Validation of Hershfield probable maximum precipitation estimation using homogeneous region in Malaysia

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Abstract. Probable maximum precipitation (PMP) is used to design major hydraulic structures, such as dams and spillways, flood protection works, and nuclear power plants. Long observation data are required for PMP estimates using the Hershfield statistical approach. In Malaysia, the PMP calculated using state boundary is commonly used, but the estimated PMP values are close to historical maximums. Homogeneous regions are regions containing stations with similar rainfall characteristics. Therefore, homogeneous region boundaries could be used for PMP estimations. In this paper, 1-day rainfall data of more than 25 years for 161 stations in Peninsular Malaysia; were analysed to estimate the PMP for 1-day duration based on an appropriate frequency factor by considering homogeneous regions. Using PMP estimates, a generalised graph was prepared to show the spatial distribution of 1-day PMP. The 1-day PMP estimates in Peninsular Malaysia by considering state boundary, varied from 146 to 1364.7 mm and by considering the homogeneous regions, the 1-day PMP estimates varied from 208.5 to 2094 mm. Hence, the PMP considering homogeneous regions is considered more accurate and safe to be used in designs.

1. Introduction

A flood is an overflow of water that submerges land that is usually dry. Flooding may occur as an overflow of water from water bodies, such as drainage, rivers and lakes, in which the water overtops resulting in some of that water escaping its usual boundaries. Some floods develop slowly, while others can develop in just a few minutes and without visible signs of rain [1]. Record-breaking extreme rainfalls have been on the rise, notably since the 2000s, according to international publications like [2] released by The Economic and Social Commission for Asia and the Pacific (ESCAP) and the United Nations International Strategy for Disaster Reduction (ISDR). Flood occurrences are seen to be rising in line with the trend of increasing extreme rainfalls [3].

In Malaysia, floods in December 2014 and January 2015 were two recent examples of heavy rainfall occurrences. Flood causes losses of lives and property of thousands of people. This does not only impact the society but the economics of the country will also be affected. Therefore, it is necessary to evaluate mitigation strategies for dealing with issues or disasters brought on by the increase in this intense rainfall. The preparation for upcoming excessive rainfall can be accomplished through a variety of actions and strategies. One of them is to estimate the likelihood that an intense rainfall event will occur.

Frequency analysis is a widely used and accepted technique. Another suitable approach is to estimate the probable maximum precipitation (PMP) predictions to determine the highest potential quantity of rainfall that could occur.

1.1 Problem Statement
Death and destruction were brought to Bertam Valley in Ringlet, Malaysia, by water that was released from the Sultan Abu Bakar hydroelectric dam in Cameron Highland after the siren, which was either not heard or ignored. Over 100 homes were demolished or submerged, there were three verified deaths, and over 100 cars suffered significant damage. At the Ringlet community centre were 38 persons from roughly 80 families. This was due to the increase in the level of water in the dam from 3498 to 3508 . The water level rose due to heavy rainfall in a quick span of time [4].

In order to minimise such events from occurring, the future precipitation events are very important to be determined. There are several methods to determine these future events. One of the methods is PMP. This method estimates the most possible rainfall data in different regions in Peninsular Malaysia. Two methods for estimating the PMP are physical and statistical methods. However, the physical method is not suitable to be used as it requires a large amount of data and meteorological parameters, such as the dew-point temperature, relative humidity, and surface temperature. The Hershfield statistical method is the most suitable to estimate PMP as an initial estimation in determining extreme precipitation that could occur in Peninsular Malaysia because the method only requires precipitation data. However, PMP estimation using state boundary gives values closer to the highest rainfall data. For example, Chin Chin (Tepi Jalan) station in Melaka has a PMP estimated value of 146 mm, which is much closer to the 1-day annual maximum rainfall value of 141.5 mm. Therefore, there is a need to improve statistical estimation as statistical PMP requires long observation rainfall data. This may be compensated by considering homogeneous regions as the boundary.

1.2 Objectives of the Study
The research objectives can be summarised as follows:

- To estimate PMP using the Hershfield statistical method,
- To estimate the PMP using the Hershfield statistical method considering homogeneous regions, and
- To assess the difference between the PMP estimation using the Hershfield statistical method with state boundary and homogeneous region.

1.3 Scope of the Study
This research aims to estimate statistical PMP using the conventional Hershfield method considering homogeneous regions. The area of study is limited to only within Peninsular Malaysia and only the rainfall stations with data of more than 25 years within Peninsular Malaysia. This study employed the statistical method. This study analysed the differences between the PMP estimation using the Hershfield statistical method with state boundary and homogeneous region.

