Estimation of peak discharge using a rational method in Kodil Sub-Watershed, Purworejo Regency, Central Java

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Abstract. The Kodil Sub-Watershed is one of the areas that has a high potential for flooding in Bogowonto Watershed. Flood disasters can cause significant losses to society, both in terms of physical, social and economic. This causes are need for information on the estimated peak discharge in The Kodil Sub-Watershed. Peak discharge estimation uses the rational method and The Cook Method to measure runoff coefficient or C value. Runoff coefficient using The Cook Method uses physical parameters, i.e land use, slope, drainage density, and infiltration. These parameters are extracted using remote sensing technology and Geographic Information System (GIS). Remote sensing data used for extraction of physical land parameters of Sentinel 2A Imagery and DEM ALOS PALSAR imagery. The results of the processing of peak discharge by the method obtained an estimate of the peak discharge of the Kodil Sub-Watershed of 209,659 m³/second and an average peak discharge of 135,024 m³/second.

Keyword : Sub DAS Kodil; Peak Discharge; Cook Method; Rational Method; Remote Sensing

1. Introduction
Flooding is a problem that has a major impact on people's lives. Flooding can result in several losses including economic, social, and physical losses for the affected communities. Flooding can be influenced by several factors that affect the watershed conditions and peak discharge in the watershed area. Several factors affecting watershed conditions include decreasing carrying capacity of watersheds, changes in land use patterns, changing rainfall and river morphometry related to river width and depth that affect the watershed's ability to accommodate water in maximum conditions [1]. The runoff flood will cause many losses for residents affected in several regions in Indonesia, one of which is in The Kodil Sub-Watershed, Purworejo so that information is needed related to the estimated peak discharge in The Kodil Sub-Watershed area.

The development of technology has an impact on the runoff estimation process that can be seen spatially by utilizing remote sensing technology and geographic information systems (SIG) [2]. Remote sensing technology is used to extract peak discharge parameters, i.e. runoff coefficient, land use, and watershed area. While GIS is used to model these parameters and analyze from the peak discharge data generated [3]. Therefore, the utilization of new technologies can be more effective and efficient in estimating peak discharge.
Estimation of peak discharge conditions, watershed using the rational method and runoff coefficient using The Cook Method. Peak discharge estimates using the rational method are determined based on runoff coefficient, rainfall intensity and watershed area. Surface runoff can occur when the rainfall that falls to the surface of the earth has reached a certain concentrated time, namely the travel time of groundwater in the upstream of the watershed down to the downstream of the watershed [4]. This is in accordance with the working principle of rational methods related to the amount of rain frequency and flow on the surface of the earth is the same [5]. However, the weakness of this method is that it can only describe the peak discharge that occurs in the rain catchment area and has not been able to describe the large capacity of the major rivers that hold the water [6].

The study aims to estimation of peak discharge in The Kodil Sub-Watershed, Purworejo Regency, Central Java. The results of the estimated peak discharge are used to analyze the potential for flooding and watershed health by allocating surface runoff values in the study area. Therefore, can provide an effective research method in mapping to reduce the risk of disaster as a form of passive mitigation against flooding in an area.

2. Material and Method

2.1. Study Site

The study was conducted in the Kodil Sub-Watershed of Purworejo Regency. The Kodil Sub-Watershed is the largest sub-watershed found in the Bogowonto Watershed, which is in the area of Magelang, Wonosobo, Purworejo and Kulon Progo Regencies. It has an area 204,816 km². The Kodil Sub-Watershed has a long elongated and curved shape so it has high runoff potential in Indonesia.

