# Flood Indices for Java Island Using Global Satellite Mapping of Precipitation

**A Rojali[12], DA Putro[2], YS Pribadi[1], R Suwarman[4], MR Syahputra[4], TW Hadi[14], C Soekardi[2]**

[1]P.T. Inteligensi Risiko, Office 8, SCBD, Jakarta, Indonesia.
[2]Universitas Mercu Buana, Kampus D, Bekasi, Indonesia.
[3]Research, Development, and Innovation Division, P.T. Reasuransi MAIPARK, Jakarta, Indonesia.
[4]Institut Teknologi Bandung, Department of Meteorology, Bandung, Indonesia.

[1]aditia.rojali@mercubuana.ac.id

**Abstract**. Flood is the most frequent natural disaster, with regards to the very large area of Indonesia, flood hazard related information is urgently required especially in a Geospatial format which requires a mapping effort of flood-prone areas. This is required to address which area need detail analysis and to support projected damage and loss assessment. We utilized a simple yet robust SCS method which is a well-known method to calculate runoff composed of simple calculation formula but proven to be able to do flood-prone area mapping effectively. Satellite rainfall dataset has been given as the main forcing factor in SCS formula to generate runoff values. The results of this research experiments have been successfully produced the map of the flood-prone areas in Java Island and therefore confirm that rainfall data is the primary forcing factor to develop flood hazard map rather than solely use topographic data. A combination between runoff and the other hydrological parameter such as flow accumulation might be useful to enhance the existing Java island flood index. According to the results, we proposed to do a more in-depth study in the northern part of Java Island.

**Keywords:** Flood, SCS-CN, GSMap, Runoff, Flood Index

## 1. Introduction

Flood is the most frequent natural hazard in Indonesia. More than 1000 flood incidents are recorded from 2008 to 2017 in National Disaster Management Authority Database (DIBI-BNPB). Based on Indonesia's DIBI-BNPB, from 1815 to 2013, there were 4,261 flood events (38% of the total disaster). The number of fatalities caused by the floods is ranked third after the earthquake and volcanic eruption. However, in term of devastating effect, floods are ranked highest above the other natural disasters. This can be inferred from the evidence of the number of refugees due to the flood disaster which has reached 6,065,622 people. This number is higher than the number of refugees caused by earthquakes (4,484,993 people), landslides (611,440 people) and tsunamis (600,726 people).

Jakarta flood event loss were estimated at 20 trillion rupiah in January 2013 (Billiocta, 2013) which is only for direct losses where, in this case, business interruption was not accounted. Consequently, flood information is critically important, moreover, to summarize it in a Geospatial format will be beneficial. This hazard information is fundamentally valuable to make it easier to be informed to every region stakeholder, and furthermore, they can use the flood map as a basic information for more advanced actions

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such as preparedness, mitigation, and financial loss projection. Not only it will helpful for disaster mitigation and quick response organization like BNPB and BPBD but also it will be beneficial for the private sector such as the insurance industry. Fortunately, BNPB has done a significant effort on collecting hazard information which is summarized nicely in their InaRISK website; for example, figure 1 and figure 2 are captured directly from InaRISK.

Java is that the most inhabited island and its 128 million inhabitants comprised around 59% of the republic's population in 2005 (BPS-Statistics Indonesia, 2005). Java island has the highest level of economic development of any region in Indonesia of which 59% of the national gross domestic product (GDP) contributes significantly to the national economy (H Kusharjanto and D Kim, 2011). However, according to DIBI BNPB, Java island is the island where floods frequently occur, it has the highest events number among the other islands (figure 1). From this information, it can also be inferred that Java is also the most vulnerable island due to flood hazard.

