

Estimation of probable maximum precipitation for tropical catchment

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Abstract. Probable Maximum Precipitation (PMP) is the maximum precipitation depth for specific region or station within a certain time. The main purpose of PMP estimation is calculate the Probable Maximum Flood (PMF). The PMF is considered necessary for design and manage the hydraulic structures. PMP can be estimate using two methods, either using a physical method or by using statistical method. In this study, statistical approach was used to estimate the PMP for Temengor catchment in Perak state, Malaysia. Extreme value type-1 distribution (EV1) is adopted to estimate the extreme rainfall and Hershfeid method was used to estimate PMP value. Also, intensity duration curve (IDC) was derived for 1, 2 and 3 days storm duration with return period 5, 10, 50, 100, 500 years. The results showed that the values of PMP for 1000 return period are 222.361mm, 311.847mm and 348.307mm for 1, 2 and 3 days respectively.

1 Introduction

The PMP has been given the definition as being the greatest depth of precipitation for a particular time period which is meteorologically possible over a specified area or given station (World Meteorological Organization (WMO), 1986). Two techniques are commonly applied for calculating the PMP value, physical method and statistical method. In physical method the PMP for various time periods are calculated by maximize and transposition of actual storm events. In order to produce a PMP value that will satisfy for the lack of a sufficient storm database, storm transposition and envelopment methods are incorporated. For around the last 2 decades, the PMP has been estimated many times for dam in Malaysia using methods of maximization and transposition (NAHRIM, 2008; Desa et al., 2007).

Statistical approach is the second common technique that used for PMP estimation. A statistical method is applied for the estimation of the PMP rainfall at a given area or location which is calculated from the distribution of the frequency fitted to the maximum rainfall records annually. The annual maximum rainfall data are usually used as a key variable in problems related to hydraulic structures design. The philosophy on which this is based is that, if the structure which has been designed is able to attitude the maximum value in one year, it will also be able to attitude other values. The statistical technique is more useful when meteorological data, other than an abundance of rainfall data, are unavailable, such as wind speed and dew point temperatures.

Another kind of statistical technique used to estimate PMP values for areas which are small was developed by Hershfield (1961, 1965). This technique was based on an equation for general frequency presented by Chow (1951). This technique requires a series of maximum annual daily rainfall measurements at a particular observation point as the input data. Hershfield's statistical method has been employed, extensively, in the estimation of PMP for areas which have a long duration of recorded rainfall data. Therefore, Hershfield's method was considered desirable for undertaking in this study to estimating the PMP for 1 day and 3-day durations in the Temengor Catchment stations as their data for daily rainfall is available for long durations.

2 Study area and data collection

The study area for this work was at the Temengor catchment station covering a total area size of 3506 km². The catchment area's elevation ranges from 206m to 2156 m. Lake Temengor covers about a 150 km² area of the catchment which is otherwise forested. The location map for the catchment area of Temengor is shown in Figure 1.

One of the basic requirements for estimating the PMP is long period rainfall data. Rainfall is a vital element in the hydrological cycle; as such, rainfall needs to be quantified when various water resource projects are being planned and designed. Generally, to quantify rainfall, intensity-duration-frequency (IDF) curves are used (Chow et al., 1988). For this study, seven rainfall stations were used. These stations were located upstream

of the Temengor dam as shown in Figure 2. The properties of the rainfall stations are presented in Table 1.

3 Theory of hershfield method

Chow's (1951) method for analyzing the frequency of rainfall was adapted by Hershfield when developing his technique to estimate the PMP. For a hydrological analysis, Chow (1951) suggested applying the following formula for frequency distributions.

$$x_{PMP} = x_n + K_m \cdot \sigma_n \quad (1)$$

When estimating the PMP, the factor K_m can be calculated by applying the formula:

