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Investigation of Flash Flood Over the West Peninsular Malaysia by Global Positing System Network

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Flash flood hazard in Klang Valley becomes an annual problem among urban folks, especially during the winter monsoon. Three cases of flash flood have been identified in 2013 as a case 1 for 1 September, case 2 for 31 October and case 3 for 13 December. This paper discussed a variation of Global Positing System (GPS) Precipitable Water Vapor (PWV) responses to the amount of rainfall within pre, during and post of the flash flood event. Surface meteorological data from three meteorological stations were interpolated to the three GPS stations to accurately measure the PWV. The analyses revealed that the trend of GPS PWV was observed highest during the phase of flash flood, of which preceded by an extreme minimum peak in two to three days before the incident. The study also found a high level of GPS PWV was associated with the frequency of rainfall and spatial distribution of precipitation. The highest total of calm and light air were also contributed to the flash flood hazard. Based on the case studies, the high level of GPS PWV and wind gusts found contributed to the chance of flash flood disaster over the Klang Valley.

Keywords: Global Positioning System, Precipitable Water Vapor, Flash Flood, Klang Valley.

1. INTRODUCTION

The increasing numbers of physical and national development cause the particular changes in the urban area.[1] The safety of the urban area is crucial in attracting investors and tourists to enhance economic activity. Unfortunately, flash flood hazard over the Klang Valley results from a heavy rainfall, inefficient stormwater run-off system and low-lying area due to physical construction[2] is a frustration issue among the urban residents and a risk to the national as well as global development. Consequently, Klang Valley recorded the highest city migration rate in 2012 as reported by Department of Statistic, Malaysia.

Currently, the Malaysian flood system managed by Department of Irrigation and Drainage (DID) Malaysia is being developed, and it is dependent on the water level forecasted from the rainfall telemetric network.[3] In this regard, several advanced technologies have been applied. Global Positioning System (GPS) was widely used for meteorological studies, especially for investigating the variation of atmospheric water vapor during extreme weather phenomenon.[4] A preliminary study on GPS PWV over the east coast of Peninsular Malaysia found that the GPS is suggested in determining extreme weather driven hazard such as severe flood.[5]

The high frequency of rainfall could decrease the soil permeability of prone areas, thus resulting in flash flood hazard.[6] Therefore, this paper aims to investigate the variability of PWV and trend of rainfall during the flash flood hazard in Klang Valley within three identified phases. The effect of local wind on the distribution of precipitation is also studied.

2. DATASET AND LOCATION

This study employed the GPS data provided by Department of Survey and Mapping Malaysia (DSSM) and the surface meteorological data provided by the Malaysia Meteorological Department (MMD) and also from the flight–meteorology (www.wunderground.com). To support the analysis, Tropical Rainfall Measuring Mission (TRMM) accumulated precipitation image gathered from http://gdata1.sci.gsfc.nasa.gov with selected latitude of 0°N until 8°N and longitude of 99°E to 105°E was conducted, where the spatial resolution accuracies are up to 0.25 degree.

The GPS locations as shown in Figure 1 were represented by using triangle shape and the meteorological stations were denoted by asterisk (∗). All the stations used in this study are located in the West coast of Peninsular Malaysia. For the meteorological

