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THE CHARACTERISTICS OF ROAD INUNDATION DURING FLOODING EVENTS IN PENINSULAR MALAYSIA

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ABSTRACT: Flooding can cause damage to infrastructure and has a devastating impact on daily life. Malaysia is located in a tropical region characterized by high quantity of rainfall. Damaged roads due to flooding prevent access for emergency and assistance purpose. The purpose of this study is to identify the flooding characteristics of inundated roads in Malaysia. It includes the parameters of flood water level, flood duration, and repeated flooding. Secondary data from relevant departments and agencies are gathered for the analysis. Flood statistics were obtained from the annual flood reports issued by the Department of Irrigation and Drainage Malaysia between 1991 and 2014. Road data as well as maps were collected from the Highway Planning Division, Ministry of Works Malaysia. In this study, flash flood was defined as flood that subsides in less than 6 hr. The study revealed that the average flood depths could be grouped into 0.3 m, 0.6 m and 1.0 m depths. However, in areas under tidal effect, the depths could exceed 1.0 m and it took longer for the flood to subside, up to two days. The result of this characterisation will be used to expand the study on the effect of inundated roads during flooding on the whole road structural system.

Keywords: Flooding, Road, Road Inundation.

1. INTRODUCTION

Flooding is a significant environmental phenomenon that creates severe impacts on the socioeconomic activity and road transport infrastructure that requires costly budgetary provision [1]. Flood is a natural process that occurs when water inundates land that is normally dry. When rain falls on an area, some of the water percolates through soil while the remaining flows downhill as runoff and the amount of this runoff depends mainly on the catchment area.

The most terrible natural disaster experienced by Malaysia is flooding. Malaysia, including Sabah and Sarawak, has a total of 189 river basins with the main channels flow directly to the South China Sea and 85 of them are exposed to repeated flooding (89 of the river basins are in Peninsular Malaysia, 78 in Sabah, and 22 in Sarawak) [2].

In terms of road infrastructure, the impact of flooding can be significant after the event since it may affect the whole infrastructure involved and have a long-term effect in terms of maintenance work and future planning of road infrastructure [3]. The immediate impacts include the destruction of roads, bridges, and culverts, disruption of road transport systems, traffic jams, long travel time, loss of productive hours, stress, fatigue, as well as other stress-related issues. In the medium and long terms, the impacts include the cost of restoring damaged infrastructure, the cost of reconstructing existing infrastructure to cope with future flooding, and restoration of lost assets. This study aims to identify the characteristics of flooding on the roads in Peninsular Malaysia regarding depth, duration, and recurrence. The significance of this work is that it helps established inundation characteristics of the various flooding locations. This will enable specific strategy on design, construction and maintenance of roads in the affected area to be formulated.

2. LITERATURE REVIEW

The estimated area vulnerable to flooding is approximately 29,800 km^2 or 9% of the total Malaysia area and it affects almost 4.82 million people, which are approximately 22% of the total population of the country [4]. There are no formal categories of flood in Malaysia but it can be divided into three types of flood: flash flood, monsoon flood, and tidal flood. The main difference for each type of flood is the time taken for the discharge level to return to the normal level from the peak flood discharge.

Flash flood takes only a few hours to return to the level of normal discharge compared to monsoon flood. In recent years, severe flooding events have occurred in several parts of Malaysia, both as localised flash flood and basin-wide flood on major river systems [5]. A flash flood that is caused by excessive rainstorm in a short period (less than 6 hr)

can increase the water in a river rapidly. Most of the flash flood studies in Malaysia focused on the lowlands [6].

In addition, monsoon flood usually occurs more than 6 hr, depending on the location, cause, characteristics, the time when flood occurs, and its duration. There are two types of monsoon: the southwest monsoon from late May to September and the northeast monsoon from November to March. The latter brings heavy rainfall, particularly in east coast states of Peninsular Malaysia and western Sarawak, whereas the former normally signifies relatively drier weather [7]. Meanwhile, the monsoon in the east coast of Peninsular Malaysia means maximum rainfall in November and December [8]. Tidal flood is a phenomenon of an overflow of inland that inundates land including roads due to inadequate drainage systems. It commonly occurs around the time of high tide, which coincides with the occurrence of the new and full moon [9]. The level of interactions between various measurable flood dimensions and transportation networks determines the potential impact of flood. By determining interaction probabilities, flood impact can be modelled and visualised [10].

