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The effect of forest area change in tropical islands towards baseflow and streamflow

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The effect of forest area change in tropical islands towards baseflow and streamflow

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Abstract. Baseflow is a very important component in maintaining river flow. Baseflow is generated from groundwater flow. Baseflow is very important role in water conservation. Indonesia is located in a tropical climate. Based on the Koppen climate classification, Indonesia is included in the tropical rainforest climate (type Af), so that the characteristics of the climate, soil, flora and fauna are unique. About 70% of Indonesia's territory consists of water. Baseflow in the tropical island region has a unique characteristic. This research aimed to obtain the knowledge on the effect of forest area change in tropical islands towards the characteristics of baseflow and streamflow that involved RDF filter parameter calibration, baseflow contribution towards streamflow based on the Baseflow Index (BFI) and Q90 on Q50 ratio, rain contribution on the total baseflow, baseflow stream domination, and discharge stability of streamflow. This research was conducted in three sub watersheds with forest area percentage of ±18% Bango Sub watershed, ±23% Brantas Hulu Sub watershed, and ±59% Cobanrondo Sub watershed. The results showed that One Parameter Algorhitm method satisfied the application of baseflow separation. There was a positive correlation between rain and baseflow. Baseflow dominated the streamflow in the research location. The greater the forest area, the more stable the flow condition from year to year.

1. Introduction

Areas with tropical wet and dry climates are characterized by two main seasons: wet and dry. Baseflow can be a great predictor to display the low-flow condition. The variations of baseflows depend on the changes in groundwater abstraction, changes in land use and land cover patterns, climate change, and other factors from time to time [17]. Therefore, understanding the baseflow is vital in predicting the drought. Baseflow prediction is beneficial to understand the climate change that influences the resilience of ecosystem components and the allocation of drinking water and irrigation.

Baseflow is an essential component in maintaining river flow. Baseflow is the result of groundwater flow. According to [4], baseflow is the flow of the river that occurs during rainless period. This definition is rather tricky to understand because, during the rainless period, the river flow also contains interflow element. In his research, Harto proposed three watershed parameters that affecting the baseflow such as source frequency (the ratio between segment 1 river on the total streams in all segments), drainage density (the sum of the river lengths of all segment per unit area of the watershed), and drainage frequency (total rivers in all segments per unit area of the basin).

The technique to separate baseflow from the hydrograph of river flow has a long history in hydrology field and is used to predict the low-flow and water quality. Multiple methods were developed to separate the baseflow. One of the low-pass filter methods is the Recursive Digital Flter (RDF) method which was adapted from signal processing theory [18]. In RDF method, surface runoff is viewed as a high-frequency signal while baseflow is seen as a low-frequency signal. By filtering the high-frequency signal (surface runoff) from the flow, low-frequency signal (baseflow) can be identified [8]. The filtered results mostly depend on some specific watershed parameters. These parameters can be calibrated based on the measured data in the baseflow. However, the measured data are rare, and in practice, these parameters are often determined arbitrarily [9].

The change in forest land use and others are related to the changes in evapotranspiration, infiltration, and groundwater recharge in a watershed, which all influence the baseflow (Price, 2011; Dou et al., 2015). Planning and managing watershed requires practical knowledge in its correlation between the change in forest land towards other land uses and baseflow process. The most significant negative impact of baseflow is the changes in forest land followed by agriculture and settlement. Meadows, badlands and shrubs did not have a significant impact [5].

This research aimed to find the effect of forest area in tropical islands towards baseflow characteristics including the RDF filter parameter calibration, baseflow contribution on total streamflow based on the Baseflow Index (BFI) and ratio of Q90 on Q50, rain contribution on total baseflow, baseflow domination, and streamflow stability.

2. Location and Research Method

2.1. Research location

This research was conducted in Brantas Hulu Watershed, Malang Regency, East Java Province. Three sub-watersheds were taken as research locations to represent differences in forest area in the watershed: Bango Sub watershed, Sumber Brantas Sub watershed, and Cobanrondo Sub watershed. The coordinate for this research were 112.44976^0 - $112,94181^0$ East Longitude and 7.74690^0-7.94661^0 South Latitude with +500 up to +1,800 elevation. The characteristics from each sub watershed are: 1) Bango Sub watershed has 239.71 km^2 area and main river length of 12.5 km, 2) Sumber Brantas Sub watershed has 174.98 km^2 area and main river length of 15.5 km, and 3) Cobanrondo Sub watershed has 18.14 km^2 area and main river length of 12.16 km. The average land slope in Bango Sub watershed is ±2.0% (slope), Sumber Brantas Sub watershed is ±14.0% (rather steep), and Cobanrondo Sub watershed is ±18.0% (steep).

The forest area percentage from each sub watershed in 2018 were: 1) ±18% in Bango Sub watershed, 2) ±23% in Brantas Hulu Sub watershed, and 3) ±59% in Cobanrondo Sub watershed. The soil fraction at the study site generally consisted of 26% sand, 51% silt and 23% clay so that it was classified as silt loam texture with an infiltration rate of 7.5-15 mm / hour included in moderate slow classification [14]. This fraction caused a lower tendency of surface runoff.

2.2. Hydroclimatological data

The rain data was obtained from 11 rain stations. The rain data and rate were recorded from 2004 to 2018 (15 years). Before analyzed, the data was screened [13]. The analysis was conducted using the Polygon Thiesen method [3].