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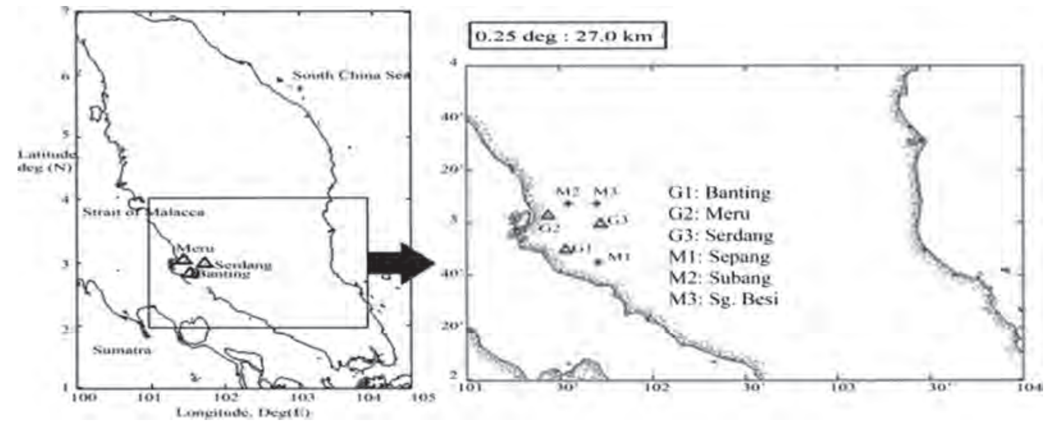

Fig. 1. Location of GPS and meteorological stations.

station that was not collocated with the GPS station, it is interpolated using Baltink et al. equation[7] to accurately obtain the GPS PWV.

In addition, the rainfall data was collected from the Department of Irrigation and Drainage (DID) at seven stations located around the reported flash flood. Apart from that, all the stations characterized in this study were identified to be located less than 60 km in distance to the point of incident.

3. DATA PROCESSING

Each case of study was investigated for 15 days of GPS and meteorological data. The time series of both data were cleaned by using translate, edit and quality control (TEQC) developed by UNAVCO. The surface meteorological data was cleaned and interpolated in daily basis. Both data were processed to determine PWV by using *TroWav* 2.0 developed in Matlab.[8] The regional weighted mean temperature, T_m of 0.83663 $T_s + 48.103$ K[9] was employed to accurately convert the Zenith Wet Delay (ZWD) into PWV. After obtaining the PWV data, then PWV is divided into three events of flash floods: pre, during and post observation, where the statistical analysis was carried out for each phase. To support the PWV analysis, the hourly average of rainfall data was collected at the surrounding areas of the reported flash flood.

The hourly meteorological data (wind profiles) at respective meteorological station were also collected, processed and classified according to the Beaufort Wind Scale. The three hourly of TRMM image was analyzed to compare their response to PWV.

4. THE VARIATION OF PWV AND RAINFALL DURING THE CASE OF FLASH FLOOD

The variation of PWV and rainfall for each case were depicted in Figure 2, where the period of reported flash flood was shaded in gray color. Figure 2(a) shows a consistent high level of GPS PWV starting from 29 August until the evening of 2 September together with the frequency of rainfall occurred every day from 30 August until 5 September. In Figure 2(b), the PWV level was

