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Modification of Curve Number on pine forest catchment at Gombong, Central Java, Indonesia

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Abstract

Flood volume of forest catchment can be predicted by Curve Number (CN) method. CN method was developed by Soil Conservation Service, USA. Application of the method in a tropical country such as in Indonesia may need some modifications since the method was developed in the temperate region. The aim of the research is to determine CN value for pine forest in a tropical region, Indonesia. Kalipoh catchment was used to apply the method. The catchment area is 45 ha and almost all of the area is covered by pine forest (95%) and the rest is shrubs (5%). Hydrological station was installed by water level recorder (logger) with interval measurement every 5 minutes. Flood volume from direct measurement was measured and compared with flood volume prediction using CN. Coefficient of determination (R^2) is used to measure the correlation between the measured and the predicted of flood volume. The collected data from 2015 to 2016 with various rainfall event from 20 mm to 93 mm were used for trial and error in selecting CN value and Antecedent Moisture Content (AMC). The results show that the observed and the predicted of flood volume has R^2 = 0.437 for CN = 60 (the original value) and R^2 = 0.459 for CN = 55. When the AMC was change to the wettest condition (AMC class III), it has R^2= 0.922. It can be concluded that pine forest in the tropical region has CN value of 55 and the value of AMC should be on wet condition (AMC class III).

Keywords: Curve Number; Pine Forest; Antecedent Moisture Content

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1. Introduction

Prediction of discharge volume using Soil Conservation Service Curve Number (SCS-CN) method has been widely used due to its simple application. The CN method was originally developed by United States-Soil Conservation Service (US-SCS) in 1954 (Dile et al., 2016). Curve Number is a simple index to determine the amount of rainfall becomes runoff (Mc.Cutcheon, 2003). According to Mishra and Singh (1999), the method is based on two hypotheses. Firstly, comparison between direct runoff and rainfall minus initial abtraction is equal to cumulative infiltration and maximum potential retention (Mishra and Singh, 1999). Secondly, the amount of the initial abstraction is one fifth of the potential maximum retention (Mishra and Singh, 1999).

The CN method was originally developed by United States-Soil Conservation Service (US-SCS) in 1954 (Dile et al., 2016). Although CN method was originally developed mainly for agricultural watershed, it has been adopted for urbanized and forested watershed (Cronshey et al., 1986). The advantages of CN method are simple, practice, predictable, stabile, rely on a single parameter, and responsive to watershed properties such as soil type, land use, surface condition, and antecedent condition (Porce and Hawking, 1996). However, it has some disadvantages such as there is no clear guidance on how to vary antecedent condition, varying accuracy for different biomes, there is no explicit provision for spatial scale effects, and the initial abstraction ratio at 0.2 (Porce and Hawking, 1996).

When the CN in the watershed has been identified therefore runoff can be estimated from a single rainfall event. Further, CN values can be used to develop relationships between runoff and rainfall. CN values depend on watershed characteristics such as hydrologic soil group, land use, surface condition, and antecedent soil moisture content (Banazik et al., 2014). In addition to the disadvantages mentioned above, the method should be adjusted to the tropical environment such as Indonesia because the the method was develop in the temperate region. The other limitation is the method does not differentiate forest type. Because there was only one value in CN method for forest cover, therefore Hawkins et al. (2010) recommended that CN for forested watersheds should be differenciated among the species. In the CN method, soils are classified into 4 classes namely Soil group A for soil with high infiltration capacity, soil group B for soil with moderate infiltration rate, soil group C for soil with slow infiltration rate, and soil group D for soil with very slow infiltration rate. Based on United States-Soil Conservation Service (USSCS), CN for forest is various from 25 for hydrology soil group A with good forest condition to 83 for hydrology soil group D with poor condition of forest cover (Dunne and Leopold, 1978). Using weighted curve number method, Mistry et al. (2017) have found that in deciduous forest watershed the CN values is 55 for Antecedent Moisture Content (AMC)-II, 35 for AMC-I and 74 for AMC-III. The Antecedent Moisture Content (AMC) levels are classified into three classes. The AMC level is classified based on total precipitation that occurs within previous 5 days. The AMC is categorized as AMC I, II, or III if the total previous 5-days rainfall are less than 35.56 mm, 35.56 mm to 53.34 mm, or more than 53.34 mm, respectively.

The CN values are affected by several parameters, i.e. soil properties, rainfall, and land cover. However, the land cover for forest is not distinguished between forest types. In this case it needs more research to determine CN value for tropical forest. In addition, the majority of forested watersheds in Indonesia lack of automatic hydrological measurements, therefore estimation of flood volume using CN method is important. This study aims to find the CN value for pine (*Pinus merkusii*) forest watershed by comparing flood volume estimate through the CN method with flood volume from direct measurement.