Roads in Malaysia are classified into two categories, namely the Federal Highway and State Road. All federal roads are gazetted under the Federal Roads Ordinance (1959). Currently, Malaysia has more than 203,791.02 km of roads [11]. This kind of infrastructure is highly vulnerable to flood occurrence and is the first to receive the impact of flooding, and it is prominent that road transport infrastructure has very high budgetary provision in the overall development process [1]. Flood can be one of the most catastrophic natural events as it can severely damage any road infrastructure. When a segment of a road is closed due to floodwater, various flood impacts can be observed on the characteristics of traffic flow, including disruption of communication, traffic congestion, and increased traffic volume [10].

3. METHODOLOGY

This is a descriptive study based on quantitative secondary data. The issue was studied by obtaining additional information and interview methods were used to obtain relevant information. This study examines the characteristics of flooding in Peninsular Malaysia and focuses on roads. It includes parameters of flood water level, flood duration, and repeated flooding. In this study, data collection was carried out based on observations and information from the annual flooding reports between 1991 and 2014 and only complete information was considered in the study.

All data were obtained from the Water Resources Management and Hydrology Division, Department of Irrigation and Drainage Malaysia and the Highway Planning Division, Ministry of Works Malaysia. Each flood area on the maps was marked with a black dot to indicate different flood areas for each state. The classification of each plot on the map was based on the scales according to the traffic census station map in the Road Traffic Volume Malaysia 2015 report. The plotted areas in the map were created manually based on the road map information issued by the Road Facilities Maintenance Branch and the maps were drawn using Paint 3D. The different colours on the map showed flood duration and the circle shape on the map represented the change of flood water level that occurred in each area.

Although many papers related to flood have been published but they lack detailed information on level of flood, flood duration, and repeated flooding on the roads in Malaysia. Besides, flood water level was used to determine the flood hazard of a particular area. Flood hazard is an input to analyse the elements at risks to flood [12] and it is vital to improve the design of roads regarding the ability of pavement thickness to withstand load-carrying capacity [3]. The data of flood events from 1991 to 2014 were analysed and presented.

4. RESULTS AND DISCUSSION

Various flood events occurred in Peninsular Malaysia due to high-intensity rainfalls and high tidal level [4]. Figure 1 shows the total cases of various types of flooding events from 1991 to 2014. Overall, there were 3,044 cases (including in Sabah and Sarawak). Monsoon flood recorded the highest number of cases (1,821 cases), which is 48% of the total number of cases.

This is because the conditions of small rivers could not accommodate large quantities of water and especially when it encountered high tide and heavy rain. Flash flood recorded 1,218 cases with 33%. Besides, many flash flood events on the roads occurred in Penang and Kuala Lumpur. The lowest cases were repeated flood with only 643 cases, which is 18% of the total number of cases.