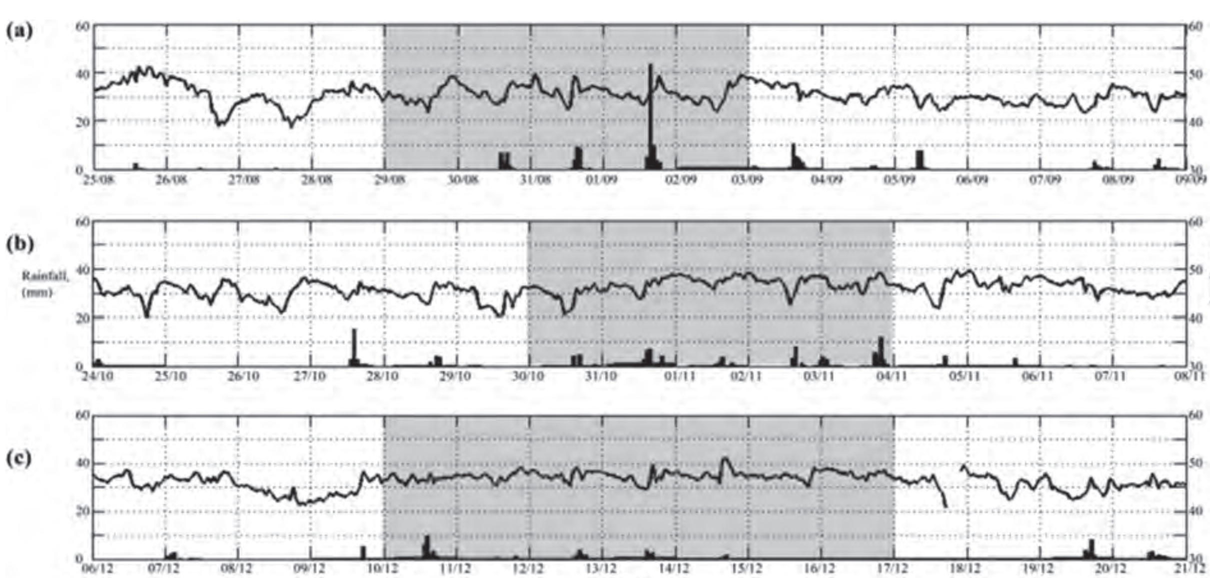

Fig. 2. The variation of PWV and trend of rainfall during the 15 days monitoring for (a) case 1, (b) case 2 and (c) case 3, where a flash flood was recorded on the eightieth day of the observation.

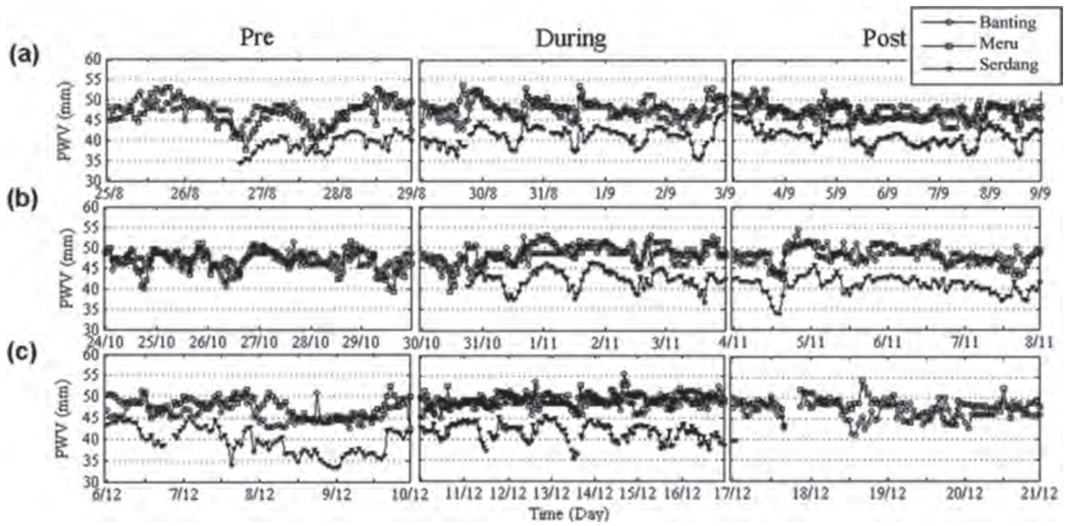

Fig. 3. The variation of GPS PWV at respective GPS station for three cases of flash flood.

