(Bari et al., 2021)
Economic and non-economic damage	75 % of the city's area (study area) was inundated, causing 150 deaths and Rupi 160 billion (approximately US$3.5 billion) in economic damages.	(Bahinipati et al., 2017)
	10 years of localised flood events	(ten Veldhuis, 2011)

2.2. Data scarcity in flash flood damage estimation

Flash flood impacts differ from place to place. In Europe, between 1950 and 2006, about 40 % of the total casualties from all types of disasters arising from natural hazards were due to flash floods (Barredo, 2007). Comparatively, in Malaysia, flash floods only caused 3 % of the total fatalities from all types of disasters (EM-DAT, 2020). Furthermore, fatalities are not associated with small-scale flash floods in Malaysia (Bhuiyan et al., 2018a). However, despite very insignificant casualties, the risk of social and economic damage may still be significant, even though early warning systems have been improved (Marchi et al., 2010; Montz and Gruntfest, 2002; ten Veldhuis, 2011). In Kuala Lumpur, the adversity associated with flash floods is reflected through physical damage, clean-up costs, mobility disruption, and traffic congestion (Samsuri et al., 2018). Some of these impacts have further adverse consequences such as delays in getting to work, spending more time idly on the road, additional fuel cost, disruption of daily activities, and the opportunity cost of productive work. This type of impact, which happens due to the direct or immediate destruction or disruption caused by the disaster events, is called an indirect impact (Hallegatte, 2014; Hochrainer-Stigler, 2012; Koks et al., 2015; Kousky, 2014; Kreibich et al., 2014; Meyer et al., 2013; Safaie et al., 2017; UN General Assembly, 2016). Many of the indirect impacts are short-term losses, which may not be measurable by stock losses (Kajitani and Tatano, 2018).

Most flash flood impact studies cover historical events (ex-post) that are severe, widespread and involving fatalities, or large insurance claims (Table 1). With respect to damage-related information and extent of affected elements, the assessments have notable property damage elements and other impact volume i.e., affecting larger areas, higher death toll, and larger number of affected people, (Grahn and Nyberg, 2014; Spekkers et al., 2011; Vozinaki et al., 2015). Flash floods that cause deaths and injuries are given serious attention, and studied with greater urgency (Li et al., 2019; Špitalar et al., 2014; Terti et al., 2017). However, flash floods have become an important research area due to their

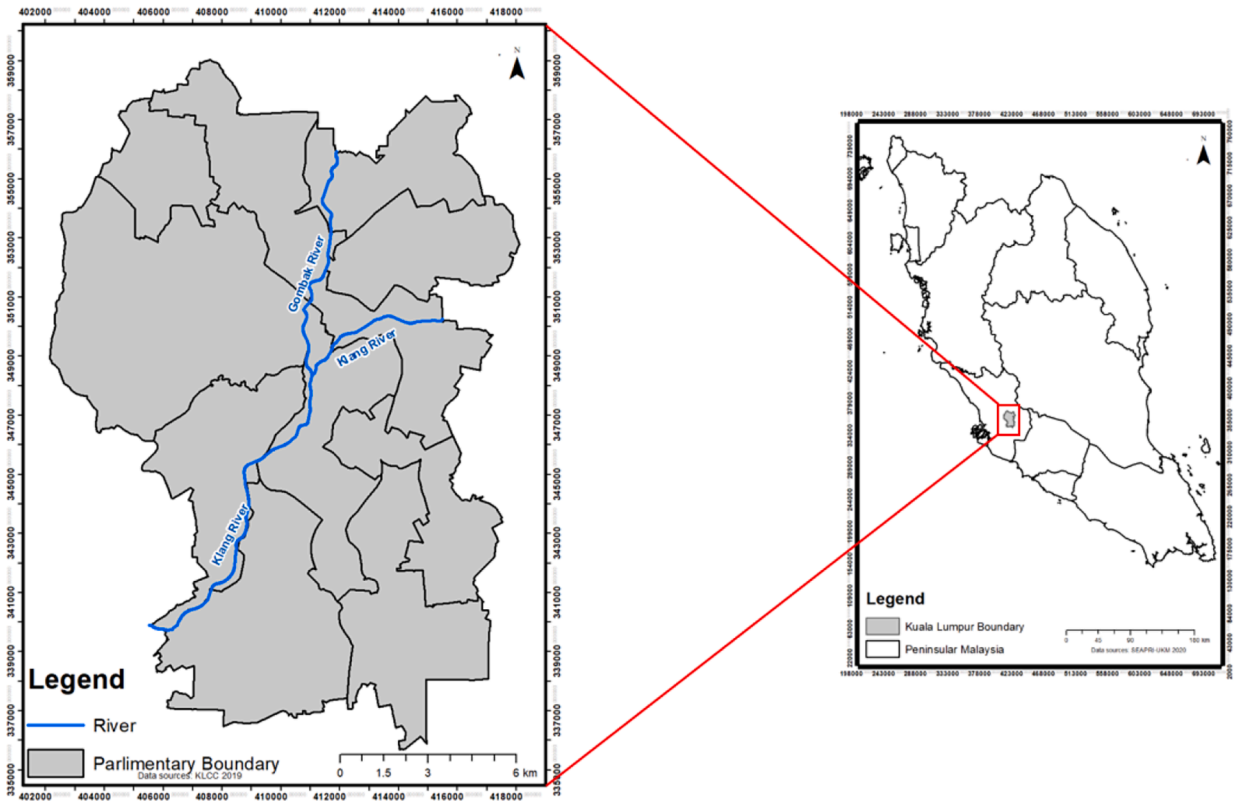

Fig. 1. The study area, the federal territory of Kuala Lumpur.

wide range of impacts and damage capabilities, as well as anticipated increase in frequency and intensity due to global warming.