2. Literature Review
The probable maximum precipitation (PMP) is "the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year," according to the American Meteorological Society's definition from 1959. The World Meteorological Organization's current definition, however, is "the theoretical maximum precipitation for a given duration under modern meteorological conditions." At a specific time of year, such precipitation is anticipated to occur over a particular watershed or storm area of a certain size [5].

There are two keyways to determine PMP's magnitude. The first method is the physical approach, which maximises the significant past storm events to determine the PMP for various periods. To make up for the lack of a comprehensive storm database, storm transposition and envelopment techniques are used to reach PMP levels. Using transposition and maximisation techniques, numerous PMP estimates have been performed for dam locations in Peninsular Malaysia during the past 20 years or so [7].

The second method uses statistics to estimate PMP rainfall for a specific site or area by fitting a frequency distribution to annual maximum rainfall data that was created by [8][9] using a basic frequency equation provided by [2]. When meteorological data, such as dew point temperatures and wind speed, are unavailable but there are a lot of rainfall data, the statistical method is more useful. The Hershfield method has demonstrated that the PMP estimates produced by this method are very similar to those produced by the complex physical method [6][10][11], suggesting that this method may be used to estimate PMP for stations where daily rainfall data are available for a long time. For sites with a lengthy rainfall record, the Hershfield statistical technique has been widely used to estimate the PMP [7].

Extreme-rainfall Homogeneous regions are those that have sites with extreme rainfall data that have similar means, skewness, and kurtosis. This shows that the areas contained inside the homogenous regions have comparable circumstances, climate exposure, and sources of excessive rainfall. The most often used technique for locating these homogeneous zones is the L-moments method, which makes use of an application that is both statistically effective and easy to use. [12]. In Malaysia, the homogeneous regions are created by the Department of Irrigation and Drainage, Malaysia (DID) [13].

3. Methodology

This research consists of two key activities: i) data collection and acquisition and ii) PMP analysis using the Hershfield method considering state boundary and homogeneous region.

3.1 Data Collection and Acquisition

Throughout the research, Peninsular Malaysia was used as the research area. Malaysia is generally considered to have an equatorial climate because of its proximity to the equator, which means that it is hot and humid all year round. The average annual temperature is 27 °C, and there is an average annual rainfall of 250 cm.

The yearly maximum daily rainfall was employed in this study to represent extreme rainfalls. The study made use of DID Malaysia's long history surface stations and daily rainfall records. For the analysis, a total of 161 rainfall stations were used. Figure 1 and Figure 2 show the dense distribution of the rainfall stations within the state boundary and homogeneous region, respectively. However, only stations with more than 25 years of observation record and no missing data were chosen for this research following data screening. As a result, the annual maximum series for N years of data contains N values for rainfall. In order to estimate PMP, the 1-day annual maximum rainfall values (X) for each year were taken from all stations and converted into an array of annual maximum rainfall values for each station.

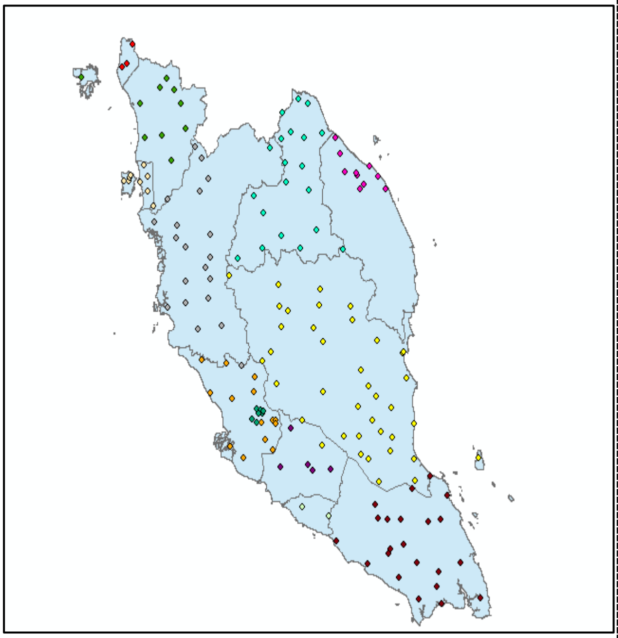

Figure 1. The rainfall stations within the state boundary.