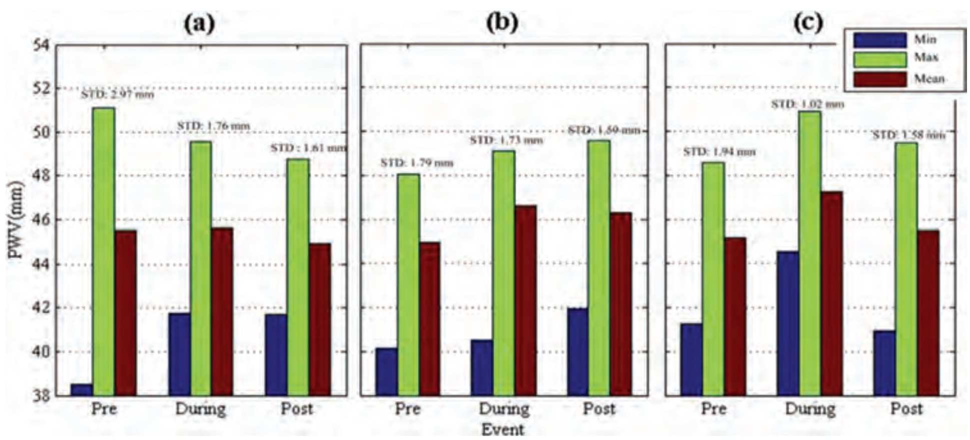

Fig. 4. Comparison of minimum, maximum and mean of GPS PWV over Klang Valley during (a) case 1, (b) case 2 and (c) case 3.

high during the five days of reported flash flood as compared to 6 days of pre and 4 days of post period of observation. It is followed by daily rainfall from 30 October until 5 November. For Figure 2(c), the level of GPS PWV was high during the seven days of reported flash flood together with a light rainfall from 9 until midnight of 13 December. As shown in the figure, an increment of GPS PWV was followed by rainfall regardless the amount of rainfall. This similar pattern clarify that a rainfall event is a result of a high level of GPS PWV other than altitude and wind profile.[10] The process of evaporation and transpiration will increase the atmospheric water vapor and continuously occurs until highly saturated to create rainfall.

Figure 3 shows the variation of PWV at respective GPS stations divided into three phases of flash flood: pre, during and post event. The variation of GPS PWV at Serdang was recorded the lowest compared to those at Banting and Meru. The location being farthest from the coastal area and located in the highest altitude compared to the other stations are likely a potential cause of this phenomenon. For the first case (Fig. 3(a)), the trend of PWV variation was quite similar for all GPS stations. A minimum value was observed early at Serdang in the evening of 29 August until 31 August. The mark indicated almost at the same period at all stations in the evening of 1 September. On 2 September, the minimum was observed early at Banting and Meru. The high level of GPS PWV at all stations was observed during the second case of flash flood (Fig. 3(b)). A minimum of PWV was observed at Banting and Meru in the evening of 26 October, and is believed that this moderate rainfall contribute

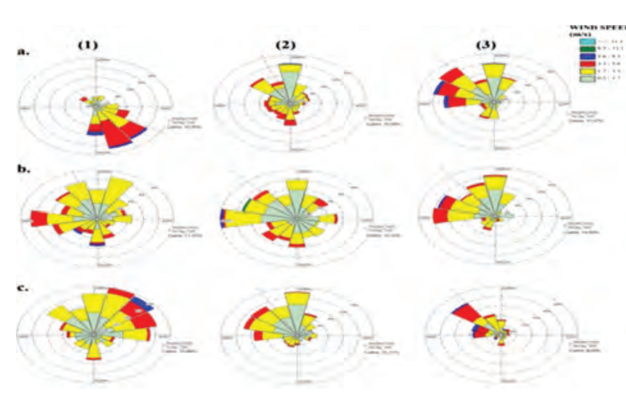

Fig. 5. Variability of wind profiles and its resultant vector for three cases: (1) Pre, (2) during, and (3) post of flash flood observation.

in the evening of 27 October (refer to Fig. 2(b)). Apart from that, a minimum PWV was marked within 1 to 2 hours prior to flash flood at all GPS stations. Later, on 5 November, the minimum was disappeared, thus resulted in low frequency of rainfall on the following days. For the third case, the minimum trend was observed at all GPS stations in the late evening of 8 December (Fig. 3(c)) followed by light rainfall on the following day until midnight of 12 December. Meanwhile, the high level of PWV was sustained from 9 until 16 December at Banting and Meru, and it decreased on 14 December at Serdang.