Looking at the methodological approaches, most studies require extensive data and a combination of hydrological information (Garrote et al., 2016; Kefi et al., 2018; Le Bihan et al., 2016). The required data includes insurance data which has limited accessibility due to privacy policy of insurance companies (Grahn and Nyberg, 2014; Spekkers et al., 2011), digital topographic map, flood water depth and flow velocity, land use information, and simulated flood inundation parameters (Vozinaki et al., 2015), fatalities data, flood points, event data (Li et al., 2019; Špitalar et al., 2014; Terti et al., 2017), population statistics, topographic map, drainage pattern data, land use map, damage map, and primary survey (Bari et al., 2021; Mahmood et al., 2016). Such a high amount of data may not be available for all cases. In reality, many developing countries have an extremely limited amount of the relevant information for conventional evaluation. Therefore, approaches that require both primary (field survey data) and secondary data (data collected by third party), as well as the incorporation of hydraulic information and depth-damage curves, have extremely limited applicability when data is scarce. As such, several impact assessment studies use insurance claims (Grahn and Nyberg, 2014; Spekkers et al., 2011), synthetic flow velocity–flood depth-crop damage curves (Vozinaki et al., 2015), and hydraulic models for simulating flood damage assessment (Kefi et al., 2018; Le Bihan et al., 2016; Vozinaki et al., 2015; Xia et al., 2011; Zeng et al., 2019). Such detailed information is generally available for major flood events or catastrophic flash flood events, where the stakeholders record and have access to more useful information. Although the stage-damage functions are well designed, the damage results are affected by uncertainties and questionable transferability of the models (Arnell, 1989; Cammerer et al., 2013; de Moel and Aerts, 2011; Büchele Kreibich et al., 2006). The models and methodologies used in above mentioned studies require integration of hydraulic aspects and physical sciences, which may not be possible for small-scale events due to insufficient information availability. Such information is certainly unavailable in the context of Malaysian flash floods. There is a gap in the literature on damage assessment of flash flood events for which information is limited. In addition, the usability of these models also becomes limited due to unavailability of specific depth-damage or stage-damage functions (Romali et al., 2018). Therefore, this study uses the best available secondary data for calculating the direct and indirect damage related cost of flash floods. It contributes to the literature by assessing small-scale events, which have been largely overlooked, and addresses the methodological limitations due to data scarcity by implementing a heuristic approach for assessing disaster damage with limited data availability.

3. Methodology

3.1. Location and description of the study site

The study was conducted in the Federal Territory of Kuala Lumpur, the capital city of Malaysia. The city is located in the centre of Selangor state and covers an area of 243 km^2 with an estimated population of 1.79 million as of 2015 (Department of Statistics Malaysia Official Portal, 2015). The City Hall of Kuala Lumpur (DBKL) administers 11 parliamentary constituencies (Fig. 1).

There are two major rivers in Kuala Lumpur, the Sungai Klang and the Sungai Gombak. The rapid pace of development has contributed to the problem clogged drainage in the area around this confluence. Thus, the rivers overflow due to high precipitation and often cause flash floods in low-lying areas (Hong & Hong, 2016). Extreme weather conditions such as greater intensity of rainfall is expected to increase in the future. This has been supported by Drainage and Irrigation Department (DID) reports that estimated that the one-hour rainfall intensity in 2000–2007 period increased by 17 % compared to the past (Ismail et al., 2018).

Table 2
Data points, descriptions, sources, and unit of measurements.

Data points	Descriptions	Sources	Unit of measurement	Used values (RM)
Clean-up cost	The household, infrastructural, and commercial cleaning cost after flash flood. Clean-up cost for buildings, house type, road, and river according to the land use (residential and commercial areas).	DBKL (collected in 2018)	Residential road cleaning = Per kilometre	278.7
			Commercial road cleaning = Per kilometre	557.4
			Landed house (Per house)	7.8
			Flat/multilevel buildings (Per house)	5.45
			Commercial buildings/areas = Per unit	12.5
			Res. Drain = Per kilometre	348.38
			Comm. Drain = Per kilometre	696.76
			Residential car parking area = Per square meter	0.0402
			Commercial car parking area = Per square meter	0.0402
Damage rates per asset	Damage ratio for buildings/houses and complexes	(DID, 2003)	Kampung house (per house)	9225
			Bungalow house (per house)	11,360
			Terraces houses (per house)	10,260
			Flat/apartment (per apartment)	6600
			Commercial buildings:[a]Small (per unit)	12,000
			Medium (per unit)	24,000
			Large (per unit)	160,000
	Damage ratio for roads	(DID, 2012)	Per kilometre road damage due to inundation	428,550
Traffic control data	Number of vehicles per hour pass through the major roads in Kuala Lumpur. Number of vehicles, motorcycles, lorries, and vans passing through a road.	DBKL (collected in 2018)	Number of each type of vehicle	NA
Other cost parameters for indirect cost calculations	Time Related Vehicle Operating cost (Per hour)	(PWD, 2009)	Car per hour	6.5
	Value of labour time in Kuala Lumpur (Per hour)	(Sander et al., 2015)	Person per hour	40.1
	Fuel used Per hour by a car	(Sander et al., 2015)	Car per hour	2–3 L
	Average Vehicle occupancy	(PWD, 2009)	Per type of vehicle	1.3 persons
	Average Passengers per bus	(Abd Rahim and Nor Ghani, 2006)	Per type of vehicle	25 persons
	Fuel Price per litre	(Sander et al., 2015)	Per litre	RM 2
Land use map	Land use map classification of Kuala Lumpur	DID and SEADPRI[b] (Collected in 2018)		NA
Hazard Map	Locations of historical hazard events	DID and SEADPRI* (Collected in 2018)	Flood location, Area (ha)	NA

Small structures are less than 0.15 ha in size, medium ones are larger than 0.15 ha, and the large structures include the multilevel complexes (DID, 2003).
Southeast Asia Disaster Prevention Research Initiative (SEADPRI).

3.2. Data collection

This study used secondary data for calculating the cost of flash flood damages. The secondary data include land use classes, flash flood maps, and damage unit values (DUVs) for different assets and property types such as roads, landed/single-story houses, bungalows, Kampung houses (village houses), flats/apartments, terraced houses, and commercial buildings. However, there are no damage and loss value available for industrial buildings, factories, shops, hospitals, and schools. The damage values of commercial building were used for estimating the cost of these items. This was considered acceptable as the buildings are similar and the difference in the damage caused by shallow levels of flood waters over a short duration is expected to be minimal. Furthermore, the majority of areas in Kuala Lumpur are classified as commercial areas, with minimal industrial zones. Information was also collected on clean-up costs for roads, rivers, drains, and parking areas according to the land use classes. Cleaning costs were estimated based on quoted prices from the cleaning companies that were accepted by DBKL (see Table 2 for the respective values). For indirect tangible costs, the number of cars passing through the affected roads, vehicle occupancy rate, economic time value for Kuala Lumpur, fuel price, and vehicle operating cost were used. Various data points, descriptions, sources, and unit of measurements were used to calculate flash flood damages (Table 2).

The country has specific damage factors for different types of damage to properties and assets for calculating the cost of major flood events (DID, 2012). However, these factors cannot be used for small-scale flash flood events without information on duration and depth of inundation, which is rarely available. The flood damage estimation guideline for the country (DID, 2003) indicates that 1 % of damage unit values of major floods can be used for flash floods. There is no explanation on how the percentage was derived but this is the general assumption by the national government agency in charge of floods. This value was adopted to calculate the building damage ratio for different types of houses. The building damage ratio is the estimated flash flood damage for each type of structure (i.e. houses, commercial block etc.). The estimated damage value for a house is only a portion of the entire value of the structure. The assumption is that flash floods do not destroy an entire house but rather damages it to different degrees depending on the type of house. As Kampung houses (village houses) are generally old and made of wood, they are more vulnerable and it is expected that the damage will be comparatively higher compared to other houses.