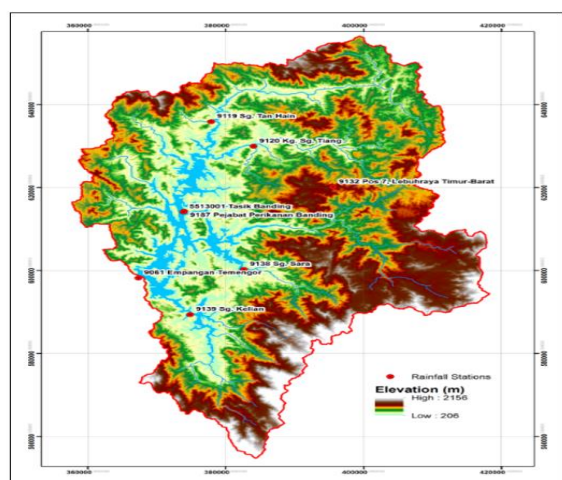


Fig. 1. Map of Temengor catchment

Table 1. Details of rainfall stations at Temengor catchment

St. No.	St. Name	Coordinate		St. Height above S.L MSE (m)
		Lat.	Long.	
9138	Sg. Sara	05 25 32N	101 25 56E	270
9132	Lebuhraya Timur	05 36 20N	101 32 54E	1042
9120	Kg. Sungai Tiang	05 41 38N	101 26 38E	260
9187	Pejabat Perikanan	05 33 06N	101 21 13 E	285
9139	Sg. Kelian	05 19 37N	101 21 43 E	259
9061	Empangan	05 24 23N	101 17 38 E	185
9119	Sg. Tan Hain	05 44 51N	101 23 18 E	258

$$K_m = (X_1 - X_{n-1})/\sigma_{n-1} \quad (2)$$

Where

X_{PMP} : PMP value for specific station
 X_n : Average of maximum annual rainfall

σ_n : Standard deviation maximum annual rainfall
 K_m : Coefficient related to Frequency
 X_1 : Maximum value of maximum annual rainfall
 X_{n-1} : Mean of annual maxima, excluding highest
 σ_{n-1} : Standard deviation of annual maxima, excluding highest

A survey conducted on more than 2600 stations worldwide calculated the factor K_m , above, as ranging from the highest value of 14.5 down to a value under 3. In Hershfield's work, he adopted the highest value and rounded it up to 15 in order to estimate the PMP.

$$x_{PMP} = x_n + 15\sigma_n \quad (3)$$

Research works undertaken in the USA, Canada, and India have shown that in areas where the annual rainfall is very heavy, the value of $K_m = 15$ tends to result in values of the PMP which are determined to be too large when using other techniques. In addition, in areas where the annual rainfall is low, the values are too small. As a result, rather than using the highest value of $K_m = 15$, used worldwide, a more appropriate K_m value was considered to be one based on stations in Malaysia, which would result in a more reliable estimation of the PMP.

The estimation of the PMP for various locations is not dependent on the single highest value of K_m in that area as was shown by Hershfield (1965). Rather, he found that, the K_m that had been derived, empirically, was different, inversely, from the mean of the series, and directly with the duration of the rainfall. That is to say, when the mean of the series (X_n) rose in magnitude, the K_m value tended to become lower. Therefore, each location will have its own K_m value which is dependent on the magnitude of the location's X_n . Following that, Hershfield (1965) employed the envelope K_m curve to obtain K_m values for a variety of X_n values. Therefore, it was concluded that, if an appropriate envelope curve could be developed based upon the locations in the study area, it would provide realistic estimates of the PMP for various time periods of rainfall. Consequently, appropriate envelope K_m curves representing the relation between K_m and the mean annual maximum rainfall were found for various time periods of rainfall. However, the natural characteristics of rainfall was realized, leading to K_m versus X_n curves being created for a variety of time periods for the location.

Recently National Hydraulic Research Institute Malaysia (NAHRIM) has conducted a PMP (Technical Research Publication No.1 - Derivation of Probable Maximum Precipitation for Design Flood in Malaysia, 2008) study covering the whole Malaysia where they have established standard method of estimating PMP by both statistical and hydro-meteorological methods. In statistical method, envelop curves for frequency factor (K_m) of different duration storm events were developed with respect to their corresponding mean annual maximum precipitation values (Figure 3). Second degree polynomial equations were then derived for each of the envelop curves which are then used to determine the K_m

value of any particular location of a catchment or station where the mean of annual maximum rainfall is available. These curves have been found useful for the determination of K_m values for any location in Peninsular Malaysia and hence been used for the Temengor catchment PMP calculation.