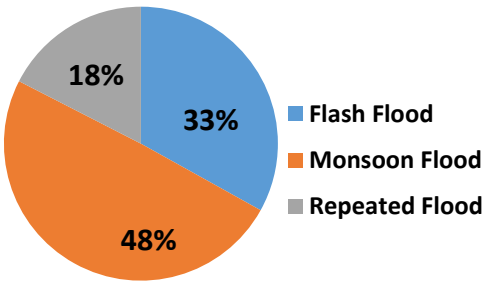
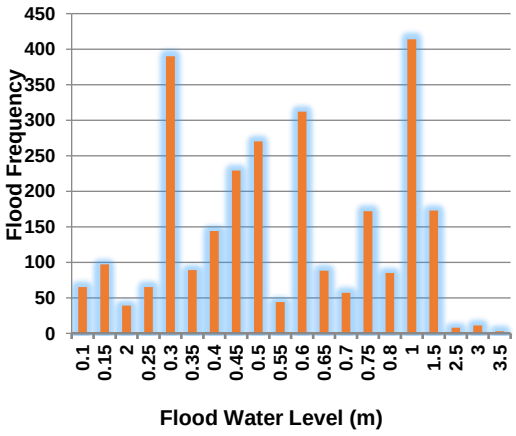
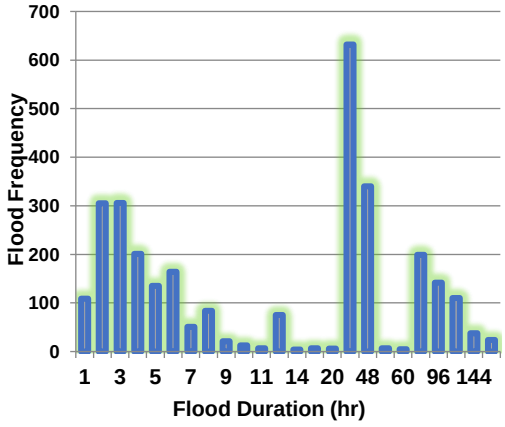


Fig. 1 Types of flooding events from 1991 to 2014

Figure 2a shows the flood water level for inundated roads. The maximum water depth was 3 m. In general, the flood water level of flash flood was less than 1.0 m and a total of 380 cases were recorded for flood water level of 0.3 m, followed by 0.6 m with 320 cases. On the other hand, Figure 2b presents flood duration. 24-hour flood duration recorded the highest number of cases (683 cases), followed 48-hour flood duration (358 cases). Generally, most monsoon flood cases occurred for 48 hr and depends on rainfall intensity. Flood duration of 1 to 6 hr is a fairly consistent flood case due to flash flood. Flash flood occurred in the duration of 2, 3, and 5 hr recorded 306, 305, and 205 cases, respectively.



(a)



(b)

Fig. 2(a) Flood water level and (b) flood duration.

4.1 Flood-Prone Map

In this study, a flood-prone map was produced in the duration of 23 years from 1991 to 2014 to illustrate the total cases of flash flood and monsoon flood in Peninsular Malaysia. In general, flash flood occurred in less than 6 hr and had high-intensity rain. Meanwhile, monsoon flood occurred more than 6 hr, with the southwest monsoon from late May to September and the northeast monsoon from November to March [7].

The plotted map was created based on the estimation on road map published by the Malaysian Public Work Department (PWD). Figure 3 illustrates the plotted map of flash flood. Three colours were used as the map indicators to differentiate flood duration. The duration of flash flood less than 2 hr, between 2 and 4 hr, and between 4 and 6 hr was represented by light blue, purple, and green colours, respectively.

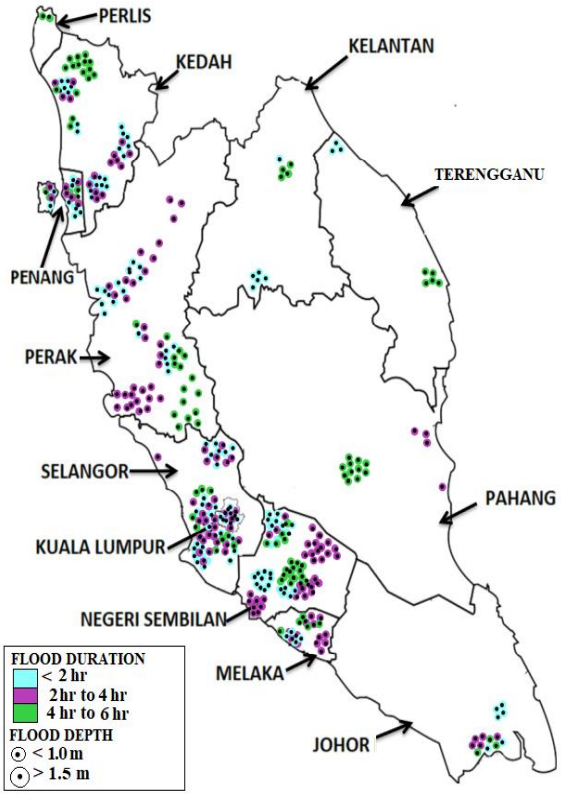


Fig. 3 Flash flood map

Figure 4 shows the plotted map of monsoon flood. Different colour plots represented flood duration. Monsoon flood with the duration less than 48 hr, between 48 and 120 hr, and between 120 and 240 hr was represented by green, purple, and orange colours, respectively. The size of the plotted circle represented flood water level. A small circle indicated that the flood water level was 1.0 m and a big circle showed that the flood water level was more than 2.0 m.