The land use map of the federal territory of Kuala Lumpur has the following classes: institutional, residential, trade, industry, green area, and others. The institutional land use class includes all institutional areas in the city such as schools, colleges, universities, hospitals, and other kinds of institutions. The residential land use class includes all housing areas. The trade areas include the busiest parts of the city which are characterised by shopping malls, mini-malls, shops, and places

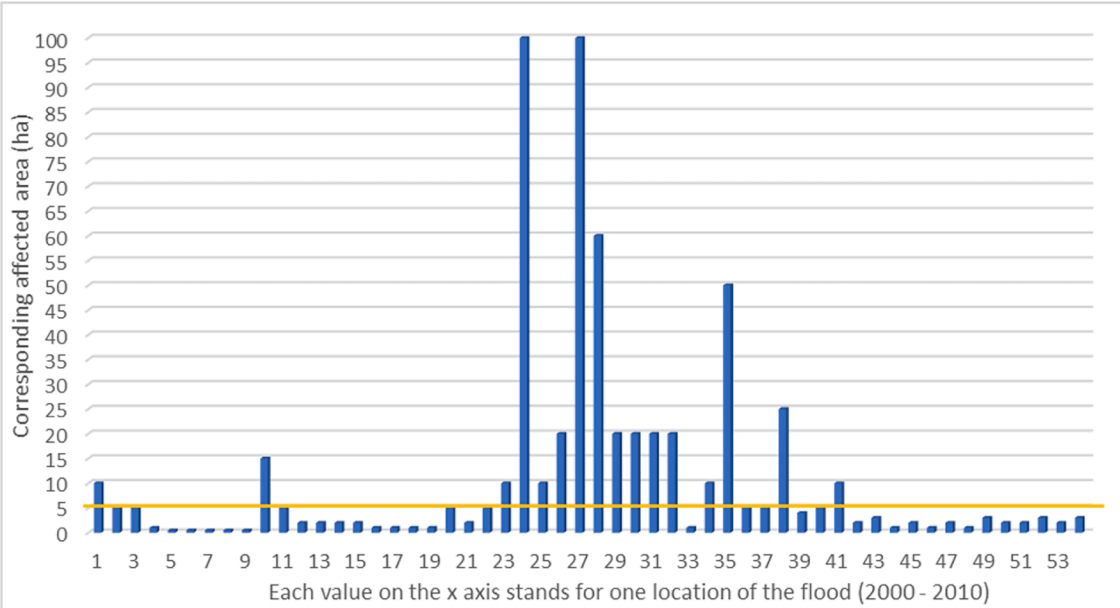

Fig. 2. The size of the inundated area (y-axis) as observed in 53 flooded locations (x-axis) of Kuala Lumpur between 2000 and 2010, where in a majority of the locations, flood waters do not spread beyond 5 ha (yellow line), and the most frequent extent is 2 ha (represented by the mode). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

where business activities are held. The industrial land use class includes firms and factories. The green areas include parks, and land with trees, plants, and grass. The 'other land use' class includes mixed used areas, rivers, roads, and highways. The land use map identifies different land classes through colour coding. While roads are separate land use class in the map, this study divided road damage based on the location of affected roads. For example, if the affected road is located within residential area that road damage was classified road damage in residential area.

3.3. Analysing flash flood locations, inundated areas, and frequencies

This study used ArcGIS software to map the flash flood areas, and to identify and count the affected buildings, types of houses, car parking areas, drains, and other physical properties using the Kuala Lumpur land use map. The physical properties were differentiated according to land use classes such as residential, commercial, industrial, institutional, and other areas.

Flash flood information obtained from the city hall (DBKL) was used to plot the location of flash floods hot spots (points that often experience recurring pluvial flash floods) between 2010 and 2017. The spatial extent of the area inundated by flash floods was not available. Thus, an older dataset for the same area was used to estimate the general extent of small-scale flash floods. The information was obtained from the national flood condition and damage assessment report on flood events from 2000 to 2010 in Kuala Lumpur, which recorded both fluvial and pluvial events (DID, 2012). The task of recording was taken over by the city hall after an underground storm water tunnel (SMART Project) started operations to handle major fluvial floods in Kuala Lumpur. While the timeline of flood events did not overlap, a high number of the locations where the flood events were recorded in both datasets are identical; an indication that the problem of small-scale flash floods was not resolved. The national dataset recorded approximately 79 flood locations in Kuala Lumpur, many of which were linked to 18 major events. The location of 53 flood events was matched in both the datasets and the extent of the corresponding affected area was delineated using information in the national report (Fig. 2). The findings revealed that the average flooded area per location was 10.92 ha, which represents the situation before the SMART Project was in operation, when major floods were prevalent. In a majority of the locations, flood waters do not spread beyond 5 ha, and the most frequent extent is 2 ha (represented by the mode value). Based on this estimation, 2-ha circular buffer zones were created for each flood location of 2010 to 2016 using the ArcGIS software to identify and quantify affected assets.

3.4. Flash flood cost estimation methods

This study evaluates the cost of the direct and indirect damages of flash floods utilising the widely used market price and restoration cost approach (Balbi et al., 2015; Middelmann-Fernandes, 2010; Rayhan and Grote, 2010). The market price approach determines the value of a property based on the selling price of the property or similar property (Freeman et al., 2014). Under this approach, relevant prices i.e., cleaning price, fuel price, value of time were used after adjusting with inflation by using Consumer Price Index (CPI) calculator provided by DOSM which uses 2010 as base year. Restoration cost approach values a good and services based on cost incurred for bringing it back to its original state (Brans, 2005). In this approach different damage unit values (DUVs) for different land use classes and property types as well as repair costs have been used in previous literature (Thieken et al., 2007). Flash floods in Kuala Lumpur commonly require clean-up activities after the event. Hence, cleaning cost data for different property types were used. The property damage and clean-up costs are considered as factors of direct costs of damages.

The direct cost of flash floods was calculated by using DUV and cost per unit for each affected element in the flood area. This can also be utilised in stage-damage function for integrating hydraulic and economic modelling (Jonkman et al., 2008; Zabret et al., 2018). Similar ideas can be implemented by using damage thresholds and unit costs (Olsen et al., 2015). The DUVs are collected from DID which is the authorised body that deals with flooding issues (DID, 2003; Suparta and Rahman, 2016). Using these DUVs and different data points in Table 2, the physical damage and the resulting costs in different land use classes was computed and summed for calculating the cost of flash flood damages. Similarly, indirect cost of flash flood was estimated by evaluating the secondary effect of flash flood (i.e., road affected by flash flood). The secondary effect includes loss of productive time, supply related loss, and traffic congestion cost which were calculated by using relevant

market values such as fuel price, value of time, and vehicle operating cost.