2. Material and Method

2.1. Site description

To determine CN value for *Pinus merkusii*, it needs a catchment or sub watershed with uniform forest cover. Therefore, Kalipoh catchment was choosen as the study area, because 95% the area of the catchment is covered by pine forest. The forest is managed by PT Perhutani I which is a State Forest Corporation. Geographically, the catchment lies between 336000 m East – 345000 m East and 9162500 m South – 9170000 m South. The study area is belongs to Kebumen Regency, Central Java Province, Indonesia.

2.2. Land cover classification

To obtained spatial distribution of land cover, worldview image 2012 is used as a basis data. The spatial resolution of the images are 1 by 1 m. Land cover classification was undertaken by on screen digitizing. Ground check of the classification results was conducted in 2015. Characteristics of the pine forests were measured at the same time with field check of the land cover.

Observations and measurements characteristics of pine forests were conducted in 20 by 20 m rectangle sample plots. These measurements included stand diameter at breastheight (DBH) at 130 cm above ground, stand density, and tree height. The detail measurements have been explained in Pramono et al. (2017). Pine forest in Kalipoh consists of 94.8% of catchment area and only 5.2 % of the area is covered by shrubs The average of tree height is 22 m, the average of tree density is 388 tree/ha, and the mean diameter is 35.35 cm (Pramono et al., 2017).

2.3. Soil type and slope

Ultisols and Inceptisols cover the Kalipoh catchment. The Ultisol is characherized by a deep soil solum with unclear boundaries between the horizons. The soil texture is dominated by clay, although some of the areas have clay loam to loam. Based on the field check, the structure is crumb due to high soil organic matter.

Slope in the Kalipoh catchment varies, however, the dominant slopes range from > 25% to 45%. The dominant slope occupy 48% of the catchment. The detail of slope classes is presented in Table 1.

Table 1. Distribution of slope in Kalipoh Sub watershed

Slope classes	Area (% of watershed area)
0 – 8 %	3
>8 – 15 %	11
> 15 – 25 %	32
> 25 – 45 %	48

> 45 %	6
Total	100

2.4. Specific Peak flow measurement

The outlet of the Kalipoh catchment has been installed by automatic water level recorder (logger) within 5 minutes interval recorded. Water level data was converted to discharge using a stage-discharge rating curve that constructed in the outlet. The stage-discharge rating curve equation is:

$$Q = 1.39\ H^{2.5}$$ (Pramono et al., 2016).

2.5. Specific peak flow prediction using SCS-CN Method

SCS-CN method has been developed by The US Soil Conservation Service for estimating storm runoff volumes from small agricultural catchment with various soil and land use types (Dunne and Leopold, 1978). The value of CN is various from 0 to 100. It depends on land uses and their treatment or practice, soil types, and antecedent moisture condition. In this research the CN value for pine forest is resulted from direct storm runoff measurement compared with prediction of storm runoff using CN method. Figure 1 explains the procedure to get CN value for pine forest.

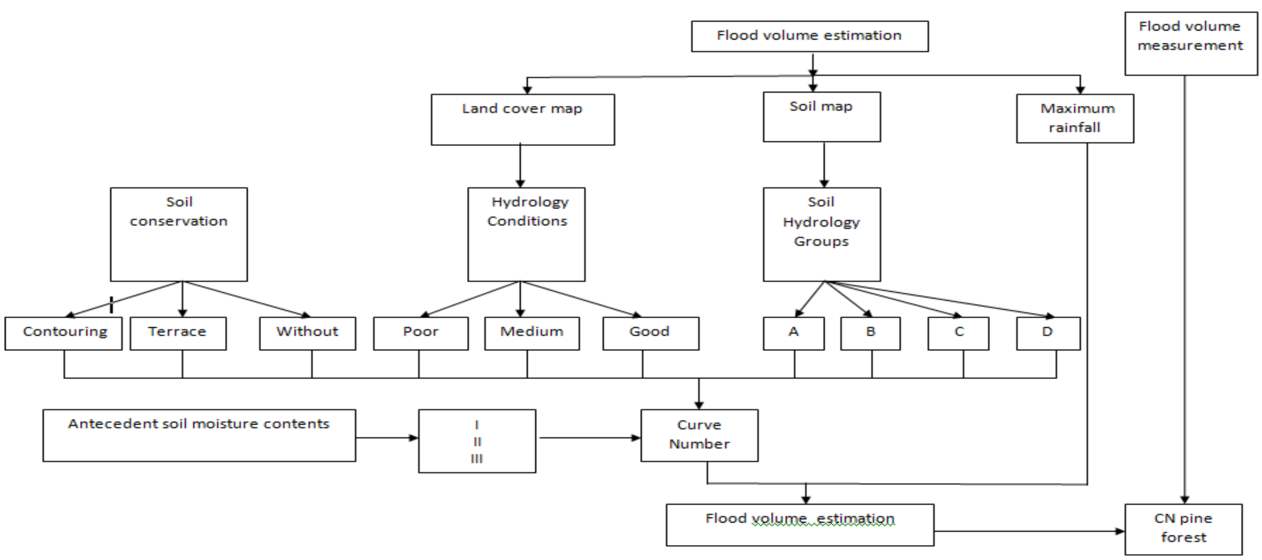

Figure 1. Flow chart for modification Curve Number (Source: Tikno et al (2012) with modification)

