Estimation of Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) Using GSSHA Model (Case Study Area Upper Citarum Watershed)

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Abstract. Probable Maximum Flood (PMF) used in the design of hydrological structures reliabilities and safety which its value is obtained from the Probable Maximum Precipitation (PMP). The objectives of this study are to estimate PMP and PMF value in Upper Citarum Watershed and understand the impact from different PMP value to PMF value with two scenarios those are Scenario A and B. Scenario A will calculate the PMP value from each Global Satellite Mapping of Precipitation (GSMaP) rainfall data grid and Scenario B calculate the PMP value from the mean area rainfall. PMP value will be obtained by the statistical Hershfield method, and the PMF will be obtained by employed the PMP value as the input data in Gridded Surface Subsurface Hydrologic Analysis (GSSHA) hydrologic model. Model simulation results for PMF hydrographs from both scenarios show that spatial distribution of rainfall in the Upper Citarum watershed will affect the calculated discharge and whether Scenario A or B can be applied in the study area for PMP duration equal or higher than 72 hours. PMF peak discharge for Scenario A is averagely 13.12% larger than Scenario B.

1. Introduction
Probable Maximum Flood (PMF) is generally used as the reference to ensure the safety of hydraulic buildings such as reservoirs [1], and as reference for flood disaster management [2] as well as to avoid the potential hazards or losses by the water runoff in the reservoir [3]. The PMF values require Probable Maximum Precipitation (PMP) data as input [3],[4],[5]. World Meteorological Organization (WMO) defines PMP as the theoretical maximum amount of precipitation that may occur and cannot be exceeded within a given duration and in a particular area. There are two methods that widely used to calculate the PMP value, those are physical approach and statistical method. The National Standardization Agency for Indonesia (Badan Standarisasi Nasional, BSN) states that the statistical method is the most suitable one to be applied in Indonesia [6], which was developed by Hershfield [7],[8]. This method requires a long period of available rainfall data to get its annual maximum value. A previous study reported that the spatiotemporal distribution of PMP with the worst incidence is essential to know in calculating the PMF value [5]. Additionally, the calculation of PMP in every part of the watershed will represent the spatial distribution of rainfall. However, the research conducted on this subject is still very rare because the isohyetal approach is mainly use [5].
The purpose of this research is to estimate the PMP value using the rainfall data from satellite observation based on the spatial distribution of rainfall. The result will be combined with a hydrological model to produce a procedure for calculating the PMF value in the Upper Citarum Watershed.

2. Data
The study area is the Upper Citarum Watershed, located in the West Java Province of Indonesia. The observation rainfall data used are obtained from seven stations (Cicalengka, Cililin, Ciparay, Cisondari, Montaya, Paseh, Ujung Berung) provided by the Centre for Research and Development of Water Resources Bandung (Pusat Penelitian dan Pengembangan Sumber Daya Air, PUSAIR) which will be shown in figure 1. The more rainfall observation station used in a particular area, the PMP value result will be more accurate. However, due to the limited ground observational rainfall data, in this study will also use satellite rainfall data. Satellite observation rainfall data obtained from the Global Satellite Mapping of Precipitation (GSMaP) with the spatial resolution is 0.1° x 0.1°, and temporal resolution is 1 hour produced by Japan Aerospace Exploration Agency (JAXA). Both of observation and satellite rainfall data have the same period from 2000 to 2014. Additionally, Digital Elevation Model (DEM) Shuttle Radar Topography Mission (SRTM) used in this study has the spatial resolution 30 x 30 meters and Land-use data on 2011 (scale 1:250.000) provided by Peta Rupa Bumi Indonesia of Geospatial Information Agency of Indonesia (BIG).

3. Method
3.1. Bias Correction
The GSMaP data is corrected by the bias correction method to all ground rainfall stations [9]. The result shows that the bias correction method can change the distribution of GSMaP data closer to the observation data, for example as presented in figure 2 for Cicalengka rainfall station.

3.2. Estimation of PMP
In this study, the PMP will be estimated using the Hershfield statistical method, which is already extensively used [10],[11] and applied in the manual book of WMO. The equation can be shown in equation 1 and equation 2 below:

\[ X_{PMP} = X_n + S_n \times K_m \]  

\[ K_m = \frac{x_{max} - x_{n-1}}{S_{n-1}} \]
Where the $X_{\text{PMP}}, X_n, S_n, K_{\text{max}}, X_{\text{max}}, X_{n-1}$, and $S_{n-1}$ are the PMP value, the average, standard deviation of annual maximum rainfall, frequency factor, the highest rainfall value, and the mean and standard deviation of the annual maximum rainfall data without highest value data respectively.

PMP is the main input value in the GSSHA hydrological model to calculate the PMF value. Spatial distribution of the rainfall will affect the PMF, thus the selected scenarios are based on the difference in rainfall values to produce PMP which was adopted through research conducted by Liu [5]. In the Scenario A, the PMP will be calculated on every grid of corrected GSMaP rainfall data and the Scenario B is using the mean area rainfall as shown on equation 3.

$$P = \frac{A_1 \cdot P_1 + A_2 \cdot P_2 + A_3 \cdot P_3 + \cdots + A_n \cdot P_n}{A_1 + A_2 + A_3 + \cdots + A_n} \quad (3)$$

Where $P$ is the mean area precipitation (mm), $A$ is the service area of the rainfall station ($\text{km}^2$), and $P_n$ is the precipitation in rainfall station.

