Probable Maximum Precipitation (PMP) over mountainous region of Cameron Highlands- Batang Padang Catchment of Malaysia

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Abstract. The Cameron Highland Batang Padang (CHBP) catchment situated on the main mountain range of Peninsular Malaysia is of large economical importance where currently a series of three dams (Sultan Abu Bakar, Jor and Mahang) exist in the development of water resources and hydropower. The prediction of the design storm rainfall values for different return periods including PMP values can be useful to review the adequacy of the current spillway capacities of these dams. In this paper estimates of the design storm rainfalls for various return periods and also the PMP values for rainfall stations in the CHBP catchment have been computed for the three different durations of 1, 3 & 5 days. The maximum values for 1 day, 3 days and 5 days PMP values are found to be 730.08mm, 966.17mm and 969.0mm respectively at Station number 4513033 Gunung Brinchang. The PMP values obtained were compared with previous study results undertaken by NAHRIM. However, the highest ratio of 1 day, 3 day and 5 day PMP to highest observed rainfall are found to be 2.30, 1.94 and 1.82 respectively. This shows that the ratio tend to decrease as the duration increase. Finally, the temporal pattern for 1 day, 3day and 5 days have been developed based on observed extreme rainfall at station 4513033 Gunung Brinchang for the generation of Probable Maximum Flood (PMF) in dam break analysis.

1. Introduction

Dams in different parts of the world are built for various purposes such as for fresh water supply, irrigation, hydroelectricity generation, flood control and for recreational activities. These dams however can break due to inadequate spillway design floods which can cause calamities in the downstream area. A survey of dam break data by Lemperiere (1993) showed that about 40 % of all dams break worldwide were because of inadequate spillway capacities. In the design of dams, the spillways are designed for the probable raingages flood (PMF) derived from the probable maximum precipitation (PMP). Considering that many of the existing dams in Malaysia could be similarly unsafe based on hydrological conditions, a PMP study for Cameron Highlands- Batang Padang (CHBP) was carried out. The catchment has a series of 3 dams known as Sultan Abu Bakar, Jor and Mahang. The present study is devoted primarily to the estimation of the design storm rainfall values for different return periods including the PMP values for 3 different durations of 1, 3, and 5 days storms for rainfall
stations in the CHBP catchment and also for the catchments above the 3 dams. The main purpose is to obtain reliable PMP rainfall values for an investigation of the adequacy of the current spillway of the three dams. The PMP and consequent floods were calculated using limited meteorological data then available. The design values were felt to be in need of new PMP estimates in light of more rainfall and hydrological data that are available from the Department of Irrigation and Drainage Malaysia (DID) and TNB organizations. Efforts are made in this study to carefully process these data and to use them as much consistent manner as possible.

2. Study Area
The CHBP catchment and the locations of the three dams is shown in Figure 1. The Telom and Bertam Rivers of Cameron Highlands, Batang Padang River and its tributaries form an integrated drainage system in the central portion of the Peninsular Malaysia that is shared by two states of Pahang and Perak. The Sultan Abu Baker dam (also called Ringlet dam) in the Cameron Highlands utilizes the runoff waters of the hill streams of Telom River and Bertam River originating from the hills of the Main Range and flowing in the Pahang state. The Jor and Mahang dams in Batang Padang utilize the Telom and Bertam waters diverted from the Ringlet dam together with the runoff of the Batang-Padang River and its tributaries. The Sultan Abu Bakar, Jor and Mahang dams are respectively 39.6 m, 44.8 m and 19.2 m in the height. The drainage areas above Sultan Abu Bakar dam, Jor dam and Mahang dam are about 110 km², 275 km² and 360 km² respectively. The catchment is mountainous and land surface elevations range from about 500 m to 2130 m above mean sea level making it as excellent potential for the hydropower generation. Table 1 summarizes some of the hydrologic parameters of the 3 dams.

![Figure 1. The CHBP Catchment and the Locations of the Three Dams](image)

| Dam          | Catchments area (km²) | Dam Height (m) |
|--------------|-----------------------|----------------|
| Sultan Abu Bakar | 110                   | 39.6           |
| Jor          | 275                   | 44.8           |
| Mahang       | 360                   | 19.2           |

3. Rain Gauge Network and Hydrological Data
For the derivation of design storm rainfalls and also PMP depths for a catchment need to use long period actual daily rainfall records supplemented with other meteorological data for several raingauges located in and around the catchment. It has been found that there are about twenty four rainfall raingauges in and around the CHBP catchment whose daily rainfall data are available in the time period from 1947 to 2009. Of these 24 raingauges, 9 raingauges are maintained by DID while the other raingauges are maintained by the TNB.