Storm runoff estimation assume that rainfall (P) will produce runoff (H) and losses (L). Then maximum potential retention of the catchment (S) is defined as the upper limit of losses (L), when rainfall (P) reaches infinity, and finally equality between H/P and L/S was assumed (Banasik et al., 2014). The equation for storm runoff is:

$$H = \frac{P'}{P+S} \quad (1)$$

where H is runoff (mm), P is rainfall (mm) and S is maximum potential retention of the

catchment (mm). After introducing initial abstraction and assuming its amount as 0.2S, the commonly used equation was presented in the form:

$$H = \begin{cases} \frac{(P-0.2S)'}{(P+0.8S)} & \text{for } P > 0.2S \\ 0 & \text{for } P \leq 0.2S \end{cases} \quad (2)$$

The maximum potential retention (S) in metric units is in the following equation:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (3)$$

CN for pine forest: flood volume from direct measurement was measured and compared with flood volume from prediction using curve number.

2.6. Data collection

Land use data are collected from World View image and field check. Soil types are obtained from Soil Map. Information on soil conservation practice is got from image and field check. Rainfall data are collected from nearby Kalipoh catchment.

2.7. Data analysis

Flood volume from direct measurement was compared with flood volume prediction using CN. Determination coefficient (R^2) was used for comparing the measured and the predicted of flood volume. The collected data from 2015 to 2016 with various rainfall from 20 mm to 93 mm were analyzed to compared the measured and the predicted of flood volume. Trial and error were conducted to select the most suitable values of CN and AMC for pine forest.

3. Results and discussions

Based on US Soil Conservation Service (1972), the CN value for forest (woodland) is various depend on hydrologic condition and soil hydrology group. The hydrologic condition in Kalipoh catchment is fair and the soil hydrology group is classified B i.e. soil with moderate infiltration rate when thoroughly wetted, moderate deep to deep, moderately well to well drained, with moderately fine to moderately coarse textures (US Soil Conservation Service 1972).

3.1. Predicted of flood volume using original CN = 60

The Kalipoh catchment dominated by pine forest has original value of CN = 60. This value is assumed for average condition of AMC between 36 to 53 mm. When AMC is less than 36 mm (1.4 inches) the CN value will be 40 and when AMC more than 53 mm (2.1 inches) the CN value for forest will be 78. The calculation of the predicted of flood volume with original CN (60) is presented in Appendix 1.

Most of the data have AMC class III, it means five days before flood has rainfall more than 53 mm, the soil condition is saturated. Therefore, the CN number for this condition will be higher (78), consequencely, surface runoff will be much higher. Comparison between the observed and the predicted of flood volume of the studied catchment is provided in Figure 2. It shows that the predicted of flood volume is higher than that observed one except in AMC class I (October 7, 2016) and class II (November 2, 2016). Based on regression analysis, the relationship between the predicted and observed has determination coefficient (R^2) = 0.437 (Figure 3)