Overall, the GPS PWV variation at Serdang was lower than at Banting and Meru. However, the diurnal GPS PWV was clearer distinguished at Serdang than other two stations. This could be an influence from the sea water vapor, where Banting and Meru stations located nearer to the coastal area. It is similar to the diurnal variation at an island where the GPS PWV is distinguishable at inland station rather than island station.[11] The possible affecting of PWV level and diurnal variation is cloud transportation and air condensation, where it is high at the station near the coastal area. The high level of PWV also can be seen at all GPS stations

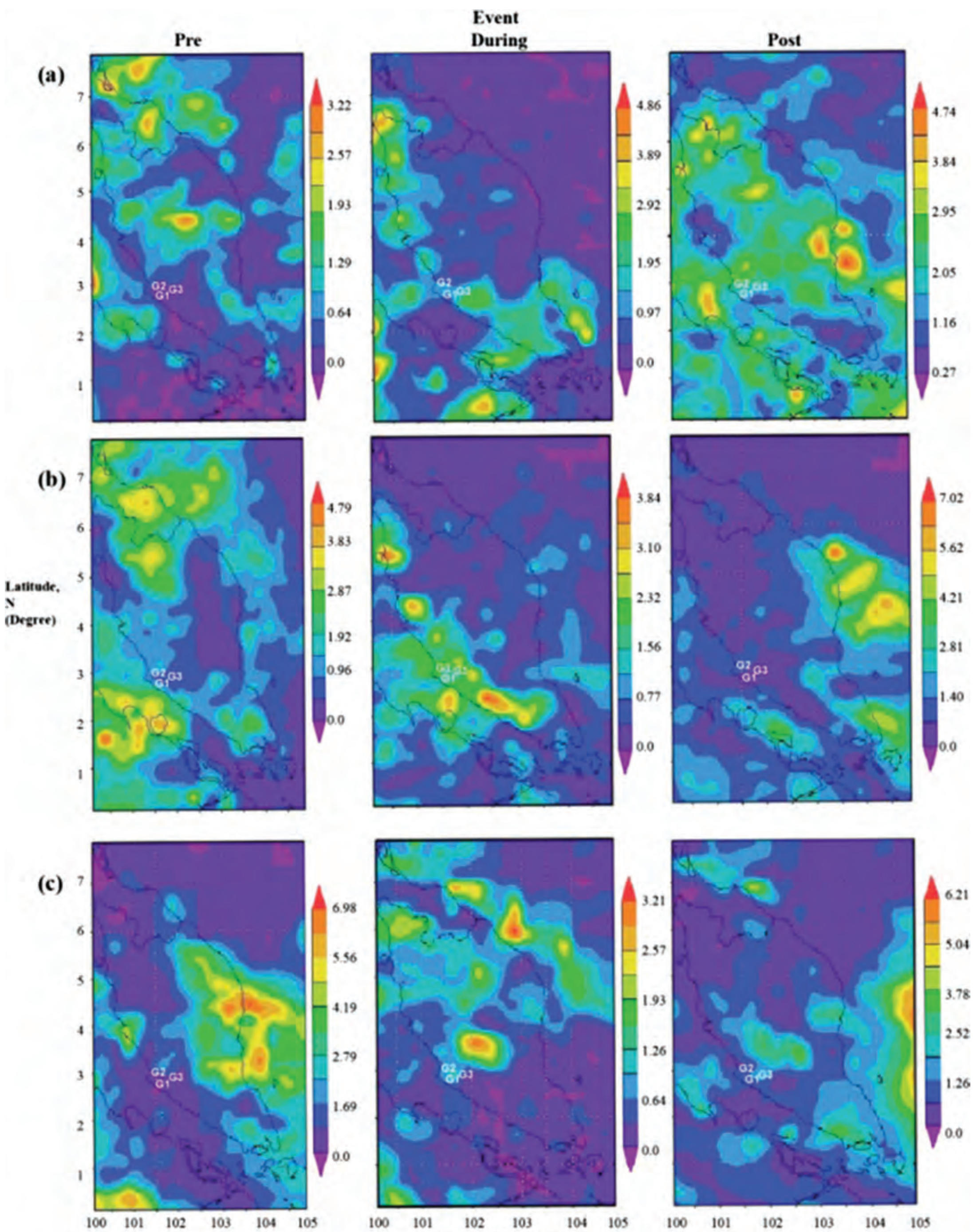

Fig. 6. Distribution of accumulated precipitations measured in millimeter (mm) for three cases of flash flood over the Klang valley.

around the Klang Valley during the period of flash flood, where the variation at Serdang showed a significant relationship to the amount of rainfall over the prone area.

Statistically, the minimum value of GPS PWV was increased according to the phase of flash flood, while its maximum value is decreased as shown in Figure 4(a). Figure 4(b) showed the increment of both minimum and maximum values of GPS PWV during flash flood events. The minimum and maximum values of GPS PWV in Figure 4(c) showed a similarity with the trend of GPS PWV average that to be the highest during the flash flood event. The possible occurrence of the phenomenon is presented in Figure 4, where the mean of GPS PWV during the flash flood was the highest over the Klang Valley. However, the average of STD value is higher during pre phase for overall the cases. This could be a result of Northeast monsoon season[12] that storm cloud covered the area to cause a flash flood.

5. CONTRIBUTION OF WIND PROFILE AND ACCUMULATED PRECIPITATION

The wind activities in Klang Valley during the study period are shown in Figure 5. The wind resultant vector of the first case (Fig. 5(a)) prevailed from southeast, then to the southeast in the second and third phase. The second case reported the highest calm and light air over the Klang Valley. A net force from the northwest during the three phases of case 2 in Figure 5(b) were reported to have the highest calm and light air in the second phase of flash flood. While, the net wind force in the first phase of the third case (Fig. 5(c)) came from the north and later moved to the northwest in the second and the third phase of the flash flood. Similarly, the highest number of calm and light air was recorded in the second phase of the flash flood case.