3.4.1. Assumptions related to the cost calculation

Based on the DBKL (2008) city plan, there is a drain on each side of the road. The drainage length was calculated by measuring both sides of affected roads for estimating the clean-up cost for drainage. For indirect cost calculation, the value of time was used as a proxy for the productivity value relating to time. Urban flash floods mostly result in traffic congestion and slowdown of mobility, resulting in loss of time that could be spent on productive pursuits. When the exact duration of disruption is not available, studies often consider the duration of the traffic congestion itself for assessing the impact. The average traffic congestion due to flash floods was assumed to be two hours. Similar assumptions were used to study localised floods in Haarlem, Netherlands (ten Veldhuis, 2011), Shanghai, China (Yin et al., 2016), and Malaysia (Nizam et al., 2019).

Vehicle occupancy for vans and lorries was assumed to be one per vehicle. Motorcycles, cars, and buses was assumed to be used by the workforce, while vans and lorries were used for delivering and supplying goods and services. Out of the 66 affected roads, vehicle per road data was only available for 25 roads. The average value of the 25 roads was used for the remaining roads for which data was unavailable. All roads within the buffer zone were considered as affected by flash floods. Once a road is classified as being affected by flash floods, the traffic mobility of the entire stretch of the road (leading to and from this zone) was considered disrupted.

3.4.2. Direct physical damage in different land use area

The direct physical damage in residential areas is comprised of damage to different types of houses, an approach followed in previous studies (Chiba and Prabhakar, 2017). The approach to attribute damage unit value for assessing direct physical damage in the commercial area is calculated based on the size of buildings. In this approach, the structures are divided into three categories: small, medium, and large. The road damage was calculated based on total length of road inundated and damage rate per kilometre inundated road (DID, 2012).

Clean-up costs comprise cleaning different types of houses in different land use classes, drainage systems, and sweeping costs for roads and car parking areas. Flash flood-related clean-up costs are implied for different elements affected such as multilevel buildings, single-story houses/landed houses, and shops/lots where sediment removal cost is included (Zabret et al., 2018). In terms of clean-up cost, the clean-up charges differ on whether the house is a single-story/landed house and whether the location is a residential or a commercial area. The rates are derived from the quotation given to DBKL from cleaning service companies. The equation for estimating direct cost of flash floods in a year is presented below (equation (1)–(3)).

$$Dffc = sd + Cc \tag{1}$$

$$sd = \Sigma_{i=1}^{n}(St_i \times Duv_i) \tag{2}$$

$$Cc = \Sigma(St_i \times Scc_i) + \Sigma(P_j \times Pcc_j) + \Sigma(R_k \times Rcc_k) + \Sigma(D_m \times Dcc_m) \tag{3}$$

where

Dffc: Direct flash flood cost.
Sd: Structural damage cost.
Cc: Cleaning cost.
St_i: Different structure type per land use area.
Duv_i: Damage unit value for each St_i.
Scc_i: Structure cleaning cost.
P_j: Parking areas.
Pcc_j: Parking area cleaning cost.
R_k: Road lengths.
Rcc_k: Road cleaning cost.
D_m: Drain length.
Dcc_m: Drain cleaning cost.

3.4.3. Cost of indirect tangible damage

The components of the indirect tangible cost of flash floods calculation are productive time loss (*Lpt*), goods and services delivery related time loss (*Srl*), and traffic congestion costs (*Tcc*). The goods and services-related time loss refers to additional time wasted in delivering and supplying goods and services due to traffic delays (specifically in terms of vans and lorries). The traffic congestion cost refers to the sum of the cost involved for operating vehicles for extra time due to flash flood-induced traffic congestion. The unit cost value used are shown in Table 2.

The equations for estimating the indirect cost of flash floods in a year are presented below (equation (4)–(7)).

$$Idffc = (Lpt + Srl + Tcc) \tag{4}$$

$$Lpt = [[Mcl \times vt] + (Car \times Ocv_{car} \times Vt) + (Bus \times Ocv_{bus} \times vt)] \times Dur \times Frq \tag{5}$$

$$\boldsymbol{Srl} = \left[\{(Van \times Ocv_{Van} \times Vt) + (Lory \times Ocv_{Lory} \times Vt)\} + \{(Van \times Voc) + (Lory \times Voc)\} + \{(Van \times Fcom \times Fp) + (Lory \times Fcom \times Fp)\}\right] \times Dur \times Frq \tag{6}$$

$$\boldsymbol{Tcc} = [\{(Mcl \times Voc) + (Mcl \times Fcom \times Fp)\} + \{(Car \times Voc) + (Car \times Fcom \times Fp)\} + \{(Bus \times Voc) + (Bus \times Fcom \times Fp)\}] \times Dur \times Frq \tag{7}$$

where

Idffc: Indirect flash flood cost.
Lpt: Loss of productive time.
Srl: Service-related loss.
Tcc: Traffic congestion cost.
Mcl: Number of Motorcycle affected.
Vt: Value of time in KL per hour (labor time) per person.
Car: Number of cars affected.
Ocv_{car}: Average occupancy of a Car.
Bus: Number of Buss affected.
Ocv_{bus}: Average occupancy of a Bus.
Dur: Average duration of floods.
Frq: Frequency of roads affected.
Van: Number of vans occupied.
Lory: Number of lories occupied.
Ocv_{van}: Average occupancy of a van.
Ocv_{lorry}: Average occupancy of a lory.
Fcom: Fuel consumption per hour.
Fp: Fuel price in the market.
Voc: Vehicle operating cost per hour.

3.4.4. Sources of uncertainty

It should be noted that the estimations of this study have some uncertainties that should be considered while making decision based on these results. Firstly, the assumption of setting 1 % of major flood damage values for flash floods is an uncertainty of concern. Although this percentage is applied for building damages only, it has to be considered as a lower bound estimation. Secondly, due to unavailability of inundated area data of flash flood events, using average conditions for all flash flood events may further underestimate the costs. This will downsize the cost level of all elements including indirect damages as well. Due to the existence of relatively more congested built-up areas and infrastructural facilities in urban areas, the cost is expected to be much higher if more severe floods are included in the analysis. Despite