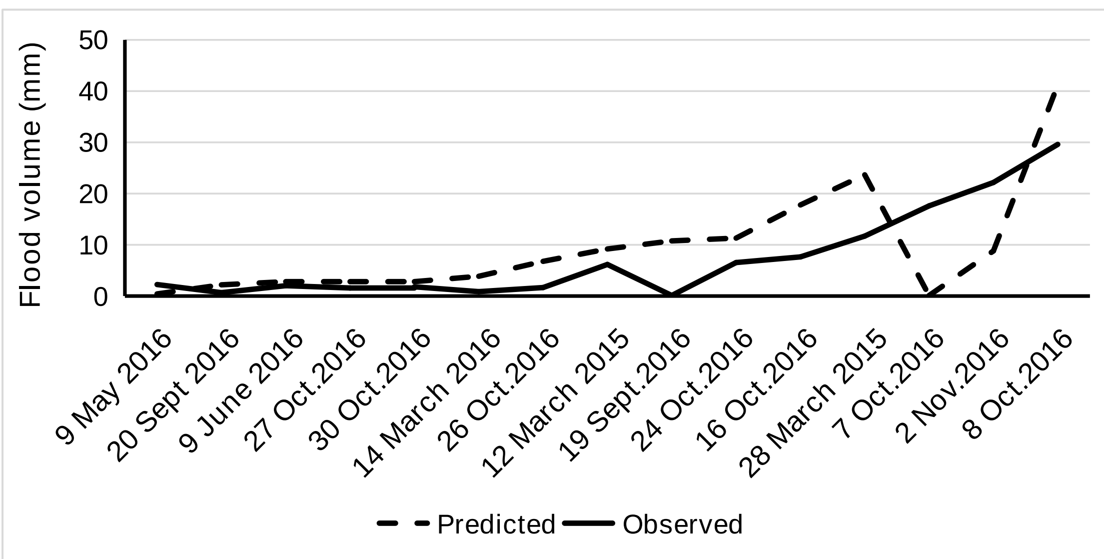

Figure 2. The observed and the predicted flood volume of 95% forested catchment with CN = 60 (Source: Data analyzed)
Note: Arrangement of the date in X axis is based on the rainfall depth per event

As a comparison to our study, Razaghnia et al. (2015) measured that CN in the dense forest in Iran was 60. However, Lyon et al (2004) examined that CN in forested sub basin of Town Brook Watershed, New York, was 51. Shaw and Walter (2009) observed that CN in French Broad River North Carolina with soil hydrology group A and B was 43, while in Fall Creek watershed, New York CN for forested watershed was 63 with soil hydrology group B and C. Further, Lin et al. (2017) concluded that on AMC II, evergreen broad leave forest had CN 51 to

59 on soil hydrology group B, whereas evergreen conifer forest had CN from 56 to 64 in Upper Tingjang River China.

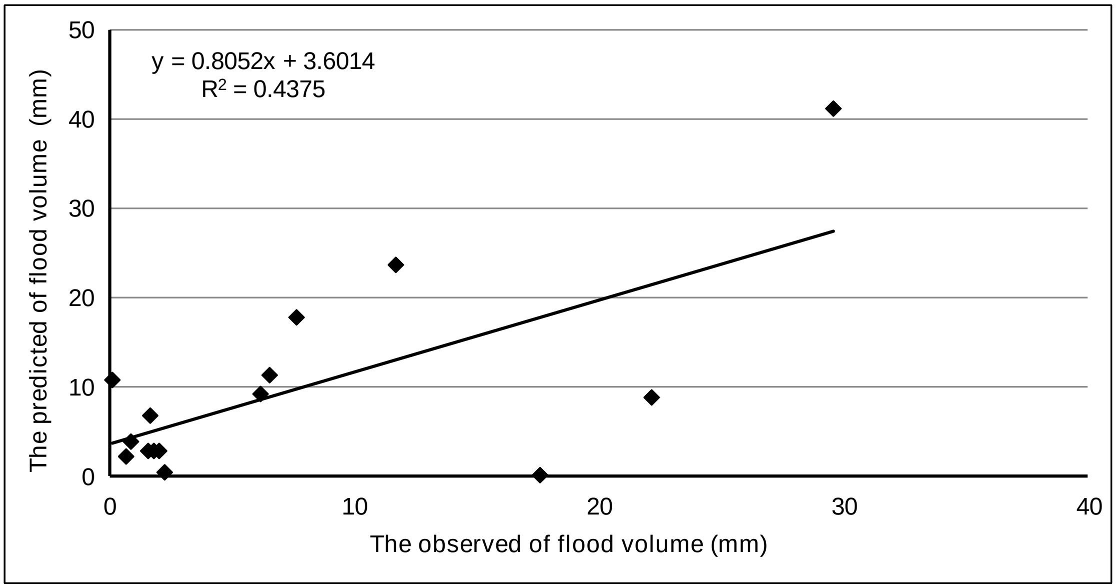

Figure 3. Relationship between the observed and the predicted flood volume on the original Curve Number, CN pine forest=60 (Source: Data analyzed)

As a comparison to our study, Razaghnia et al. (2015) measured that CN in the dense forest in Iran was 60. However, Lyon et al (2004) examined that CN in forested sub basin of Town Brook Watershed, New York, was 51. Shaw and Walter (2009) observed that CN in French Broad River North Carolina with soil hydrology group A and B was 43, while in Fall Creek watershed, New York CN for forested watershed was 63 with soil hydrology group B and C. Further, Lin et al. (2017) concluded that on AMC II, evergreen broad leave forest had CN 51 to 59 on soil hydrology group B, whereas evergreen conifer forest had CN from 56 to 64 in Upper Tingjang River China.

3.2. Predicted of flood volume using CN = 55

Based on Figure 2, it can be observed that the predicted value is higher than the observed value, therefore the CN for pine forest is reduced and it is set to 55. The result shows that the predicted value is almost the same with the observed values except on AMC I (October 7, 2016) and II (November 2, 2016) as illustrated in Figure 4. The coefficient of determination is 0.459 (Figure 5).