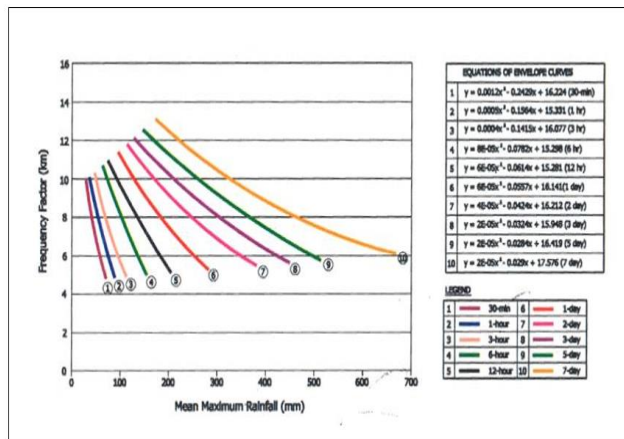


Fig. 3. K_m Envelope curves for different durations in west Malaysia (NAHRIM, 2008)

4 Methodology

The most widely used statistical method for estimating the PMP is by Hershfield (1961, 1965) which has become one of the standard methods suggested by the World Meteorological Organisation (WMO, 1986) for estimating the PMP at any location. The flow chart for PMP establishment is shown in Figure 4. Therefore, it is considered desirable to carry out a study on the estimation of PMP for 1, 2 and 3 days.

Rainfall analysis was carried out to use Gumble Extreme Value (GEV). The values were determined for 5, 10, 20, 50, 100, 1000 and 10000 year ARI. Frequency analysis was carried out for 1 day and 3 days rainfall storm duration for the Temengor Reservoir. According to Gumble theory of extreme events, the probability of occurrence of an event equal to or larger than a value X_0 is

$$P(x \geq x_0) = 1 - e^{-(e^{-y})} \quad (4)$$

Where y is dimensionless variable given by

$$y = \alpha(x - a) \quad (5)$$

$$a = x - 0.45005\sigma_x \quad (6)$$

$$\alpha = 1.2825/\sigma_x \quad (7)$$

Where: x is the mean value of the recorded rainfall and σ_x is the standard deviation of the recorded rainfall. For the required P , eq. (4) can be rearrange to

$$y_P = -\ln(-\ln(1 - P)) \quad (8)$$

If P is replace by return period ($T_P = 1/P$), y_T is given by

$$y_T = -(\ln.\ln(T_P/T_P - 1)) \quad (9)$$

Now rearrange eq. (4), the value of x with the return period (T_P) is given by

$$x_T = x + K.\sigma_x \quad (10)$$

Where: x_T is the estimated event magnitude and K is given by

$$K = (y_T - 0.577)/1.2825 \quad (11)$$

Note that eqn (10) is of the same form as the general equation of hydrologic frequency analysis.

5 Results and discussion

The rainfall intensity is commonly required for planning and designing of various water resource projects. Many sets of relationships have been developed and used in several parts of the world. Rainfall intensity were estimate for storm duration of 1day and eight different return periods of 5, 10, 20, 50, 100, 500 and 1000 years. Frequency analysis techniques are used to estimate the rainfall intensity, for different return periods from rainfall data. Distribution analysis of rainfall frequency is based on Type I extreme value (Gumbel) distributions. Areal precipitation of the study area was obtained by adopting Thiessen polygon method using Geographical Information System (GIS) technique as shown in Figure 4. Also from Thiessen Polygons, The mean area weights or proportion of rainfall that a station contributes to catchment were determined as shown in Table 2. By using this frequency distribution function, the maximum rainfall intensity for durations of 5, 10, 20, 50, 100, 500 and 1000 years return periods, have been determined as shown in Table 3. Intensity duration curve for 1, 2 and 3 days and different return period was shown in Figure 5.