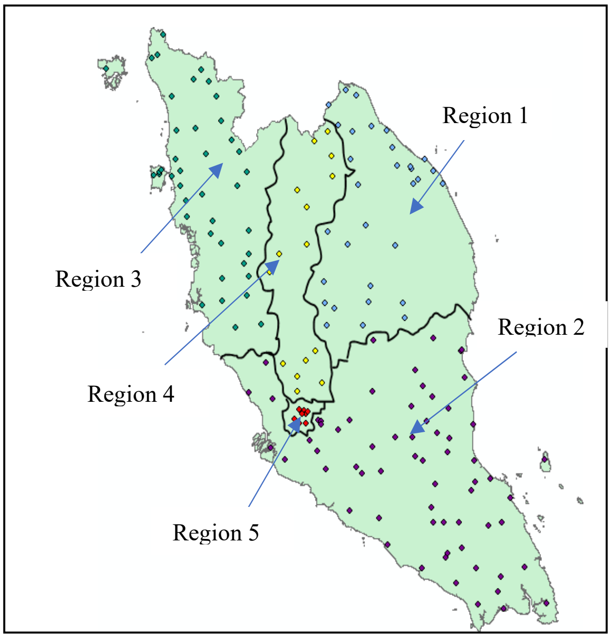

Figure 2. The rainfall stations within the homogeneous region.

3.2 PMP analysis using the Hershfield method

The following equations are used in the Hershfield method to calculate the PMP value for a station:

$$X_{PMP} = X_n + S_n \times K_m \quad (1)$$

$$K_m = \frac{X_{max} - X_{n-1}}{S_{n-1}} \quad (2)$$

Where, X_{PMP} is the PMP estimates for a station, X_n is the mean of the annual extreme series, S_n is the standard deviation of the annual extreme series, K_m is the frequency factor that depends on the availability of data period, X_{max} is the highest rainfall value at the station, X_{n-1} is the mean of the annual extreme series without the largest value, and S_{n-1} is the standard deviation of the annual extreme series without the largest value.

First, the parameters X_n, S_n, and K_m were calculated. Then, an envelope curve was produced by plotting the K_m values for each station against the corresponding X_n values. Each station's X_n 's envelope line had the revised K_m value. Finally, the PMP values for each station were determined using equation (1) by substituting the greatest K_m value and the new transposed value for K_m.