![Figure 1. Study site in The Kodil Sub-Watershed](image)

2.2. Data Collection

2.2.1. DEM ALOS PALSAR. This image can be accessed on the asf.alaska.edu site with a spatial resolution of 12.5 m. This image can be used as a basis to know the topographical condition of the area in detail because it has radar capabilities that can penetrate vegetation, so that the height obtained according to the actual conditions. In addition, it is equipped with a height and shape information that can be used to know the condition of texture and infiltration of the soil.
2.2.2. Sentinel 2A Imagery. The image of the recording on August 10, 2019 obtained from scihub.copernicus.eu. Information that can be obtained from this image is land cover and percentage of vegetation cover. The information is obtained by modeling with multispectral classification and vegetation index transformation.

2.2.3. Rainfall Data. Rainfall data from 2000-2011 is used to determine the meteorological conditions of the study area. In addition, by doing a modeling will be able to know the value of rainfall intensity so that it can be used for estimated peak discharge [7]. The data were obtained from the Meteorology, Climatology and Geophysics Agency of Purworejo Regency.

2.3. Data Pre-Processing

2.3.1. Sentinel 2A. Data pre-processing is done in order to perform analysis visually and mathematically by changing the pixel value to an ideal condition. The pre-processing includes a floating correction to eliminate the overvalued value by dividing the DN value by 10000. After that it needs to be corrected BOA reflectance because this image type has a level 1C, which indicates it is corrected to TOA reflectance. BOA's corrected results reflectance still needs to be checked from the histogram to ensure the data has been used to the next processing.

2.3.2. DEM ALOS PALSAR. This image is done processing with a slope on ArcGIS 10.5 software to find out the amount of slope value. Classification of modeling results into four classes that the pixel size of the slope will follow the spatial resolution of DEM ALOS PALSAR which is 12.5 meters. The information will help to determine the amount of surface flow that occurs in the study area.

2.4. Data Analysis

2.4.1. Runoff Coefficient (C). Cook method is used to determine the amount of runoff that occurs by comparing the amount of surface flow value with the amount of rainfall that occurs in the study area [8]. This method determines the value of runoff coefficients by approaching physical soil factors consisting of topography, soil infiltration, vegetation and surface runoff. Physical condition or health level of a watershed can be seen using the C value indicator that is when the value is getting towards the value of 1, the more rainfall becomes the surface flow and does not prescribe into the soil. It also has an impact on other natural disasters such as erosion and landslides because it has a value of C of more than 0.5 which indicates the condition of the watershed is unhealthy.

\[
GDAS = \frac{C_1A_1 + C_2A_2 + C_nA_n}{A_1 + A_2 + A_n}
\]

Explanation:
C = Runoff Coefficient
C1, 2, n = Runoff Coefficient Parameter
A1, 2, n = Parameter Area

2.4.2. Peak Discharge. Peak discharge can be known by using rational methods and utilizing GIS and remote sensing technology. Parameters required in the modeling are the value of runoff coefficient, rainfall intensity, and watershed area. The following equations are used [9]:

\[
Q_p = 0.28 \times C \times I \times A
\]

Explanation:
Qp = Peak Discharge (m³/s)
I = Rain Intensity (mm/hour)
0.28 = Correction Factor
A = Watershed Area (km²)
C = Surface Runoff Coefficient
The I value and Tc value were calculated as follows:

\[ I = \left( \frac{R^{24}}{24} \right) \times \left( \frac{24}{T_c} \right)^{2/3} \]

\[ T_c = \frac{L^{0.55}}{7700 \times S^{0.885}} \]

Explanation:
- I = Rain Intensity (mm/hour)
- R24 = Rain intensity in 24 hours (mm)
- L = Maximum length of flow (m)
- S = Difference in height between outlets with the furthest location of the watershed divided by the maximum length of flow (m)
- \( T_c \) = Rain intensity in 24 hours (mm)

C is the ratio between peak discharge and rainfall intensity [8]. C value can be obtained by using several parameters such as slope, infiltration, vegetation density, and flow density that is done modeling using cook method. The model uses a weighting system in each parameter because it has a different influence on the amount of C. While the Tc value is used to estimate the amount of peak discharge because it is related to the concentration time or duration of rainwater reaching the catchment area and becoming inundation or flooding [10].