Table 2. Weight of rainfall stations to compute main rainfall

Rainfall Station Name	Area (Km ²)	Respective Weight
9138 Sg. Sara	571.417	0.166
9132, Lebuhraya Timur-Barat	797.926	0.232
9120 Kg. Sg. Tiang	431.013	0.125
9187 Pejabat Perikanan Bading	430.361	0.125
9139 Sg. Kelian	600.925	0.175
9061 Empangan Temengor	112.374	0.033
9119 Sg. Tan Hain	490.445	0.143
	Σ Area = 3434.461	Σ Respective Weight =1

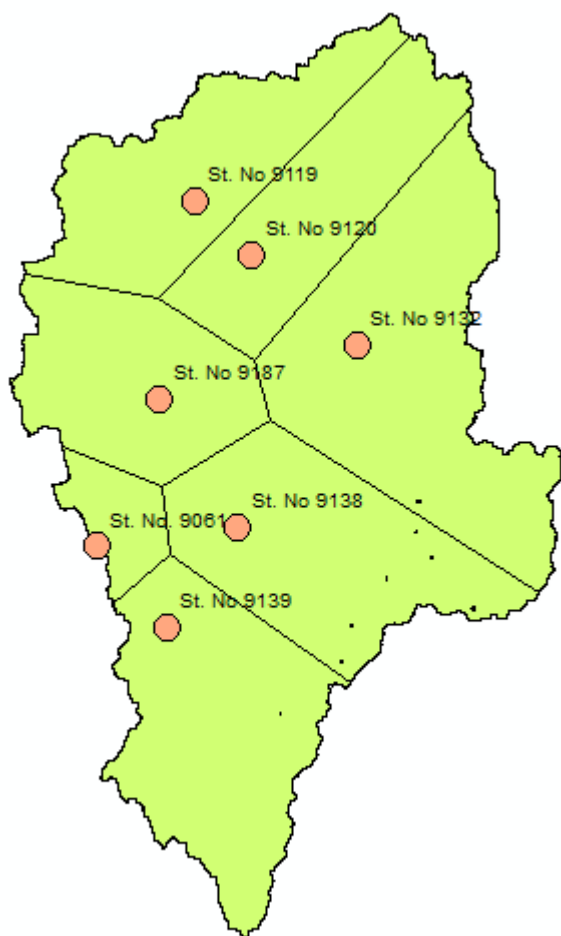


Fig. 4. Thiessen polygons derived for the study area

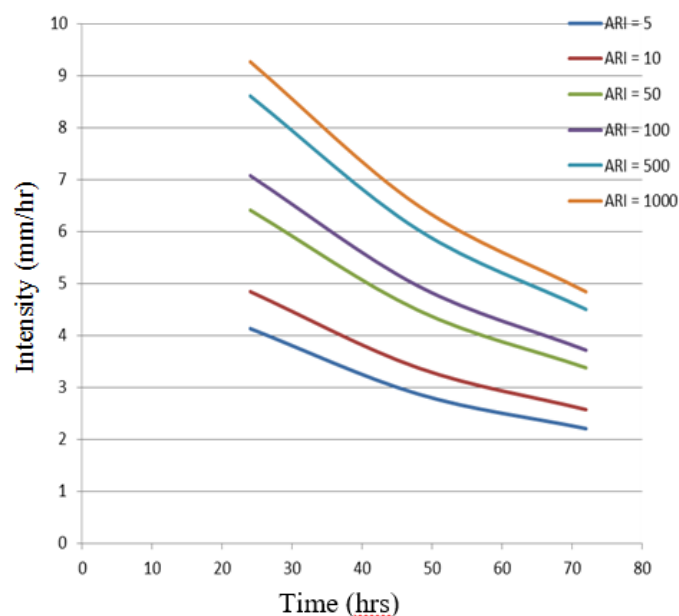


Fig. 5. Intensity Duration Curve

6 References

1. World Meteorological Organisation, 1986, Operational Hydrology Report No.1, WMO No. 332, 96-108, (Second Edition).
2. National Hydraulic Research Institute of Malaysia (NAHRIM) (2008). Nahrin Technical Research Publication No.1 (TRP 1).
3. Desa, M. N.; Rekhecha, P. R., 2007, Atmos, Res, 84, 84 – 90.
4. Hershfield, D. M., 1961: J. Hyd. Div., Am. Soc. of Civil Eng., 87, Hy5, 99-116.
5. Hershfield, D.M., 1965: J. Am. Water Works Assoc., 57, 965-972.
6. Chow, V. T., 1951: Trans. Am. Geophys. Union, 32, 231-237.
7. Chow V.T., D.R. Maidment and L.W. Mays (1988). "Applied Hydrology". McGraw-Hill.