3.3. Calculation for PMF

For the PMF, the value will be processed respecting the spatial distribution and variance of the PMP 1, 3, 6, 9, 12, 72, and 120 hours. While the spatial distribution will be obtained by applying two scenarios as mentioned above.

The PMP value then use as the main input in the Gridded Surface and Subsurface Hydrologic Analysis (GSSHA) hydrological model to estimate the PMF value in each scenario. At the time of simulation, the PMP value is assumed evenly distributed on the watershed surface, and the infiltration process does not occur. The simulation of the GSSHA model is carried out using a time-step of 10 seconds with the aim to produce a more accurate output value, and a total-time simulation is 12000 minutes to get the discharge output in a long time.

4. Results and Discussion

The spatial distribution of the PMP value obtained with Scenario A will be shown in figure 3. It is showing that the PMP value is gradually increasing most in the study area for duration 1, 3, 6, 9, 12, 72, and 120 hours. For 1-hour and 3-hour duration, PMP value is spread unevenly. However, the 48-hour duration showing it is developed and included the southern part, additionally on the 120-hour duration showing that the besides the northern and southern part, highest PMP value also calculated in the middle part of the study area which it is consist of Bandung and Cimahi.
PMP value result using Scenario B will be presented in Table 1. The PMP value is likewise increasing from duration 1 to 120 hours.

### Table 1. PMP value using Scenario B.

| Duration (hour) | $X_n$ (mm) | $X_{max}$ (mm) | $S_n$ | PMP (mm) |
|----------------|------------|----------------|-------|----------|
| 1              | 6,7        | 7,1            | 1,1   | 9,2      |
| 3              | 19,8       | 21,3           | 3,9   | 27,3     |
| 6              | 38,9       | 41,9           | 8,2   | 53,7     |
| 9              | 58,4       | 60,4           | 11,6  | 77,5     |
| 12             | 16         | 81,6           | 16    | 104,7    |
| 24             | 152,2      | 164,1          | 29,5  | 210,3    |
| 72             | 518,3      | 528,2          | 87,3  | 678,1    |
| 120            | 867,8      | 890,1          | 144,5 | 1142,4   |

By employed both PMP values from Scenario A and B to the GSSHA model, it is found that there are similarities and differences in watershed responses. One of the responses can be seen from PMF peak discharge which indicated the maximum discharge or volume that could be accommodated by a watershed [12]. As a result, Scenario A yields the peak discharge 13.12% larger than Scenario B averagely. Both PMF value from Scenario A and B with duration 1, 3, 6, 9, 12, and 24 hours consistently

![Figure 3. PMP Spatial distribution for Scenario A with duration (a) 1 hour, (b) 3 hour, (c) 6 hour, (d) 9 hour, (e) 12 hour, (f) 24 hour, (g) 72 hour, (h) 120 hour.](image-url)
increasing. However, the 72-hour and 120-hour duration show the super-saturated state (indicated by a stagnant straight line on the hydrograph in figure 4) where the watershed has reached its maximum volume, but the rainfall continues. The maximum volume of a watershed will occur when the rainfall duration is close or equal to the concentration-time. Therefore, it should be noted that Upper Citarum Watershed concentration time is approximately 21 hours.

The responses of watershed presented by PMF peak discharge is notably affected by the PMP value. The ratio between peak discharge PMF and PMP in figure 5 below shows that there is a similar or equivalent pattern for both scenarios. Thus both PMF and PMP in scenario A and B consequently has the same relationship pattern.

**Figure 4.** Hydrograph for PMF discharge for Scenario A and Scenario B. PMF-1hr means that PMF value obtained from PMP 1 hour duration and this applied for other duration for both scenarios.

Furthermore, this condition checked with the comparison of the PMP intensity as shown in figure 6. As the result, there is a contrary intensity value between PMP from scenario A and B, particularly for PMP duration 1 to 24 hour but exceptionally happened for duration greater than 72 hour. PMP intensity for Scenario A has a trend that the longer PMP duration happened, then the intensity is decreasing. However, the PMP intensity for Scenario B is slightly constant in 9 to 10 mm/hour. Moreover, both of these scenarios have the same intensity when it reached equal or greater than 72-hour duration.
5. Conclusion
The results presented that the spatial distribution of rainfall in the Upper Citarum watershed will affect the calculated discharge, which was obtained by employing Scenario A that is the PMP calculated by processing in each GSMA-P rainfall data grid, and Scenario B calculate the PMP value from the mean area rainfall. PMF in 72-hour and 120-hour have quite similar output discharge for both scenarios. It indicated that both scenarios could be employed to calculate the PMF value with PMP higher than 72 hour duration in the study area. Nevertheless, for the PMP duration less than 72-hour, there are relatively differences, in general, the peak discharge for Scenario A is 13,12% larger than B.

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