AMC plays an important role in the runoff estimation (Ahmad and Verna, 2016), and it has been in agreement with the research findings of Walega and Rutkowska (2015) who have concluded that the values of CN parameter greatly depend on AMC for flood analysis. Furthermore, Castillo et al. (2003) have found that runoff does not depend on AMC when infiltration excess overland flow is predominant (less permeable soil), however runoff depends on AMC when the soil has a higher permeability. Based on trial and error for finding CN, the most suitable value for pine forest is AMC III.

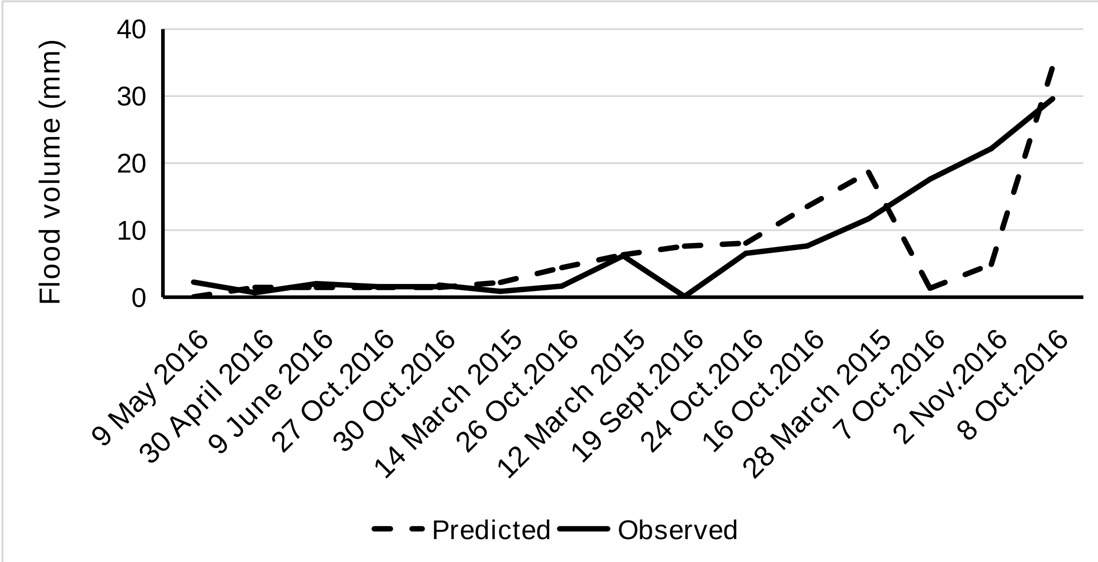

Figure 4. The observed and the predicted flood volume of 95% forested catchment with CN = 55 (Source: Data analyzed)

Note: Arrangement of the date in X axis is based on the rainfall depth per event

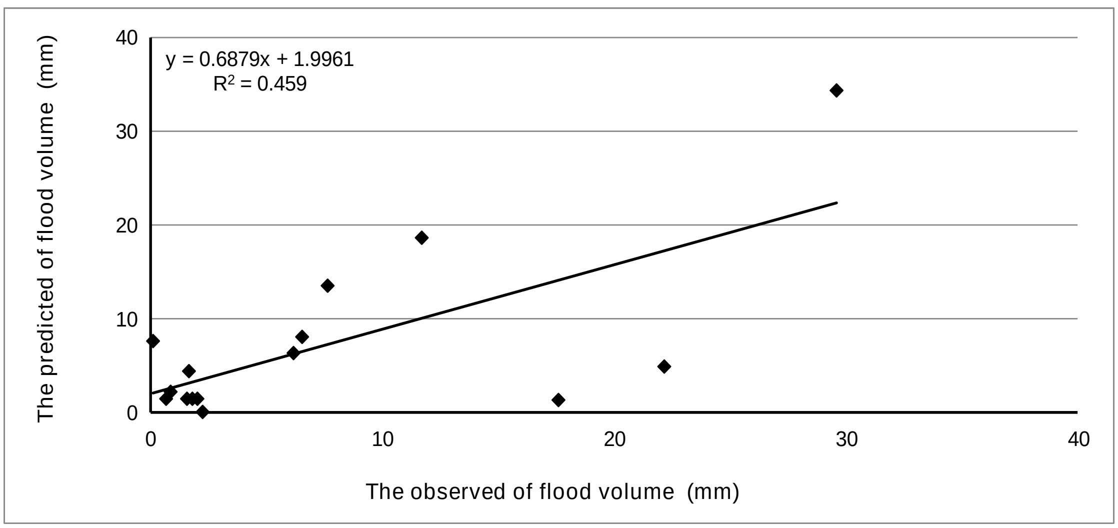

Figure 5. Relationship between the observed and the predicted flood volume with CN pine forest = 55. (Source: Data analyzed)

AMC plays an important role in the runoff estimation (Ahmad and Verna, 2016), and it has been in agreement with the research findings of Walega and Rutkowska (2015) who have concluded that the values of CN parameter greatly depend on AMC for flood analysis. Furthermore, Castillo et al. (2003) have found that runoff does not depend on AMC when infiltration excess overland flow is predominant (less permeable soil), however runoff depends on AMC when the soil has a higher permeability. Based on trial and error for finding CN, the most suitable value for pine forest is AMC III.