4.2 Repeated Flood

According to the annual flood report from 1991 to 2014, 643 cases of repeated flood were recorded. It included the first and second repeated flood.

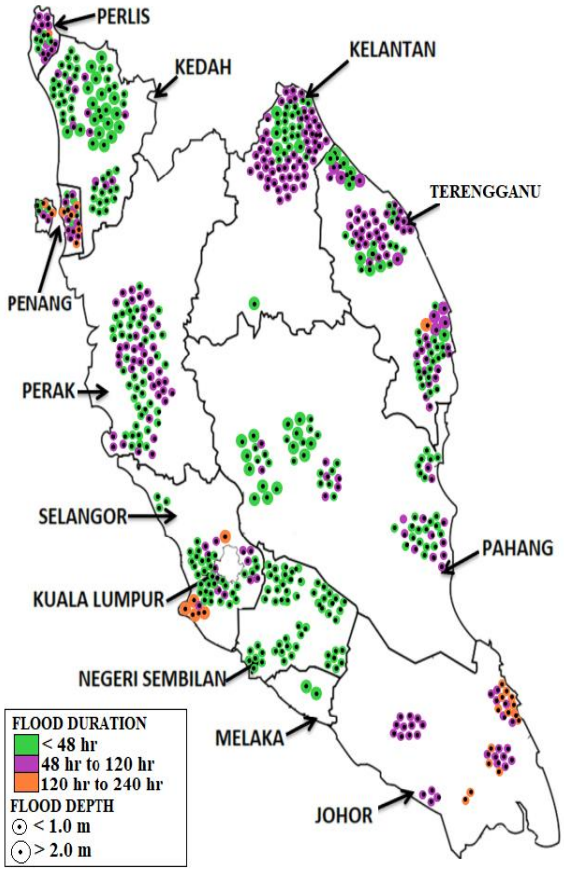
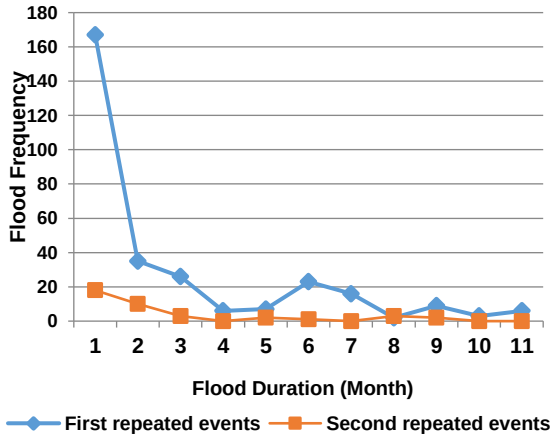


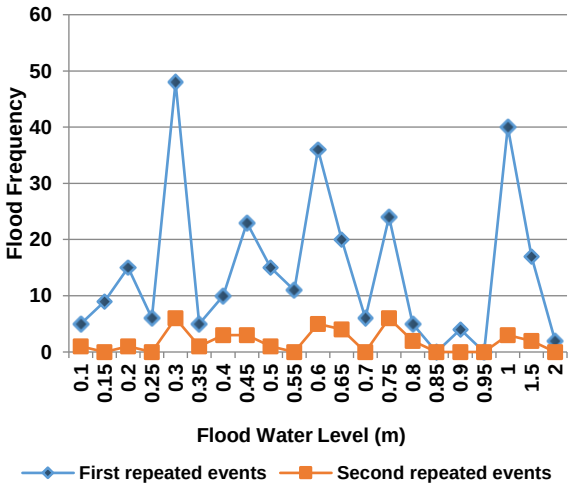
Fig. 4 Monsoon flood map

Figure 5a shows the flood duration for repeated flood. The highest cases recorded were 168 cases and usually happened within a month after the first flooding and followed by 35 cases in the second month and 23 cases in the third month. This is because the duration of flood is affected by the northeast monsoon and southwest monsoon. The average of flood that occurred on the roads in Malaysia is usually within 24 hour before the flood recedes.