4. Estimation of PMP by Hershfield Statistical Method
The PMP is defined as the greatest depth of precipitation for a given duration that is physically possible over a given point or a specified area at a certain time of the year (WMO, 1986). Estimates of PMP are required for calculating the PMF which is the design flood for spillways of dams where no risk of dams break can be accepted. A statistical method for estimating the PMP for small areas has been developed by Hershfield (1965) based on a general frequency equation given by Chow (1951).
The method considers the annual raingauges rainfall series of a raingauge or an area and can be used at any place where there is sufficient rainfall data and in particular to make estimates when other meteorological data such as dew point, wind etc are lacking. The general equation for hydrologic frequency analysis

\[ X_t = \overline{X}_n + K \sigma_n \]  

Where \( X_t \) is the rainfall for the return period \( t \) years, \( \overline{X}_n \) and \( \sigma_n \) are the mean, and standard deviation for the series of \( n \) annual raingauges rainfall values respectively of a given duration and \( K \) is the frequency factor which varies with the different frequency distributions. The frequency factor \( K \) is mainly a function of the recurrence interval for a particular distribution. For example, when analyzing the 1- day series of annual raingauges 1-day rainfalls by the Gumbel method (Gumbel, 1958), \( K \) is about 3.2 for the 100 year value and about 2.33 for the lognormal distribution.

\[ X_{pmp} = \overline{X}_n + K_m \sigma_n \]  

The calculated the frequency factor \( K_m \) for the station by using the equation

\[ K_m = \frac{X_1 - \overline{X}_{n-1}}{\sigma_{n-1}} \]  

Where \( X_{pmp} \) is the PMP depth for a given raingauge for a given duration, \( \overline{X}_{n-1} \), \( \sigma_{n-1} \) are respectively the mean and standard deviation for this series excluding the maximum value \( X_1 \) from the series. Representing graphically \( K_m \) as function of the mean ( \( \overline{X}_n \) ), the enveloping of the frequency factor \( K_m \) (Figure 3(i) and 3(ii)) can be traced thus determining its limit value for the mean of the annual raingauges rainfall series.

**Figure 3(i).** Envelope curves for \( K_m \) 1 – day

**Figure 3(ii).** Envelope curves for \( K_m \) 3-day

5. Derivation of point PMP values for raingauges in CHBP catchment

The values of \( \overline{X}_n \), \( \sigma_n \), \( \overline{X}_{n-1} \), \( \sigma_{n-1} \) and the coefficient of variation (CV) were calculated for all the annual raingauges rainfall series for three different durations of 1, 3 & 5 days pertaining to 24 raingauges in the CHBP catchment. The frequency factors \( K_m \) for each of the station for 3 different durations were determined by equation (3). Based on the 24 raingauges, the maximum values of \( K_m \) for the 1, 3 & 5 days durations were found to be 8.0, 6.3 and 5.9 respectively which corresponds to the return period of more than \( 10^5 \) years. It is very interesting to note that in a humid region of Malaysia the \( K \) value tends to decrease as the duration of rainfall increase. The maximum value of 8.0 for 1 day duration is obviously an appropriate value for PMP computations for raingauges in the CHBP catchment. The 1-day, 3-day and 5-day PMP estimates for all 24 raingauges were plotted separately on the base maps of the CHBP. Isopleths of PMP were drawn at interval of 50 mm taking into consideration the effect of topography of the catchment. Before drawing the isopleths of PMP, the coefficient of variability (CV) values for all 24 raingauges were plotted separately for 1, 3 & 5 days durations on the maps of the catchment to see whether in certain area the CV value for a station...
differed too much from nearby raingauges. This needs to be done to smooth out inherent errors indicated by large standard deviations. The PMP values obtained at the dam sites can be transformed using a rainfall-runoff deterministic model into a PMF hydrograph in the dam safety studies. In this process the catchment is taken as a system that has as input the PMP histogram and as output the flow hydrograph.

Figure 4. Spatial distribution of 1-,3- and 5-day raingauges rainfall (clockwise).

6. Conclusions
The hydrology analysis revealed that the annual rainfall decreases at much higher elevation thus indicates the orographic effect. This was −0.570 which is significant thereby indicating that rainfall decreases with elevation. The consistency and reliability of records at Gunung Brinchang station is found to be consistent by double mass curve technique. The maximum values for 1 day, 3 days and 5 days PMP values are found to be 730.08mm, 966.17mm and 969.0mm respectively at Station number 4513033 Gunung Brinchang. The PMP values obtained were compared with previous study results undertaken by NAHRIM. However, the highest ratio of 1 day, 3 day and 5 day PMP to highest observed rainfall are found to be 2.30, 1.94 and 1.82 respectively. This shows that the ratio tend to decrease as the duration increase. Finally, the temporal pattern for 1 day, 3day and 5 days have been developed based on observed extreme rainfall at station 4513033 Gunung Brinchang for the generation of Probable Maximum Flood (PMF) in dam break analysis.

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