The prevailing winds that bring a certain amount of water vapor in a form of storm clouds over the area will create the local weather condition. The calm and light air could be resulted from wind convergence from the East and West part of the Valley,[13] which significantly increase the accumulation of water vapor. It is proven by the high level of GPS PWV during the period of flash flood for these three cases.

The distribution of precipitation from TRMM image over the area of Klang Valley is compared to that of wind and PWV. For the first case (Fig. 6(a)), the precipitation started to increase during the phase of flash flood and then it covered central part of Peninsular Malaysia in the post flash flood event. The precipitation was recorded up to 3.0 mm for the second case was highly saturated during the period of flash flood (Fig. 6(b)). The highest distribution of precipitation was observed at the third case (Fig. 6(c)), where the accumulated precipitation in the Klang Valley was measured up to 4.0 mm.

Based on the overall observation, the highest precipitation was captured within the second phase of flash flood. The high level of precipitation could lead to weather hazard with a contribution from wind and water cycle activities. In this study, the high distribution of precipitation was similar to the high level of GPS PWV at Klang Valley when the flash floods were reported.

6. CONCLUSION

The studies on the three cases of flash flood on 1 September, 31 October and 13 December found that flash flood was occurred during high level of GPS PWV and during high frequency of local rainfall. In terms of diurnal variation, extreme minimum values of GPS PWV were observed in the evening within two to three days before the flash flood and the average level of GPS PWV was the highest during the phase of flash flood. This minimum peak can be suggested as an indicator of early warning system of flash flood. Besides that, the wind convergence from the west and east part resulting in high frequency of calm and light air to sustain the high water vapor at the Klang Valley during the phase of flash flood. This indication is supported by TRMM satellite image, where the precipitation was highly distributed during the hazard.

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