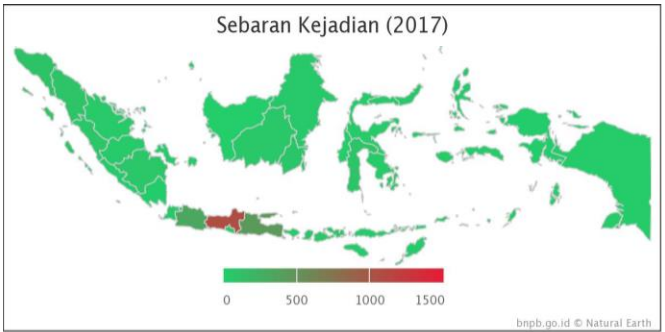


**Figure 1.** Natural disaster event distribution accumulated in 2017 for Indonesia region. Red means more frequent and green means less frequent. (DIBI-BNPB, 2017).


**Figure 2.** Natural disaster event occurrence per year. Red shows flood, blue for landslide, green hurricane, and brown for forest fire. (DIBI-BNPB, 2017)

The most recent notable flood event in Indonesia is Pacitan flood event in late 2017. According to BNPB and city major, there were 8 affected districts where 20 people died, 14 landslide victims and 6 flood victims. There were 4 injured and 1.879 refugees. Physical damages include 1,709 houses located in Kecamatan Kebonagung (1,225 units), Ngadirojo (9 units), Pacitan (160 units), Nawangan (148 units) and Arjosari (167 units). In addition, there are damages in 17 units of educational facilities and other buildings. Total loss, according to the calculation of the disaster response team, approximately has reached 600 billion rupiahs. Roads with a 19 kilometres length in 78 segments have been damaged. In addition, damage on bridges, including suspended bridges, were recorded as much as 21 spots, embankments failure at 23 points with a total length of 462 meters. Meanwhile, the agriculture area loss reached 1,285 hectares and as much as 1700 cattle were lost.

Flood hazard index map and flash flood index map for Indonesia has been published by BNPB in 2016. BNPB conducted hazard analysis by following the method by Manfreda (2011), primarily using Digital Elevation Model (DEM), which is relatively static, as the basis of calculation to get the potential inundated area. In general, the index is sufficient to inform the hazard to the community; however, it is not ready to use for calculating the value of financial losses with regards to the absence of information of the rainfall return period which is an important statistical parameter in Catastrophe Modeling toolbox.

Catastrophe modelling is a computational chain toolbox which integrates hazard information to financial model as described in more detail in Samson et al. (2014).

Surface runoff is a hydrological parameter that shows the quantity of rainfall that is not absorbed by land, consequently, higher runoff value leads to a higher indication of flooding area. There are several methods to calculate surface runoff, one of them is the Curve Number (CN). The Curve Number (CN) method is a conceptual model supported with empirical data to estimate direct runoff volume from single precipitation events on small agricultural watersheds (Ponce and Hawkins, 1996). It was developed by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture. While the CN method was originally built primarily for agricultural watersheds, the CN method has been adjusted for urbanized and forested watersheds (Cronshey et al., 1986). It shortly became one in every of the foremost widespread techniques among the engineers and therefore the practitioners, as a result of it's a straightforward yet well-established methodology, it features easy to get and well-documented environmental inputs, and it accounts for several of the factors influencing runoff generation, incorporating them in a single CN parameter. Several examples of SCS-CN implementation, namely, Tailor and Shrimali (2016) successfully use SCS-CN using Geospatial technology. Songara et al., (2015) showed that estimation of runoff by SCS-CN method integrated with Geographic Information System can be effectively used in watershed management. Dhawale (2013) utilize SCS-CN model to estimate surface runoff depth in a scarce data area. Meanwhile, Dale et al. (2016) show that SCS-CN can be useful for water management in tropical regions. But like any other method in runoff estimation, it needs rainfall as its primary forcing factor.