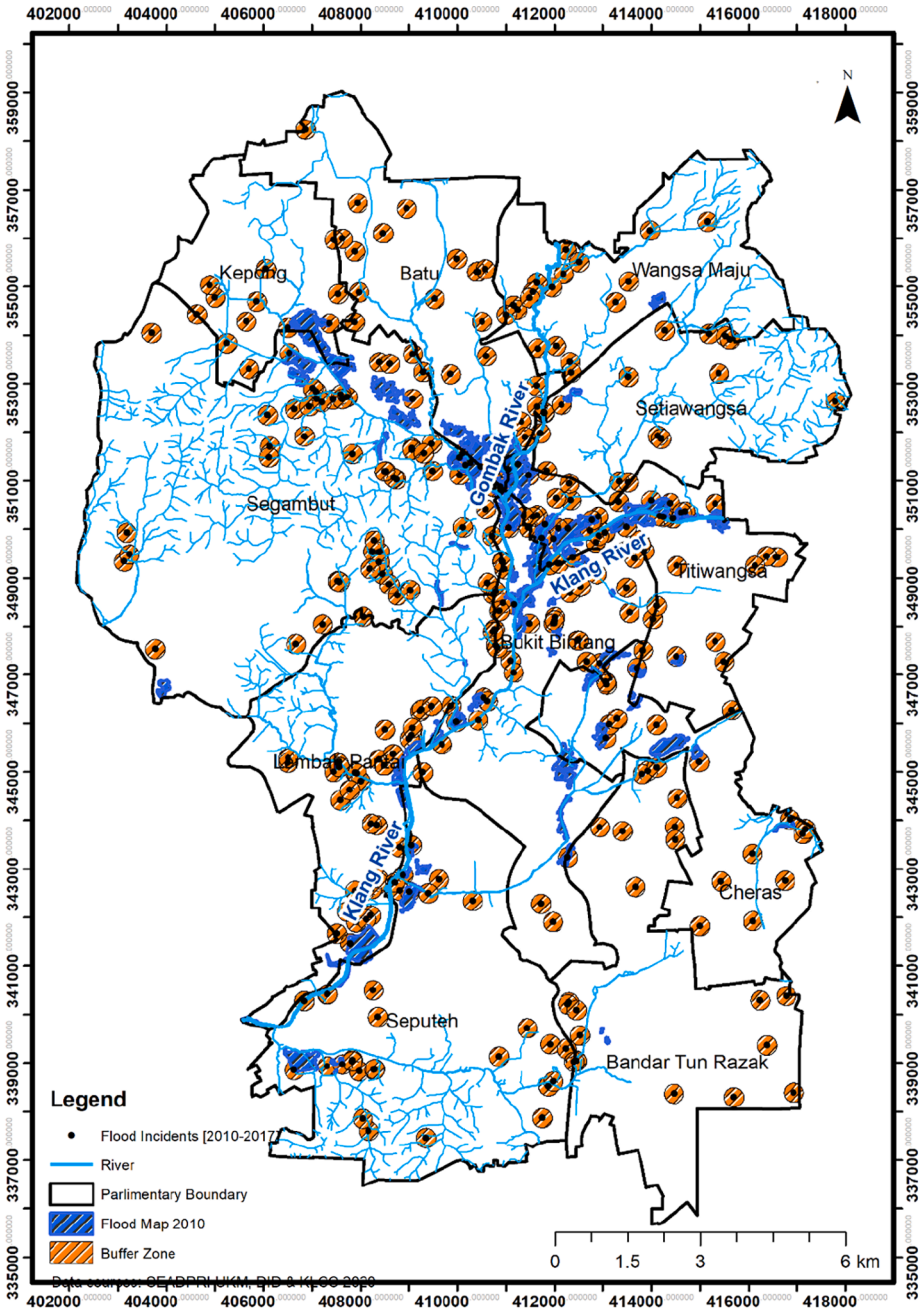

Fig. 3. Flood extent and flash flood locations in Kuala Lumpur. The blue zones are the areas that were flooded prior to 2010 as mapped by DID, and the orange circles represent buffer zones around flash flood events that occurred between 2010 and 2016. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

these uncertainties, the simplified and conservative method used in this study will still be able to provide useful insights to relevant stakeholders for planning and decision-making.

This study has its limitation for not being able to include various other cost aspects owing to data scarcity. For example, the latest data on rainfall intensity and duration, and several other meteorological and hydrological data were not found for the flash flood events. The direct tangible costs could include data on household contents which may be damaged or lost due to flash floods, the economic value of damage caused to affected vehicles, and the cost incurred by shops and business outlets as well as business interruptions. Adding these costs factors may increase total direct tangible costs of flash floods significantly.

4. Results and discussion

4.1. Flash flood locations and frequencies

Flash floods are common in Kuala Lumpur. A majority of the flash floods are located in the central part of the city, along the Gombak and Klang rivers and their major connecting branches (Fig. 3). There are several areas with high density of river networks such as in the eastern and western parts of the city, which have not experienced flash floods. These high density networks are located in relatively higher ground and have been converted into open concrete drains to service surrounding built-up areas, as part of the development process. The water in these drains flow downward into the connecting branches in the lower terrain,

Table 3
Number of floods per considered year.

Years	2010	2011	2012	2013	2014	2015	2016
Number of flash floods	14	23	24	35	8	39	61

which then empty into the Gombak and Klang rivers. Many of the connecting branches have also been converted into open drains for adjacent built-up areas. In some areas, the natural channels have been filled and the drains are more narrow that the original waterway. The combination of built-up areas and conversion of natural channels into concrete drains have impeded the capacity of water infiltration after rainfall in much of Kuala Lumpur. The rapid runoff of water after a heavy rainfall along fewer surface water paths in some areas, then accumulates in the relatively lower terrain along the Gombak and Klang rivers as well as its confluence in the central part of the city, resulting in flash floods. This issue of reduced infiltration capacity has also been highlighted in previous studies where it is suggested that retaining water for infiltration and preserving water bodies works better than constructing large pipes for ensuring flood safety (Kefi et al., 2018).

A total of 204 flash flood events were recorded in Kuala Lumpur between 2010 and 2016 (Table 3). The highest number of events occurred in 2016 (61 events) and the lowest was in 2014 (8 events. Except for 2014, the frequency of flash floods appears to have increased over this period. All the events were taken into account in the evaluation of damages and losses.

4.2. Costs of flash floods

4.2.1. Cost of direct flash flood damage

The cost of direct damage due to flash floods is presented according to the land use categories in Kuala Lumpur (Table 4). The results show that the direct costs in the residential areas exceeded a million ringgit in 2012, 2013 and 2016 with RM1450904, RM1273742, and RM2011734, respectively. In 2013, 2015, and 2016 the direct costs of flash floods in the commercial areas were higher compared to other years with monetary loss of RM 2518816, RM2101084, and RM3759675, respectively. The direct cost of flash flood damage was also found in other land use areas in 2015 and 2016; exceeding a million-ringgit of damage valued at RM2608061 and RM1096651, respectively (Table 4). The institutional and industrial areas had lower direct damage. This lower damage is attributed to the lesser extent of industrial and institutional areas in Kuala Lumpur. Although there are many institutions (e.g., educational buildings and hospitals) in the city, this land use category had lower damage due to the lesser number of flash floods in these areas. The total direct cost increased annually except for 2014 due to the low number of flash floods events in that year (Table 3). The three highest damage costs due to flash floods were in 2013, 2015, and 2016; amounting to RM4121883, RM5819043, and RM8066458, respectively (Table 4).