Table 3. Rainfall depth (PMP) for different return period

Return Period (years)	Rainfall Intensity		
	1 day	2 days	3 days
5	99.084	137.736	158.69
10	116.192	161.899	185.00
50	153.845	215.079	242.92
100	169.763	237.56	267.40
500	206.547	289.512	323.98
1000	222.361	311.847	348.30

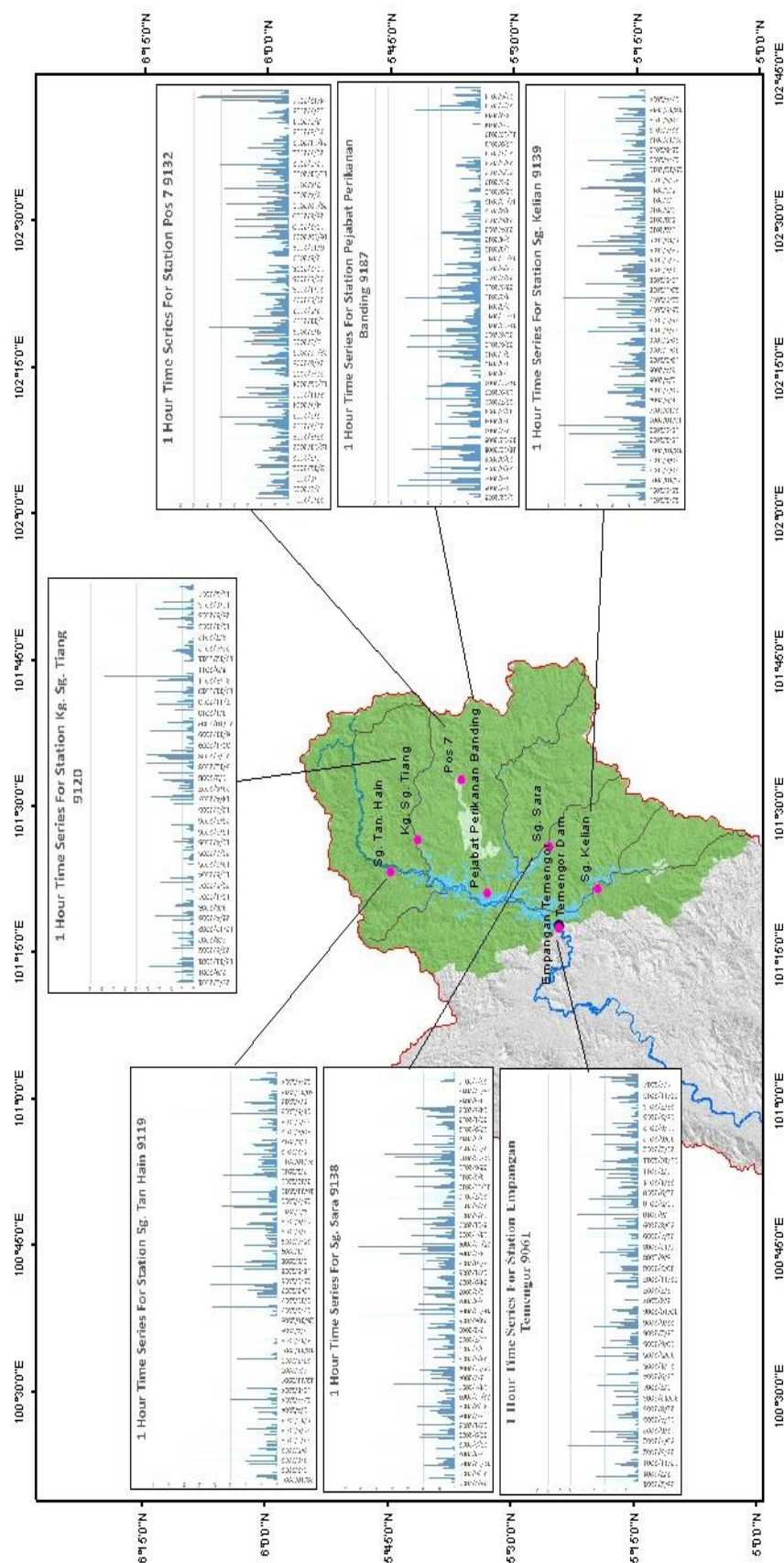


Fig. 2. Location of rainfall stations at Temenggor catchment at