Satellite-based rainfall datasets as an input for flood modelling is commonly accepted especially when rainfall radar and measurement stations are not present, or it does not meet the requirement for probabilistic calculation; for instance, it has time series length shorter than 30 years. Some of the datasets that can be considered as alternatives are Global Satellite Mapping of Precipitation (GSMaP) (Okamoto et al., 2005; Kubota et al., 2006), and Global Precipitation Measurements (GPM) (Hou et al., 2013). Basically, GSMaP is created using the same satellite data source as TMPA (TRMM Multisatellite Precipitation Analysis), the TRMM (Tropical Rainfall Measuring Mission) satellite, but using different algorithms. In addition, GSMaP also uses Passive Infrared Geostationary Satellite data, as a result, its coverage, as well as resolution, is better than TMPA. GPM is an advanced program of TRMM, but with much better satellite technology because it uses a combination of constellations of satellites that have Precipitation Radar (PR) and passive microwave sensors. GPM data has a much better resolution than TMPA and GSMaP but the data is only available starting from 2014 (Liu et al, 2016). Hence, GSMap datasets, which is combined with CHIRPS (Climate Hazard Group InfraRed Precipitation), is selected to provide rainfall distribution in SCS-CN calculation.

Therefore, this research aims to provide a flood information based on a simple yet robust calculation method in Geospatial form and ready to use in financial loss modelling toolbox which incorporates rainfall return period information. The objective is addressed by implementing the SCS-CN method to produce run-off distribution index for Java Island. Moreover, the data produced in this research will also be a baseline information for more in-depth flood study in Java island.

## 2. Data

The data in this research is a common data in hydrological analysis such as rainfall, catchment, land use and soil type. In this study, the selected dataset is GSMaP which is extended by CHIRPS. This is based on the availability of data that meet the criteria to calculate the return period. Moreover, relatively high spatial resolution of GSMaP data (0.1 º grid size) is expected to provide more accurate calculation results. Figure 3 shows the sample of GSMaP grid covering Java island.

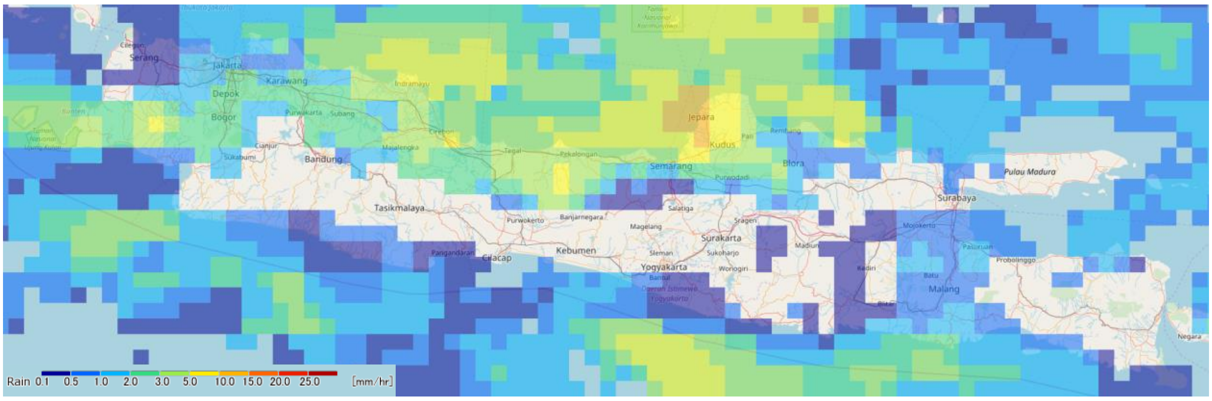

**Figure 3.** GSMap dataset sample for Java Island on 14 January 2013 01.00 GMT+7. Rainfall map overlaid on top of OSM map. Red means higher value of rainfall and blue to darker blue show lower quantity of rainfall. (http://sharaku.eorc.jaxa.jp/GSMaP/)

However, GSMaP data is only available between 2000-present, in this study up to 2014 are available to be processed, therefore we have only 14 years of time series. In order to calculate the return period parameter, ideally, it is necessary to have twice the length of the climate period of 60 years; or at least one climate period (30 years). GSMaP then was extended (merged) with another comparable dataset. In this case, the selected dataset is Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) version 2.0 (Funk et al., 2014) because the spatial resolution is similar to GSMaP data. The method used to combine GSMaP data with CHIRPS is a method of bias correction with quantile-quantile mapping as applied by Boe et al. (2007). Hereafter, rainfall data used for return period analysis is 33 years baseline data which is a combination between GSMaP (2000-2014) and CHIRPS (1982-2000).