Figure 5b shows the flood water level for repeated flood. For the first repeated events, there were three highest cases recorded at 0.3 m with 49 cases, followed by 0.6 m with 36 cases, and 1.0 m with 40 cases. Basically, the first wave of flood heavily influenced the second wave of flood based on the information obtained. There was a significant difference in the level of flood for the first and second repeated events. For the second repeated events, the highest cases were recorded for 0.3 m with six cases, followed by 0.6 m with five cases.



(a)



(b)

Fig.5 (a) Flood duration for repeated flood and (b) flood water level for repeated flood from 1991 to 2014

Figure 6 illustrates the plotted map of repeated flood. The different colour indicators showed the flood duration. Flood duration was represented with light blue, green, and purple colours for the duration of less than 24 hr, between 24 and 72 hr, and more than 72 hr, respectively. The size of the plotted circle represented the flood water level. The smallest circle indicated that the flood water level was below 1.0 m and the big circle indicated that the flood water level was more than 1.5 m. From the result, it can be concluded that the cases recorded under 6-hour period for the first repeated flood and many flash flood events occurred in the initial flooding events.

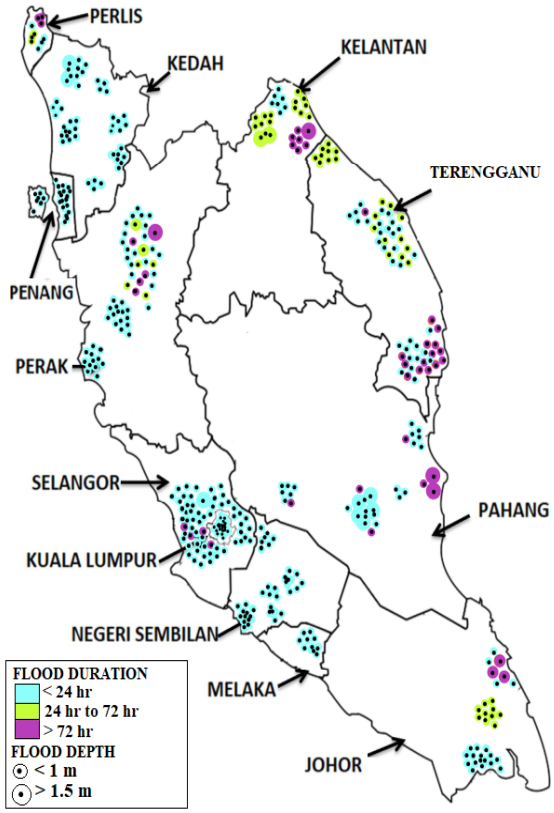


Fig. 6 Repeated flood map

5. CONCLUSION

This study was carried out to determine the characteristics of real flooding events and how it affected roadways in low lying area. It can be concluded that:

i) The average flood water level in Peninsular Malaysia is 0.3, 0.6, and 1.0 m for various types of flooding in Malaysia.

ii) The average flash flood occurred in less than 6 hr in most locations, but flash flood may exceed more than 6 hr with the flood water level above 1.0 m due to heavy rain and high tidal level.

iii) On another note, the average flood duration for monsoon flood is two days with an average flood water level of 1.0 m, depending on rainfall conditions.

iv) It has also been noted that, the most frequently repeated flood usually happened within a month after the first flooding event.

For future works, this study will continue to investigate the effect of the period for inundated roads and recurring inundation and how these could affect the whole road structural systems in the different localities and sub-grade properties.

6. ACKNOWLEDGEMENTS

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