The direct flash flood damage included road damage due to inundation, building damage and clean-up activities (Fig. 4). The results showed that residential and commercial areas were leading in road damage (Fig. 4a). The commercial areas also had high costs due to road damage in 2010, 2011, 2012, and 2013, with approximately 69 %, 49 %, 47 %, 61 % of total road damage, respectively. The residential areas had the second highest road damage in most of the years, especially in 2011, 2012, 2013, and 2014, with approximately 37 %, 47 %, 31 %, and 34 % of total road damage, respectively. The third highest rate of road damage were from other land use areas. Notable road damage years in this land use category were in 2010 (20 %), 2014 (27 %), and 2015 (46 %) (Fig. 4a). In terms of building damage, the residential areas had the leading rate of building damage in 2010 (82 %), 2011 (60 %), 2013 (51 %), and 2014 (81 %). The commercial areas had the leading rate of building damage in 2015 (66 %) and 2016 (52 %). In 2012 and 2013, the commercial areas had almost equal rates of building damage with residential areas, with 44 % and 48 % of damage respectively (Fig. 4b).

In terms of cleaning costs, the commercial areas had the highest rate of cleaning cost due to flash flood with highest rates in 2011 (57 %), 2012 (60 %), 2013 (73 %), and 2014 (50 %). The rest of the years also had more than 40 % of cleaning costs in commercial areas (Fig. 4c). The cleaning cost was higher in the commercial areas due to the higher price rate of cleaning activities for this land use category. The building damage (Fig. 4d) were expectedly lower as flash floods in Kuala Lumpur do not usually cause much physical damage due to their lower intensity and magnitude. Building, structure, and material related damages are mostly related to the inundation level and its duration. As these elements are resistant to short-duration floods (Grahn and Nyberg, 2014), they expectedly experience less damage from small-scale flash floods. Overall, the cost categories were found to be highest in commercial areas followed by residential areas and other land use areas (Fig. 4d). In addition, costs associated with road damage was the leading category for flash floods in the city. A possible reason is that road maintenance is highly expensive and they are also very vulnerable to inundation (Nizam et al., 2019). When a road is repeatedly inundated, the strength of the material that is used to make the structure decreases, and even gets damaged; which involves higher expenditure to restore (Ghani et al., 2016).

4.2.2. Cost of indirect flash flood damage

The results of indirect damage related costs showed that loss of productive time related costs exceeded a million ringgit for all studied years. However, the costs exceeded RM15 million in 2015 and 2016, amounting to RM19405416 and RM29135955, respectively (Table 5). The supply related loss and traffic congestion related costs had similar ranges in all years. The highest supply related loss were in 2013, 2015 and 2016, with values of RM1788534, RM3702375 and RM5488670, respectively. Similarly, the highest traffic congestion related loss occurred in 2013, 2015 and 2016, amounting to RM1951618, RM4059560, and RM6010995, respectively. High indirect costs occur when small-scale pluvial flash floods spatially and temporally reduce the connectivity and accessibility of people (Yin et al., 2016). A large number of people are stuck on the road, which cause loss of their productive time, additional fuel and vehicle operating related loss (Pyatkova et al., 2019).

Comparing three indirect cost categories, the results show that loss of productive time related cost was the leading source of indirect cost, which contributed 70 %–73 % of the annual cost (Fig. 5). In comparison,

Table 4
Costs of direct damages due to flash floods (in RM).

Years	2010	2011	2012	2013	2014	2015	2016
Residential (RM)	68,806	947,133	1,450,904	1,273,742	268,640	778,460	2,011,734
Commercial (RM)	706,879	1,208,592	1,440,744	2,518,816	225,815	2,101,084	3,759,675
Industrial (RM)	0	96,595	550	0	0	71,551	309,360
Institutional (RM)	65,581	151,202	14,919	199,495	68,104	259,888	889,037
Other Land use areas (RM)	201,010	109,742	168,529	129,831	198,299	2,608,061	1,096,651
Total direct cost	**1,042,275**	**2,513,264**	**3,075,646**	**4,121,883**	**760,857**	**5,819,043**	**8,066,458**

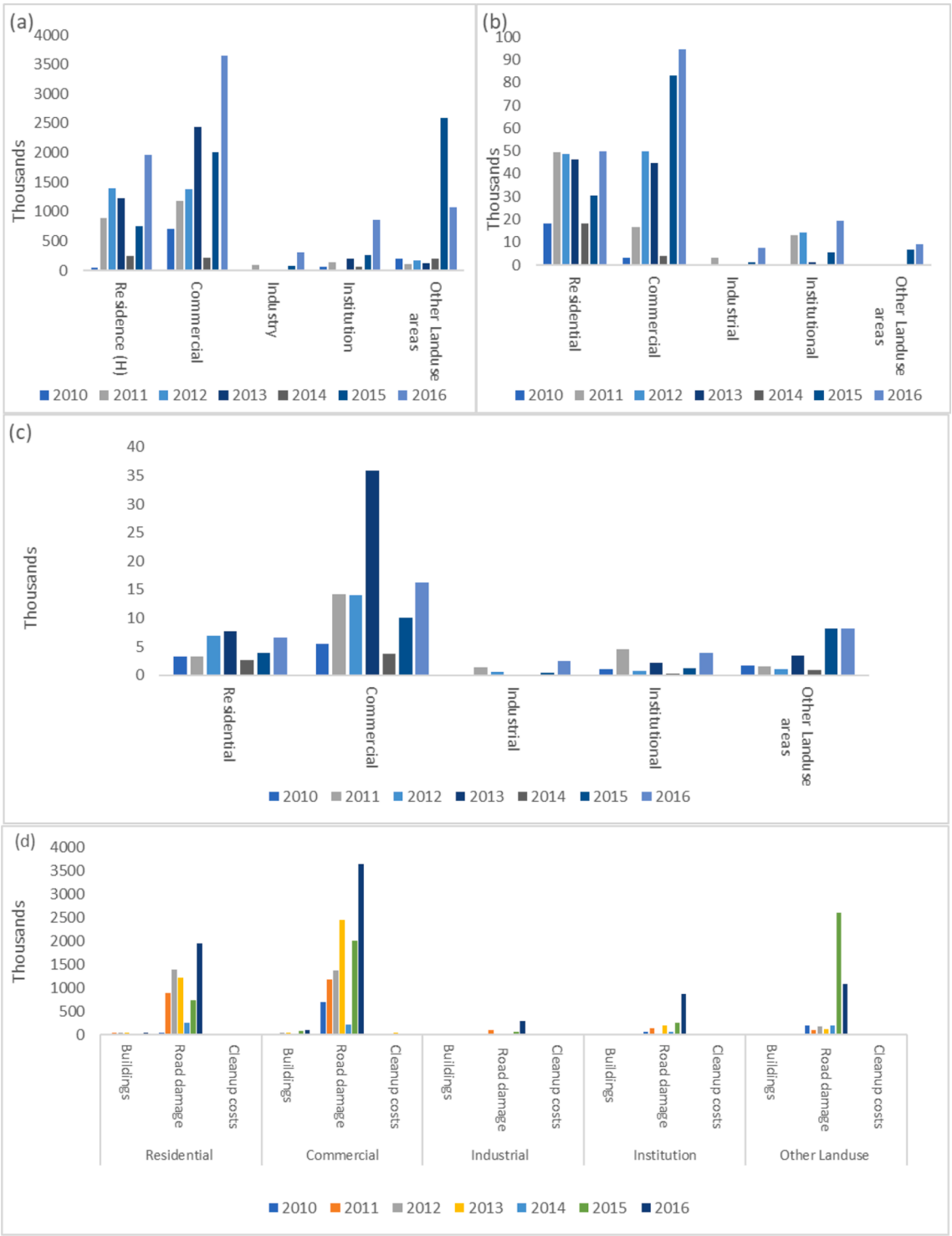

Fig. 4. The direct flash flood cost distribution according to land use categories, showing (a) road damage, (b) building damage, (c) clean-up cost, and (d) all direct flash flood cost categories in land use areas.