This research used catchment border from Kementerian PUPR (Ministry of Public Works and Housing). The other data is land cover from Badan Informasi Geospatial (BIG) or Geospatial Information Agency. In addition to land cover, soil types also significantly determine the behaviour and volume of surface flow, which is influenced by the value of water infiltration into the soil. In this study, we obtained the soil type from the Harmonized World Soil Database (HWSD) which has a resolution of 1:250000. These two data are the primary sources of CN grid generation.

## 3. Methods

In the SCS-CN method, the runoff (Q) value is given by the equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a \mp S)} \tag{1}$$

with S is the maximum potential retention and where is the initial abstraction ($I_a$) ratio of values between 0.1 and 0.3, while this research used 0.2 as $I_a$. The potential retention value S has a relationship with the conceptual surface parameters called the curve number (CN) in the SI units (with S in mm) through the equation:

$$S = \frac{25400}{CN} - 254 \tag{2}$$

Rainfall dataset for return period analysis is the baseline data having 33 years length which is a combination between GSMaP (2000-2014) and CHIRPS (1982-2000) as discussed in previous part. Rain volume is calculated to get volume time series with daily time interval in each watershed. Furthermore, we searched for the maximum volume of rainfall in each year and then we analysed the return period of the annual maximum values using Log-Pearson III method. Finally, the rain volume calculation results are redistributed (disaggregated) into rainfall in each grid for parameter P (eq. 1) in the runoff calculation. Figure 4 shows rainfall volume calculation, starting from volume calculation per catchment resulting volume timeseries figure 4(b) and then every maximum value on each year are utilized as Log Pearson III input. Figure 4(c) shows results of which calculated statistical volume from 1 to $10^4$ years return period but only up to 250 years return period that we used as input to runoff calculation.