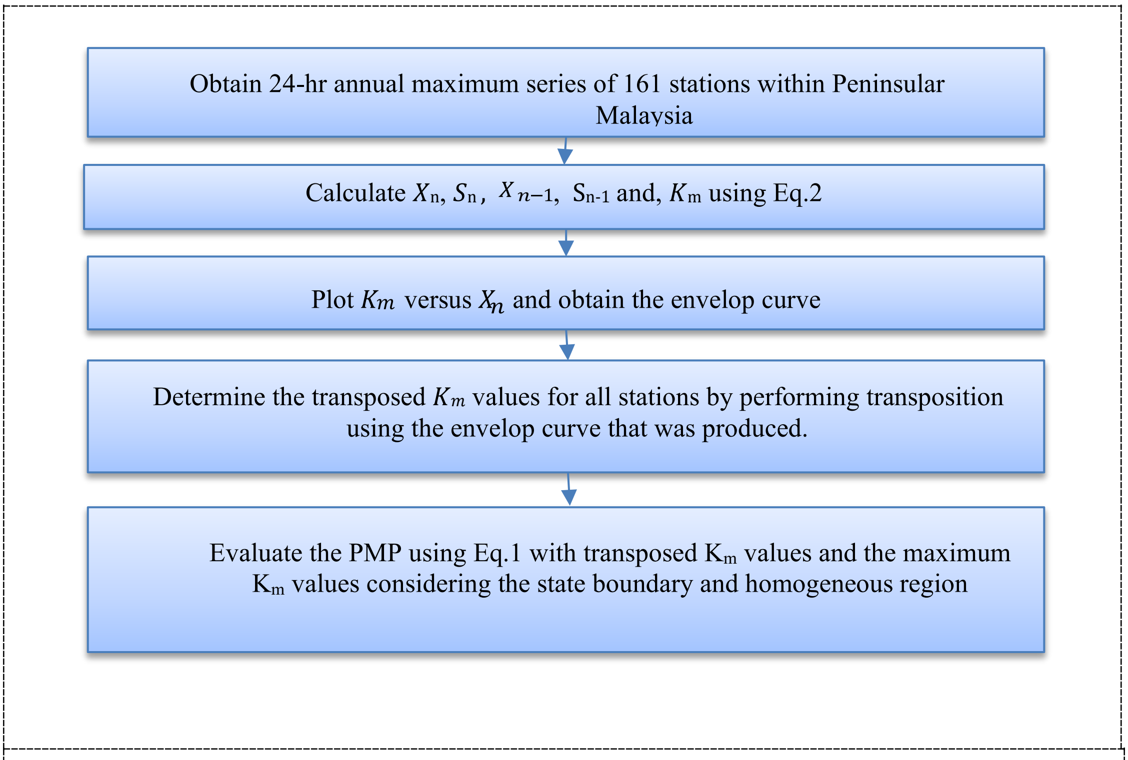

Figure 3. Hershfield statistical procedure as recommended by WMO (2009).

4. Results and Discussion

In order to efficiently construct canal openings in bridges, highway and railroad culverts, urban storm drainage, airport drainage, flood control works, and many other hydraulic structures, it is helpful to know the amounts of the heaviest rainfall.

For this paper, only Johor state and Region 2 were selected. The highest recorded annual maximum rainfall values of 1-day duration for each 22 rainfall stations within the state of Johor and for each 67 rainfall stations within Region 2 were calculated. Ibu Bekalan Kahang, Kluang station recorded the highest rainfall of 433.5 mm within the state of Johor. Meanwhile, Sg. Cabang Kanan, Pahang station recorded the highest rainfall of 621.5 mm within Region 2.

To determine PMP estimates, the 1-day annual maximum rainfall values for all stations were assessed. The values of X_n, S_n, X_{n-1}, and S_{n-1} were computed. Using Eq. 1-2, the frequency factor, K_m for each station was calculated.

For every station in the state and region, a plot was generated of K_m against the mean 1-day greatest rainfall, X_n. Figure 4 shows the graph of K_m versus the mean 1-day highest rainfall, X_n within the state of Johor and Figure 5 shows the graph for Region 2. From there, the new K_m values of all stations within the state and regions were transposed. In the Johor state, the K_m transposition used the envelope equation of: K_m = - 0.002994493 X_n + 6.981646712 and Region 2, the K_m transposition used the envelope equation of: K_m = - 0.01101529 X_n + 8.278415006.

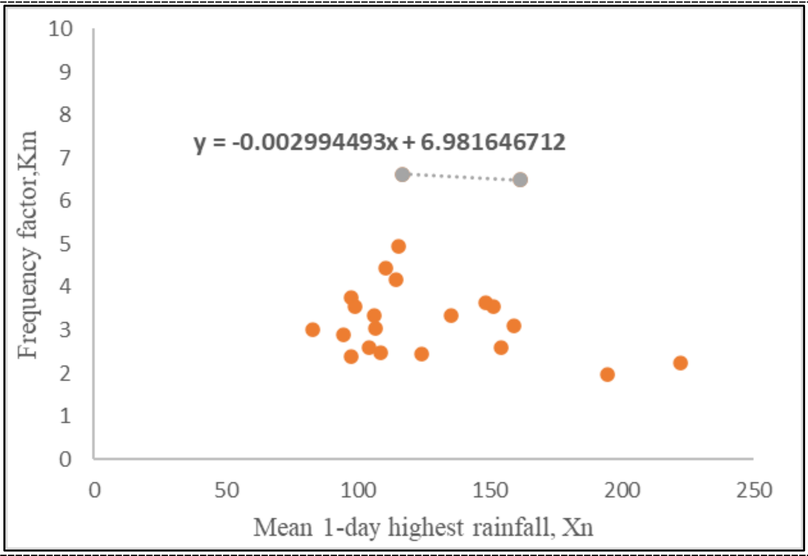

Figure 4. The graph of frequency factor, K_m against the mean 1-day highest rainfall, X_n within the state of Johor.