AMC is important to determine the value of flood volume. In order to get a better prediction of runoff volume, all of flood events use AMC class of III. The calculation of flood prediction using CN = 55 and AMC class of III is presented in Appendix 3. Based on Figure 6, it shows that the predicted and the observed of flood volumes are almost the same. The coefficient of determination (R^2) was 0.92 (Figure 7). It is the highest R^2 compared to the others CN and AMC values. Therefore, the suitable CN for pine forest is 55 and the AMC is III for all flood event prediction.

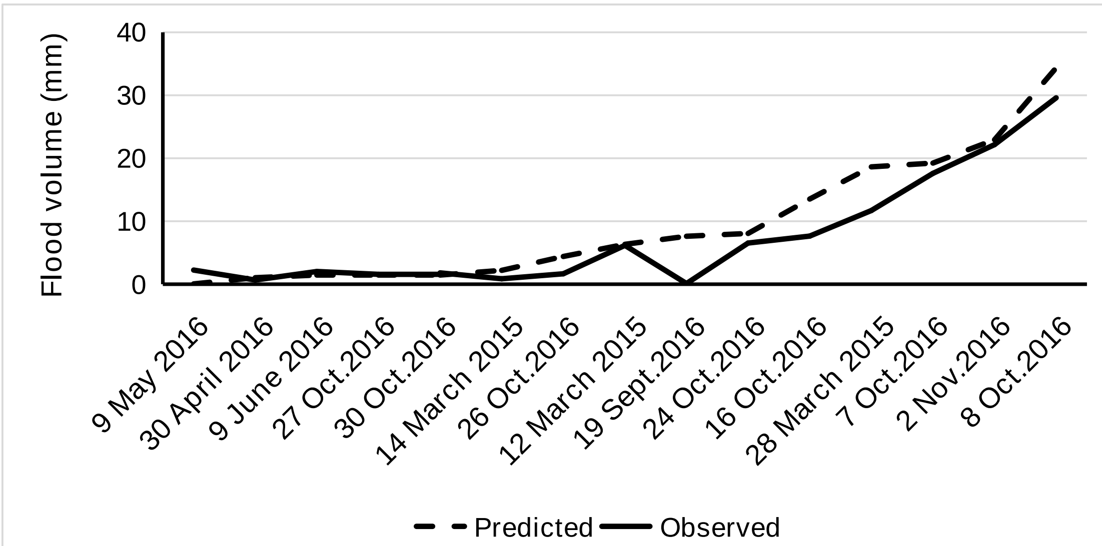

Figure 6. Observed and predicted flood volume on 95% forested catchment with CN = 55 and ASMC class III (Source: Data analyzed)

Note: Arrangement of the date in X axis is based on the rainfall depth per event

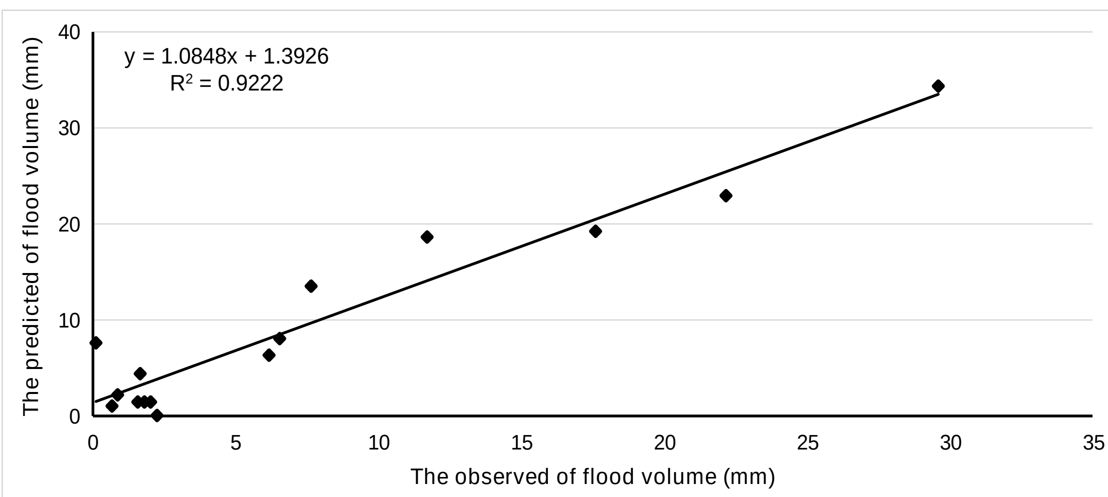

Figure 7. Relationship between observed and predicted flood volume with CN pine forest= 55 and AMC class of III for all flood events (Source: Data analyzed)

The result shows that the most suitable CN value for pine forest is 55 and the AMC class should be III or wet condition. It can be understood that soil condition under pine forest during rainy season is always wet although the rainfall is less than 53 mm during 5 days before flooding took place. In addition, ground cover under pine forest is also dense, therefore the soil is always wet as presented in Figure 8.