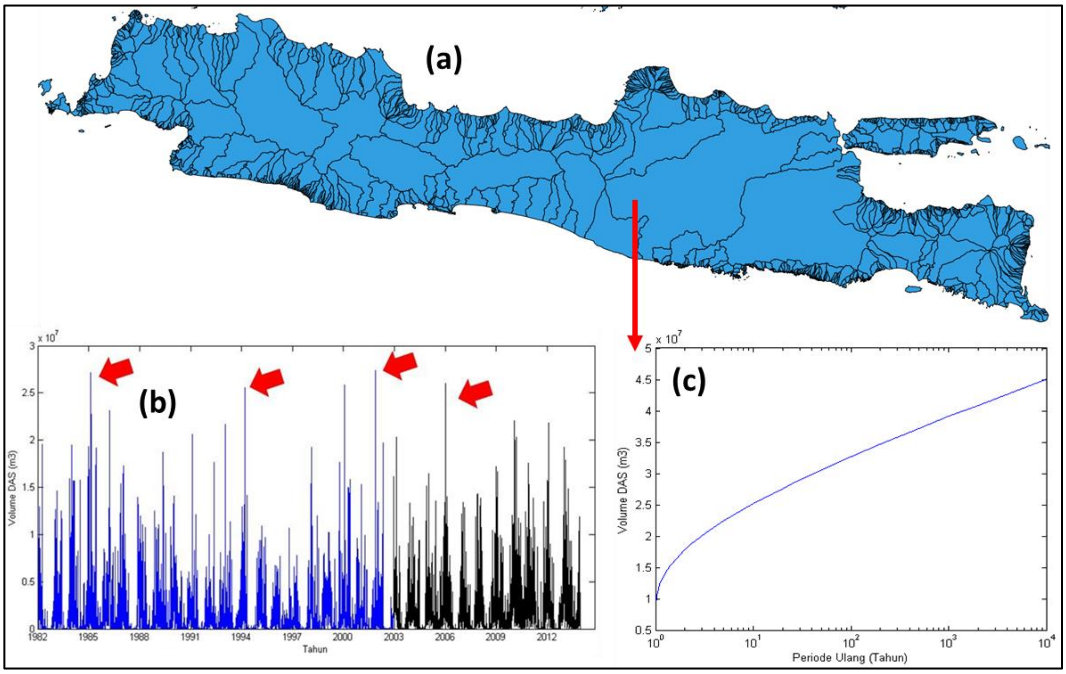


**Figure 4.** Rainfall volume calculation for Java island. (a) Catchment border in Java island. (b) 33 years time-series in Bengawan Solo catchment. (c) Calculated statistical volume from 1 to $10^4$ years return period using Log Pearson III method in Bengawan Solo Catchment.

## 4. Results

SCS-CN method results are CN grid map (non-dimensional) and runoff in millimetres. The Curve Number (CN) has been calculated for the whole Java Island. The result is the distribution map of CN values in figure 4. In general, the higher CN value implies that the area is likely to have high potential runoff as well. From figure 4 we can see that relatively high CN values spread around Jakarta and East Java.

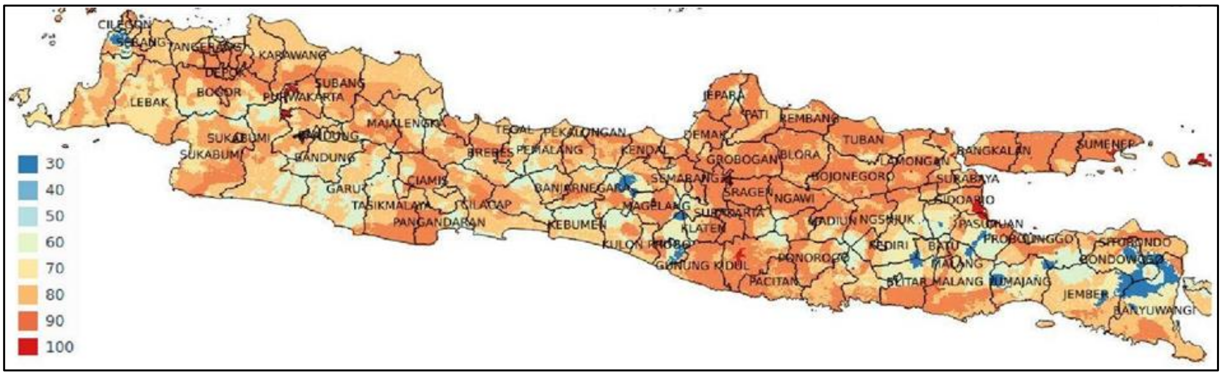


**Figure 5.** CN grid distribution within Java Island.


**Figure 6.** Runoff distribution within Java island for 100-year return period

Run-off calculations for a return period of 1, 2, 5, 10, 25, 50, 100, and 250 years have been performed by the methods previously discussed. It is interesting to consider the runoff map because after we incorporated the rainfall dataset into the calculation, the runoff distribution shows a different pattern compared to pure CN grid result. Areas that have a darker blue means they have a higher runoff potential and vice versa. Figure 6 shows the result of a run-off map across Java island for the 100-year return period scenario. The runoff has not been classified into a standard flood depth classification as widespread use in the insurance industry. The general format in the insurance industry is that they divide flood depth into 4 classes, namely, below 30cm, 30cm to 60cm, 60cm to 1m, and higher than 1 meter. If we used this classification, consequently, the value of 30 cm and below for flood depth parameter will be prevalent across Java Island (figure 6). This will not reflect realistic flood hazards; therefore, we must employ carefully aggregation method. However, for the purpose of practicality, determination of flood index from runoff parameter is determined through normalization values by referring to the value of runoff in DKI Jakarta province. This method is inspired by an assumption that DKI Jakarta is one of the most severe areas due to flood hazard impact and this is emphasized by DKI Jakarta has more advanced flood study than the other cities (e.g. Putra H.E. et. Al. 2015) of which those research results will be used in the next study for benchmarking the index results. In this case, only runoff values from 100-yr and 250-yr return period are averaged for each city administrative border, then the runoff average value is divided by the value of runoff in DKI Jakarta, as a result, the value for DKI Jakarta is 1, accordingly, the other area will be the same or will be below 1. Furthermore, we used the value of 1 as a threshold for high hazard classification with the index value of 4. As for other administrative regions, its value is classified into indexes with values between 1 (lowest) to 4 (highest) as shown in figure 7. Figure 7 shows that most cities in Java Island are at a high and very high flood hazard levels (index value of 3 and 4).