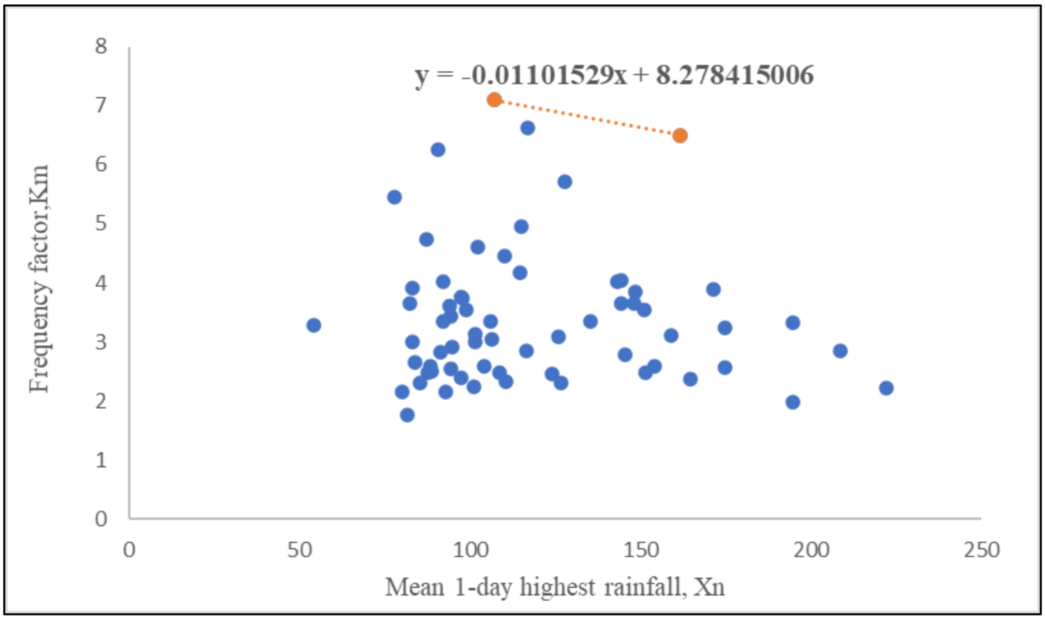

Figure 5. The graph of frequency factor, K_m against the mean 1-day highest rainfall, X_n within Region 2.

Eq. 1 was used to calculate the statistical PMP estimates for the Johor state and Region 2 after determining the envelopes and receiving the transposed Km values. However, the transposed K_m values are smaller and only differed slightly from the old K_m values. According to [7], using the highest K_m value will give more reasonable PMP value. Using the mean, X_n, standard deviation, S_n and K_m values equal to the maximum values within the state boundary and homogeneous region. the PMP values for all stations over a 1-day period were calculated using Eq.1. The results are presented in Figure 6 for the Johor state and Figure 7 for Region 2.

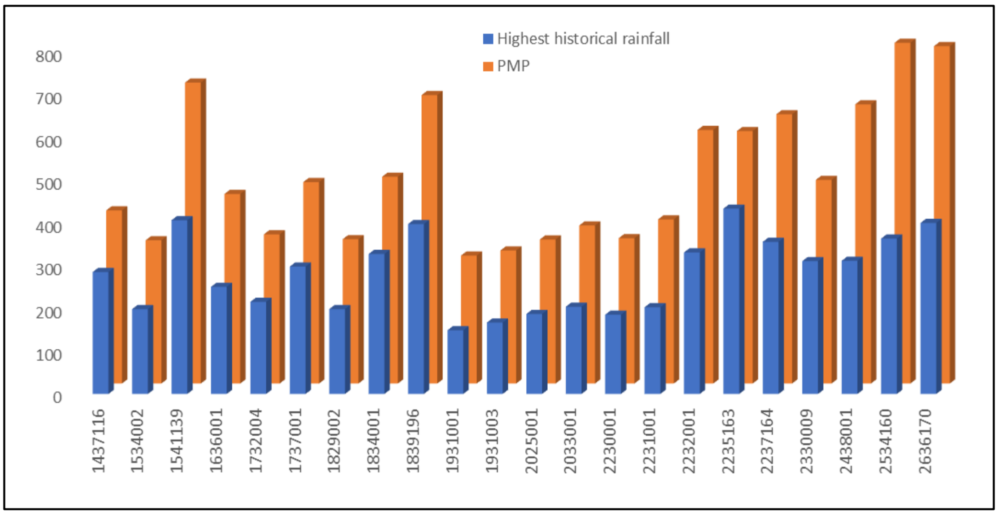

Figure 6. The 1-day highest rainfall and the PMP values calculated using the Hershfield method for the Johor state (transposed using the highest K_m value).