Figure 8. Pine forest and ground cover condition at Kalipoh catchment

The soil moisture conditions are also supported by the moderate slope. Slope steepness less than 25 % occupy about 46% of the catchment area. Besides that, the soil type Ultisols also has moderate water holding capacity. Therefore, the soil under pine forest in Kalipoh catchment is always wet and it can be classified in AMC III.

The influence of soil type is higher than slope on generating runoff as observed by Jha et al (2014). During the study for the effects of slope, soil, and AMC on runoff (or CN), the SCS-CN parameter S shows a distinguished inverse relation with the physically measured antecedent moisture content. The effect of slope of catchment is not as prominent as that of soil on both runoff and CN, and thus, it is possible that a plot of higher grade may generate lesser runoff depending on the type of soil.

CN on pine forest has almost the same with deciduous forest, the difference is only on the Antecedent Moisture Content. In deciduous forest watershed, Mistry et al (2017) concluded that weighted curve number for the study area calculated, using SCS-CN method is 55 for Antecedent Moisture Content (AMC)-II, 35 for AMC-I and 74 for AMC-III. In agriculture watershed, Kowalik and Walega (2015) mentioned that usually *CN observed* corresponded to AMC II. Furthermore, in Agricultural watershed at Indiana, USA, Rajib et al (2016) mentioned that fusion of AMC of CN method causes decrease in runoff volume and increase in profile soil moisture content, associated with larger groundwater contribution to the stream flow.

Based on the direct measurement, CN method is suitable on small rainfall events but it over estimate on large rainfall events. This result was different with Huang et al (2006). Huang et al. (2006) concluded that the standard CN method underestimated large runoff events and overestimated small events. This difference may due to different in land cover, Huang et al. (2006) used some catcments covered by Pasture and Alfalfa while in our research using a catchment covered by Pine forest. Antecedent Soil Moisture Content (AMC) under Pasture and Alfalfa are not always wet or not as wet as in Pine forest.

4. Conclusions

Antecedent Moisture Condition is an important factor in determining flood volume prediction. For pine forest in the tropical country Indonesia, the proposed AMC is AMC-III and the CN is 55. The most suitable of the AMC and the CN values do increase the accuracy of the prediction as twice as the original value. Using the original CN value = 60, the R^2 is 0.437, however, using the proposed variables CN = 55 and AMC-III, the R^2 is 0.922. In order to improve the accuracy of flood volume prediction, further research in determining CN values of various forest types is needed.

References

Ahmad, I. and Verma, M.K. (2016), "Surface Runoff Estimation Using Remote Sensing and GIS Based Curve Number Method", *International Journal of Advanced Engineering Research and Science (IJAERS)*, Vol. 3 N0. 2, pp. 73-78.

Banasik, K., Krajewski, A., Sikorska, A. and Hejduk, L. (2014), "Curve Number Estimation for a Small Urban Catchment from Recorded Rainfall-runoff Events", *Environmental Protection*, Vol. 40 No. 3, pp. 75–86.

Castillo, V.M., Gomez-Plaza, A. and Martinez-Mena, M. (2003), "The Role of Antecedent Soil Water Content in the Runoff Response of Semi-Arid Catchments: A Simulation Approach", *Journal Hydrology*, Vol. 284 No. 1-4, pp. 114-130.

Cronshey, R., McCuen, R.H., Miller, N., Rawls, W., Robbins, S. and Woodward, D. (1986), *Urban Hydrology for Small Watersheds* -TR-55. U.S., Department of Agriculture (USDA), Washington, D.C.

Dile, Y.T., Karlberg, L., Srinivasan, R. and Rockström, J. (2016). Investigation of the Curve Number Method for Surface Runoff Estimation in Tropical Regions, *Journal of the American Water Resources Association,* Vol. 52 No. 2, pp. 1155-1169. DOI: 10.1111/1752-1688.12446.

Dunne, T. and B.Leopold, L.B. (1978), *Water in Environmental Planning,* W.H. Freeman and Company, New York.

Hawkins, R.H., Ward, T.J., Woodward, E. and Van Mullem, J.A. (2010), "Continuing evolution of rainfall-runoff and the curve number precedent", paper presented at 2nd Joint Federal Interagency Conference, Las Vegas, NV, 27 June-1 July, Las Vegas, available at: https://acwi.gov/sos/pubs/2ndJFIC/Contents/ 10EHawkins.pdf (accessed 13 April 2018).