3. Result and Discussion

Figure 2. Infiltration Factor (a), Drainage Factor (b), Land Cover Factor (d), Slope Factor (d), and Runoff Coefficient (e).
Based on the results of overlapping physical parameters of the land that affect the runoff surface of the study area, the runoff coefficient value is 0.54. This shows that as much as 54% of the rain water that falls to the surface of the earth does not enter into infiltration but instead turns into surface runoff. Based on the runoff coefficient map in Figure 2, the highest runoff occurs in the upstream part of the watershed while the lower surface runoff is found in the downstream part of the watershed.

The magnitude of the surface runoff coefficient is largely determined by the slope level of the study area. On the slope map of the sub-watershed contained in Figure 2, most of the watershed area has a fairly steep slope with a slope of > 30% especially in the upstream part of the watershed. This causes the rain that falls to the surface of the earth will tend to flow to a lower place very quickly so that it reduces the level of infiltration. Different things occur in the downstream watershed areas that have a flat to gently topography ranging from 0 - 10%. The flat topography causes the downstream watershed to have a fairly high level of infiltration compared to the upstream watershed. This is evidenced in the infiltration level map in Figure 2 where the upstream watershed has low to moderate infiltration rates while in the downstream watershed has a very good infiltration rate. The greater the level of infiltration, the runoff coefficient will be lower, but conversely the smaller the level of infiltration will have a high runoff coefficient.

Another physical factor affecting land runoff coefficient is land cover. In Figure 2 shows that in the study area most of the area is covered by vegetation with land use in the form of forests, especially in the upstream. The higher the density of vegetation, the greater the infiltration, but this does not occur in The Kodil Sub-Watershed area. In the upstream part it is mostly covered by high to medium density forest but has a low runoff coefficient. That is because the run over coefficient of The Cook Method not only considers land use factors but also the slope and drainage density. In the upper part of the slope, the slope is quite high, causing the rainwater to fall not into the ground as infiltration but rather to become surface runoff [11]. This also occurs in downstream areas where downstream areas are covered by buildings and paddy fields that have low infiltration values, but have high slope and high infiltration levels which causes higher runoff coefficients in the upper watershed section.

Drainage density factors also affect the runoff coefficient in The Kodil Sub-Watershed. Drainage density is directly related to the time the concentration of rain water will be flowing into the river, the higher the drainage density, the more paths that carry water to the river so that runoff will be smaller because the water directly flows into the river, and vice versa. Rain intensity is measured from 3 rain gauge stations, namely Ngasinan, Bener and Banyuisin. It was measured with a repeat period from 2000 to 2011. The results of rainfall data measurements used were the highest rainfall data for the year.
Calculation of rainfall intensity using The Thiessen Method produces a maximum intensity value of 6.7 mm/hour. According to the BMKG (Geophysical Climatology Meteorological Agency) of Purworejo Regency, its intensity is classified as heavy rainfall. The maximum intensity data used is because the expected runoff is the maximum runoff discharge, so it can be compared with the maximum dam capacity.

Based on the calculation of peak discharge with a rational method that involves the value of the flow coefficient generated from The Cook Method, the maximum peak discharge value of The Kodil Sub-Watershed is 209.659 m$^3$/s and the average peak flow of 135.024 m$^3$/s. This shows that the peak discharge can cause flooding because the flow velocity is high enough so that it must ensure that the value is constant at all times so that The Kodil Sub-Watershed can be said to be healthy watershed. This can prevent flooding due to excess peak discharge and experiencing drought if the peak discharge occurs [7].

4. Conclusion
The result of runoff coefficient is 0.54 which indicated the condition of Sub-Watershed Kodil area is unhealthy. The results also affect the value of the estimate of peak discharge. The estimated peak discharge for The Kodil Sub-Watershed with rational method is 209.659 m$^3$/s and estimated average peak flow of 135,024 m$^3$/s.

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