Table 5
Cost of indirect damages due to flash floods (in RM).

	Years						
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Loss of Productive Time *Lpt* (RM)	2,487,306	2,895,904	5,334,422	9,301,917	3,459,413	19,405,416	29,135,955
Supply-Related Loss *Srl* (RM)	506,884	510,681	1,044,639	1,788,534	624,740	3,702,375	5,488,670
Traffic congestion cost *Tcc* (RM)	502,129	594,735	1,136,677	1,951,618	656,554	4,059,560	6,010,995
Total Indirect costs	**3,496,319**	**4,001,320**	**7,515,738**	**13,042,070**	**4,740,707**	**27,167,352**	**40,635,619**

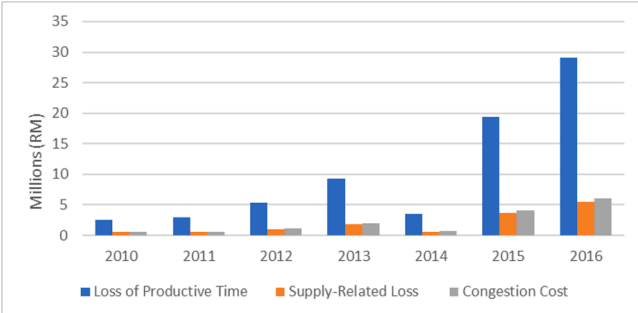

Fig. 5. Comparison between indirect cost categories.

supply related loss and traffic congestion related costs varied between 13 % and 15 % of contribution during the same period. The productive time related costs was higher because the flash floods indirectly affected a large number of people. On the other hand, although supply related loss had contributed less, the delay in services such as delivering goods and services may have further economic consequences. Therefore, these indirect damage aspects demand more careful attention.

4.2.3. Total flood damage cost

A comparison between total direct and total indirect costs indicate that the level of indirect costs is much higher than the direct loss (Fig. 6). The reason is that flash floods directly affect fewer people and cover less area as they are of small-scale in nature. Therefore, direct damages are logically lower than indirect costs (Grahn and Nyberg, 2014). However, flash floods affect a larger number of people by disrupting road-networks on which a significantly larger number of people and their productive activities are dependent (Pyatkova et al., 2019; Yin et al., 2016). As a result, while direct flash flood costs hardly exceeded RM5 million (Fig. 5a), the indirect costs were always more than RM5 million and even exceeded RM20 million in 2016 (Fig. 6b). The results also indicate that the road network was a major part of flash flood damage in terms of both direct and indirect costs. The flood inundation related road damage significantly inflated direct damage compared to clean-up cost and building damage. The reason for lower damage to buildings was due to the lower inundation level and shorter duration. However, as roads were frequently affected by flash floods and there were more road structures in the study area due to its urban characteristics, the road damage was higher. The reason for direct and indirect flash flood costs being very high in 2015 and 2016 was due to higher frequency of flash flood occurrences and affected roads in these two years. The cost of flash floods was comparatively low in 2010, 2011 and 2014 due to two reasons. Firstly, in these years, flash flood frequency was low and secondly, the number of roads affected by flash flood was comparatively low as well.

A comparison of total clean-up, physical damage, indirect, and total costs (Fig. 7) show that the clean-up cost is very negligible compared to the other cost categories. The physical damage, which included road damage and building damage was also much lower compared to indirect costs. In this case, the evidence clearly reveals that the indirect cost of flash floods was not only higher but is also increasing. Flash flood-induced traffic congestion affects the work force (Benjamin, 2017), which would induce additional economic cost due to traffic congestion, productive time loss and service-related loss. This has not been accounted for in this study. As the major source of indirect tangible loss

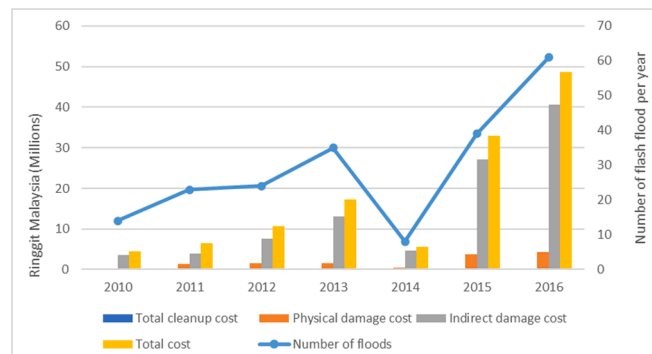

Fig. 7. Overall flash flood cost distribution per cost categories.

Table 6
Total flash flood costs against Kuala Lumpur's GDP.

Year	GDP of Kuala Lumpur (RM)	Total flash flood cost	Total costs (as % of GDP)
2010	169,971,000,000	4538593.6	0.003
2011	169,971,000,000	6514583.2	0.004
2012	160,490,000,000	10,591,384	0.007
2013	152,477,000,000	17,163,952	0.011
2014	140,534,000,000	5501564.2	0.004
2015	131,514,000,000	32,986,395	0.025
2016	122,890,000,000	48,702,077	0.040