Huang, M., Gallichand, J., Wang, Z. and Goulet, M. (2006), "A modification to the Soil Conservation Service Curve Number Method for Steep Slopes in the Loess Plateau of China"**,** *Hydrol. Process,* Vol. 20, pp. 579–589.

Jha, R.K., Mishra, S.K. and Pandey, A. (2014), "Experimental Verification of the Effect of Slope, Soil, and AMC of a Fallow Land on Runoff Curve Number", *Journal of Indian Water Resources Society*, Vol. 34 No.2, pp. 40-47.

Kowalik, T. and Walega, A. (2015), "Estimation of CN Parameter for Small Agricultural Watersheds Using Asymptotic Functions", *Water*, Vol. 7, pp. 939- 955, DOI:10.3390/w7030939.

Lin, W., Yang, F, Zhou, L, Xu, J. and Zhang, X. (2017), "Using Modified Soil Conservation Service Curve Number Method to Simulate the Role of Forest in Flood Control in the Upper Reach of the Tingjiang River in China", *Journal of Mountain Science*, Vol. 14 No.1, pp. 1-14.

Lyon, S.W., Walter, M.T. Gérard-Marchant, P. and Steenhuis, T.S. (2004), "Using a Topographic Index to Distribute Variable Source Area Runoff Predicted with the SCS Curve-Number Equation", *Hydrol.Process*, Vol.18, pp.2757–2771.

McCutcheon, S.C. (2003), "Hydrologic Evaluation of the Curve Number Method for Forest Management in West Virginia". Report Prepare for the West Virginia Division of Forestry, Charleston, West Virginia, available at: www.researchgate. net/people/steven. mccutcheon/publication(240635601 (December 18, 2018).

Mishra, S.K. and Singh, V.P. (1999), "Another Lool at SCS-CN Method", *Journal of Hydrologic Engineering*, Vol. 4 No. 3, pp. 257-264.

Mistry, A., Lodha, P.P., Prakash, I. and Mahmood, K. (2017), "Estimation of Direct Runoff for Purna River Sub Basin, Using SCS-CN Method, Dangs Distric, Gujarat", *International Journal of Advance Engineering & Research Development*, Vol. 4 No. 4, pp. 581 - 593.

Ponce, B.V.M. and Hawkins, R.H. (1996), "Runoff Curve Number Has It Reached Maturity?", *Journal of Hydrologic Engineering,* Vol. 1 No.1, pp. 11-19.

Pramono, I. B., Budiastuti, M.T.S., Gunawan, T.and Wiryawan. (2017), "Water yield analysis on area covered by pine forest at Kedungbulus Watershed Central Java, Indonesia", *International Journal on Advanced Science, Engineering and Information Technology*, Vol. 7 No. 3, pp. 943-949.

Pramono, I.B., Gunawan, T., Wiryanto and Budiastuti, M.T.S. (2016), "The Ability of Pine Forests in Reducing Peak Flow at Kedungbulus Sub Watershed, Central Java, Indonesia", *International Journal of Applied Environmental Sciences*, Vol. 11 No. 6, pp. 1549 -1568.

Rajib, M.A. and Merwade, V. (2016), “Improving Soil Moisture Accounting and Stream flow Prediction in SWAT by Incorporating a Modified Time-Dependent Curve Number Method”, *Hydrol. Process*, Vol. 30, pp. 603-624.

Razaghnia, L., Solaimani, K., Sani, N.A. and Zandi, J. (2015), “Runoff Estimation and Mapping within GIS Based Arc-CN-Runoff”**,** *Adv. Biores*, Vol. 6 No. 3, pp. 16-20.

Shaw, S.B. and Walter, M.T. (2009), “Improving Runoff Risk Estimates: Formulating Runoff as a Bivariate Process Using the SCS Curve Number Method, *Water Resour. Res*, Vol. 45, pp.1-10, W03404, doi:10.1029/2008WR006900.

Tikno, S., Hariyanto, T., Anwar, N. and Karsidi, A. (2013), “Comparison between the Calculations of Surface Runoff Using Curve Number Method and the Observation Data in the Upstream Ciliwung Watershed – West Java”, *J. Basic. Appl. Sci. Res.*, Vol. 3 No.5, pp. 386-397.

US. Soil Conservation Service. (1972), *Hydrology*, National Engineering Handbook, Washington DC.386-397.

Wałęga, A. and Rutkowska, A. (2015), “Usefulness of the Modified NRCS-CN Method for the Assessment of Direct Runoff in a Mountain Catchment”, *Acta Geophysica*, Vol. 63 No. 5, pp. 1423-1446.