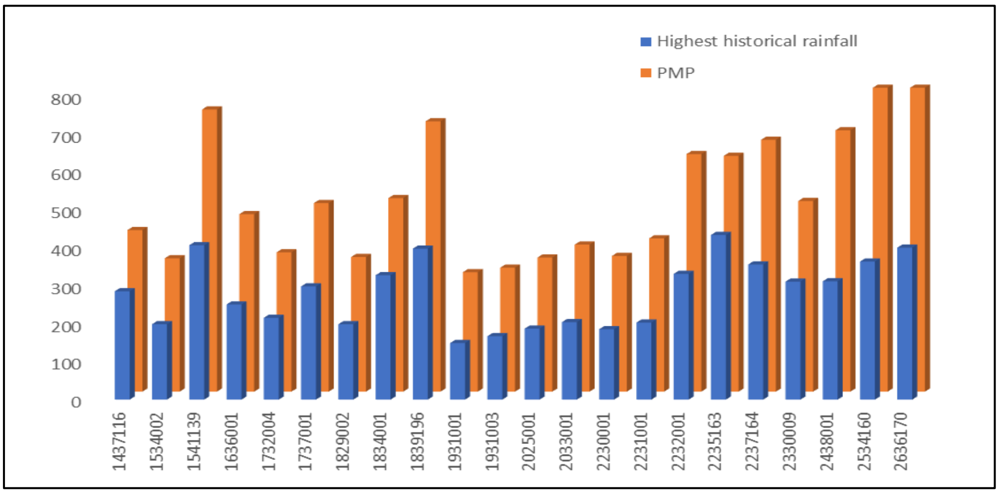

Figure 7. The 1-day highest rainfall and the PMP values calculated using the Hershfield method for Region 2 (transposed using the highest K_m value).

Observational data from recent observations was used to compare the statistical PMP estimations. Referring to Table 1's summary of the validation analysis for the state of Johor, it can be seen that the state boundary has higher values for the PMP calculated using the maximum Km value. However, additional findings demonstrate that by using the homogeneous region as the transposition boundary, PMP estimations can be improved. When using the Johor state as the limit and a PMP estimate of 405 mm, for station Stor JPS Johor Bahru (1437116), for instance, a significant improvement may be seen. The PMP estimate is 425.3 mm, though, if the homogenous region is considered as the boundary. Additionally, it can be seen that there is a 1.49 ratio between the PMP number and the heaviest rainfall in recorded history. If the PMP estimate is to be employed for the design of flood defence structures, this gives higher precautionary measures. The station in Peninsular Malaysia can also be evaluated in a similar manner.From the overall observation, the PMP estimates are economically safe to be used in designs as the factor varies from 1.0 to 2.5 for all stations in Peninsular Malaysia.

Table 1. Summary of the validation analysis of the Johor state by considering state boundary and homogeneous Region 2.

Station	1-day PMP Estimates from 1969 to 2012 (mm)		1-day Highest Rainfall from 1969 to 2021	Factor
	State Boundary (Johor)	Region 2		
1437116	405.0	425.3	285.3	1.49
1534002	335.1	351.1	198.5	1.77
1541139	704.0	742.8	406.4	1.82
1636001	443.5	467.2	250.5	1.86
1732004	349.1	366.7	215.5	1.70
1737001	471.3	496.3	298.0	1.66
1829002	337.7	354.4	198.5	1.79
1834001	483.8	509.5	327.5	1.56
1839196	674.7	711.7	397.5	1.79
1931003	311.2	326.2	167.0	1.95
2025001	337.0	353.0	245.5	1.44
2231001	384.0	387.0	202.9	1.91
2232001	593.2	625.3	331.1	1.89
2235163	590.6	620.7	433.5	1.43
2237164	629.9	662.9	355.9	1.86
2330009	476.3	501.9	310.7	1.62
2438001	653.1	688.1	324.9	2.11
2534160	797.1	839.4	468.3	1.79
2636170	789.3	829.0	477.4	1.74

5. Conclusion

By taking into account state boundaries and homogeneous regions, statistical estimates of 1-day PMP rainfall for 161 sites in Peninsular Malaysia were developed. By taking into account the state boundaries, it was shown that the 1-day PMP over Peninsular Malaysia ranged from 146.0 to 1364.7 mm and from 208.5 to 2094 mm when taking into account the homogenous region. The southwest and northeast monsoons across the region brought about the long-lasting PMP rainfall. The major goal of this study was to evaluate the discrepancy between the Hershfield method's PMP estimation and the homogeneous region by taking into account state boundary regions. By using the homogeneous region as the boundary, it may improve statistical PMP estimates for cases with shorter observation records or poor quality of rainfall data.

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