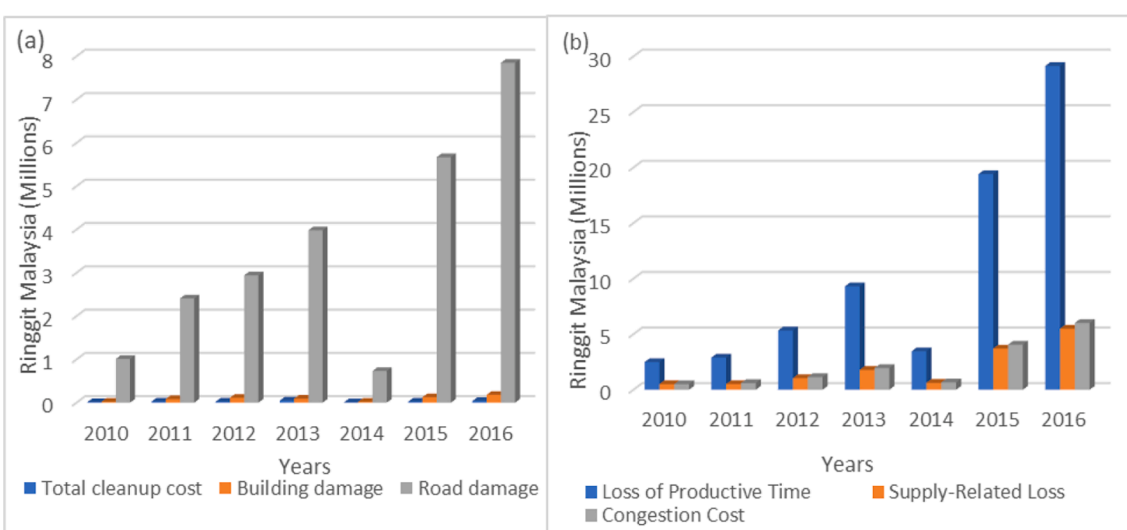

Fig. 6. Comparison of (a) total direct cost and (b) total indirect cost of flash floods.

Table 7
Total flash flood loss with respect to the frequency of events and affected roads.

Year	Flood frequency	Affected roads	Total flash flood cost (RM)	Average loss per event (RM)	Population	Loss per capita (RM per person)
2010	14	5	4,538,594	324185.3	1,674,800	2.7
2011	23	5	6,514,583	283242.7	1,693,000	3.8
2012	24	7	10,591,384	441307.7	1,710,100	6.2
2013	35	13	17,163,952	490398.6	1,724,500	10.0
2014	8	6	5,501,564	687695.5	1,740,000	3.2
2015	39	29	32,986,395	845805.0	1,780,000	18.5
2016	61	45	48,702,077	798394.7	1,790,000	27.2

was traffic congestion and other mobility disruptions, policy interventions and adaptation strategies that focus on how to prevent road networks from being inundated and affected indirectly is an important aspect to consider.

The total damage values of flash floods in Kuala Lumpur are all below 1 % of the GDP of the city (Table 6). This might seem exceptionally low compared to the damage costs of major floods. However, as a conservative calculation and associated uncertainties have contributed to a lower bound estimation in this study, this could be just the tip of the iceberg. Moreover, flash flood losses may increase in the future if more cost and damage information was added to the calculation. If they were available, additional explanatory variables such as depth, duration, and flood extent for each event as well as urban drainage system and rainfall data could have be included for a more accurate evaluation. Considering the limitations of this study a higher actual cost is a possible reality. The study also makes a case for judicious recording of data related to small-scale flash flood events so that more accurate assessments could be conducted. Even with the limited data and using a conservative approach, the flash flood damage was about 0.04 % of Kuala Lumpur's GDP in 2016 (Table 6). With global warming and the projected rise in frequency and intensity of climate hazards, and growing exposure and vulnerability of the city due to rapid development, the risk of much higher impact and economic cost due to flash floods is expected to increase in the future.

The total loss and number of affected roads consistently correspond to the frequency of flash floods in the city; and this has generally increased over a period of seven years, except for 2014 (Table 7). The average loss per flash flood has increased consistently during the same period, except for 2011. Flash flood loss per capita does not show any particular trend over the seven years, with the highest value of RM27.2 per person in 2016 when the frequency of flash flood was also the highest. However, the indirect damage cost related to flash floods was higher as the number of roads affected increased. This is because when a road network is disrupted, various economic aspects will be affected in a vast city such as Kuala Lumpur; as people from outside the disrupted area also have to use road network.

The findings on affected roads in Kuala Lumpur is supported by a previous study conducted in Haarlem, Netherlands, where disrupted road networks resulted in a larger number of people affected by floods of similar severity (ten Veldhuis, 2011). The Haarlem study that estimated costs using data from citizens on urban drainage problems, also revealed that pluvial floods caused significantly higher damage costs to residential buildings compared to commercial buildings and flooded roads. In Kuala Lumpur, building damage and road damage are higher in commercial areas than residential areas. This indicates that damage costs associated with small-scale floods is context and area specific. A proper comparison can only be done if the damages and losses are contextualised to the GDP of the city or some other common denominator.

Moving forward, this study can now provide baseline information for Kuala Lumpur on small-scale flash floods. A methodological approach has been demonstrated where the cost of disaster damage can be evaluated with minimum information. The findings indicate that the indirect damage may be higher than the direct damage, and may continue increasing as the elements at risk to flash flood are increasing due to the combination of rapid development in the city, and extreme weather due to global warming. These results may be helpful for insurers in deciding if small-scale flash floods are damaging enough for developing insurance policies to transfer the risk of the affected people. Policymakers should also understand that data should be recorded more systematically, to delineate aspects that are most likely to receive high damage, so that the information can be used to inform policy. Such evidence based information is the way forward for achieving climate resilience for sustainable development in cities.

5. Conclusion

This study conceptualises disaster impacts due to small-scale flash floods in Kuala Lumpur, which are short duration events of about less than six hours with shallow depths of flood waters, generally less than two meters, with limited spatial extent, and without associated fatalities. Such events are considered disasters in the local context, specifically for the affected population in the city. The annual damages and losses associated with 204 small-scale flash flood events between 2010 and 2016, range between RM4.5 million and RM48.7 million. The highest flash flood damages and losses (RM48.7 million) represented 0.04 % of the gross domestic product (GDP) of Kuala Lumpur in 2016. While this number may seem insignificant, it is useful baseline information for further studies when more data is available, to conduct a robust evaluation.

Although the assessment was very conservative, and associated with several uncertainties due to limited information, there were some useful insights obtained. Direct costs were associated with damage to roads as well as commercial and residential areas to a lesser extent, while loss of productive time was the leading factor for indirect costs. The findings indicate that indirect damage costs are higher than the direct damage. The total direct damage of flash floods hardly exceeded RM5 million, but the indirect costs could be up to four times higher. Disrupted road networks were the highest contributor to both direct and indirect costs, as they disturb various economic aspects and people, both within the city and outside of the affected areas. The damage costs are expected to increase due to the combination of rapid development and extreme weather due to global warming. An important aspect to be considered in Kuala Lumpur are policy interventions and risk reduction strategies that focus on the transportation sector.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

Tariqur Rahman Bhuiyan, Ah Choy Er, Nurfashareena Muhamad and Joy Jacqueline Pereira: Conceptualization and Methodology. **Tariqur Rahman Bhuiyan, Er Ah Choy, Nurfashareena Muhamad and Joy Jacqueline Pereira.:** Formal analysis and Writing-Original draft preparation. **Er Ah Choy, Nurfashareena Muhamad and Joy Jacqueline Pereira.:** Supervision and Writing - Review & Editing. **Joy Jacqueline Pereira:** Funding acquisition.

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