We found the interesting part from this index result; for example, that Pacitan district recently hit by floods due to the Cempaka tropical cyclone is classified as a very high flood hazards city. However, the area of both Bandung and Kabupaten Bandung that often experiences annual floods are classified into the area of moderate flood hazard (index value of 2). This probably caused by less representative rainfall data for mountainous areas or floods that often occur in Bandung are mostly due to high vulnerability and that utilization of runoff only parameter as the main flood parameter is not enough to describe the danger of flooding in the area. Hence, further investigation needs to be performed incorporating more details on data input resolution such as rainfall, DEM, land classification, and especially on more sophisticated calculation method involving hydrodynamic equation in each catchment to sub-catchment. We tried to compare, qualitatively, our calculated index to index by InaRISK BNPB (figure 8). Both agreed that at the northern part of Java island, the indices show a high flood hazard indication.


**Figure 7.** Calculated flood index based on runoff parameter


**Figure 8.** Flood index for Java Island by InaRISK BNPB

Furthermore, we highlight and compare our calculation results to BNPB flood hazard indices, indeed, it is a qualitative comparison since they are not in the same class of data. It can be inferred from figure 7 and 8 that northern part of Java island is a flood-prone area of which almost all of our indices relatively find agreement. Moreover, it is intriguing to see the comparison in, recently flooded, Pacitan city. Both flashflood (banjir bandang) and flood (banjir) indices of BNPB show moderate indices and more importantly, the inundated area is seemingly less severe than in 2017 flood event which reported to be the most devastating event in Pacitan city. Although BNPB index is fully reached seamless mode of which it is in gridded format, and thus smoothly integrated with the OpenStreetMap basemap layer, it is relatively a high-risk judgement to use directly BNPB's both flood and flashflood indices for calculating financial loss due to, in general, BNPB's indices will cause less number of predicted financial losses. Meanwhile, runoff-based flood index shows red color in Pacitan area. It can be concluded that, in this particular data scarce condition, it is safer to use the runoff-based index for the insurance industry in adopting hazard information.


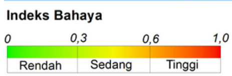


**Figure 9. I**ndices for Java Island by (a) SCS-CN BNPB's InaRISK 2016. (b) Flood. (c) Flashflood.

## 5. Remarks

In this research, GSMap and CHIRPS rainfall dataset has been utilized for generating flood index in Java island. It is also success to prove once again that the SCS-CN method is a robust method yet simple and computationally efficient to handle data scarce area in flood hazard analysis. The flood index accomplished to show paralleled hazard indication as compared to BNPB map and real flood event in Pacitan. This also states that rainfall parameter contributes significantly in flood mapping and thus incorporating rainfall data in flood hazard mapping pushes forth the reliability level of the flood hazard map compare to the method of which uses only land topographic information. However, more in-depth research in regional and local scale are still required, involving a more sophisticated method. Therefore, from this research results, we should prioritize some area on Java island such as the northern coast of Java island, Citarum basin, Bengawan Solo basin, and Brantas basin after Ciliwung-Cisadane basin.

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