2.3. Baseflow separation method

This research used the Recursive Digital Filter (RDF) with One Parameter Algorithm, and Flow Duration Curve (FDC) filters to separate the baseflow. The RDF method used Hydro Office BFI+ 3.0 software [2]. The RDF equation with One Parameter Algorithm filter is presented in Equation 1:

$$q_{b(t)} = \frac{k}{2-k} q_{b(t-1)} + \frac{1-k}{2-k} q_t \quad (1)$$

Where:

q(t) : The actual river discharge value on the t-day

qb(t) : The actual baseflow value on the t-day
qb(t-1) : The baseflow value before t-day
k : Filter parameters given by recession constants
t : Daily time interval

This research used the Equation 2 Flow Duration Curve (FDC) [16].

$$P = 100\ (\frac{m}{n+1}) \quad (2)$$

Where:
P: The probability of specifics flows to be equal or exceeded
m: Ranking for daily or monthly flow in descending order
n: The total number of observations (e.g., 365 for daily data in a year)

The flow rate at P=50% (Q50) was taken as the river flow median. The flow higher than Q50 was picked as the low-flow rate. Also, the slope of the curve outside the Q50 mark illustrates the dominant flow type of river flow. The low slope represents the baseflow domination, whereas the steep slope after Q50 shows the surface runoff domination. The ratio of Q90 on Q50 displays the proportion of groundwater flow contributions or percentage of baseflow components [6].

2.4. *Assessment of river flow stability*

The river flow stability assessment in the watershed used the Coefficient of River Regime and Coefficient of Variation (CV) parameters.

2.4.1. *A subsubsection Coefficient of River Regime (KRS*).

KRS is the comparison between maximum rate (Qmax) and minimum rate (Qmin) of a watershed.

$$\text{Coefficient of River Regime (KRS)} = (Q\ max)/(Q\ min) \quad (3)$$

Note:
Q max (m3/sec) = highest average daily discharge (Q)
Q min (m3/sec) = lowest average daily discharge (Q)

Table 1. Coefficient of River Regime Classification [4]

No	Value	Classification
1	< 50	Good
2	50 – 120	Medium
3	> 120	Poor

2.4.2. *Coefficient of Variation (CV)*.

The coefficient of variance (CV) is a description of the variation conditions of the annual discharge (Q) from a watershed.

$$CV = \frac{\mathbf{Sd}}{\mathbf{Qaverage}} \times 100\ \% \quad (4)$$

With:
Sd = annual standard discharge data deviation (Q)
Qaverage = annual average discharge data

Table 2. CV Classification [4]

No	CV Value	Classification
1	< 10 %	Good
2	10% – 30%	Medium
3	> 30%	Poor

2.5. *Baseflow characteristics evaluation*

The baseflow characteristic evaluation consisted of the below steps:

- Calibration evaluation of the RDF method filter parameters. This research used the coefficient of the determinant method (r^2).

$$r^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right)^2 \quad (5)$$

Where n is the number of observation data during the period under review, Oi is the observed value of the ith model, $\bar{O}$ is the average observed value, Pi is the output value of the ith model, $\bar{P}$ is the average output value. And the Nash-Sutcliffe Efficiency (NSE)

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (6)$$

The range of NSE lies between 1.0 (perfect fit) and - ∞

- Proportion evaluation of baseflow contribution on total river flow in a year was analyzed based on the Baseflow Index (BFI) and Q90 ratio on Q50
- Proportion evaluation of rain contribution on total baseflow in a year was analyzed based on the average rain total ratio on baseflow in a year
- Evaluation of baseflow dominance based on the slope curve of FDC outside of Q50 mark
- Evaluation of the effect of changes in forest area to the stability of river flow based on the coefficient of variance (CV) and river regime coefficient (KRS).

3. Result and Discussion

3.1. Calibration evaluation of the filter parameter

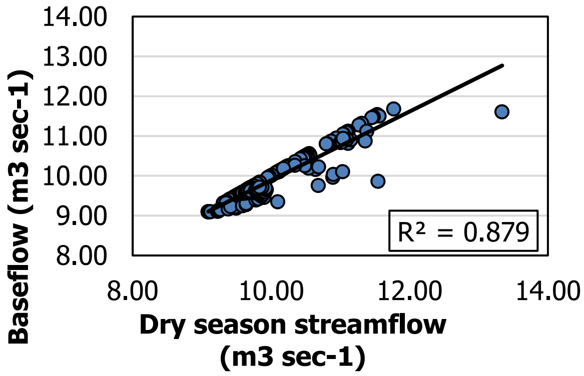

Figure 1. Comparison of discharge and baseflow in the dry season (June–November) Bango Sub watershed

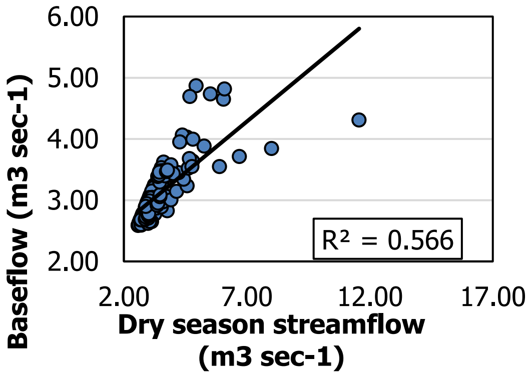

Figure 2. Comparison of discharge and baseflow in the dry season (June–November) Sumber Brantas Sub watershed

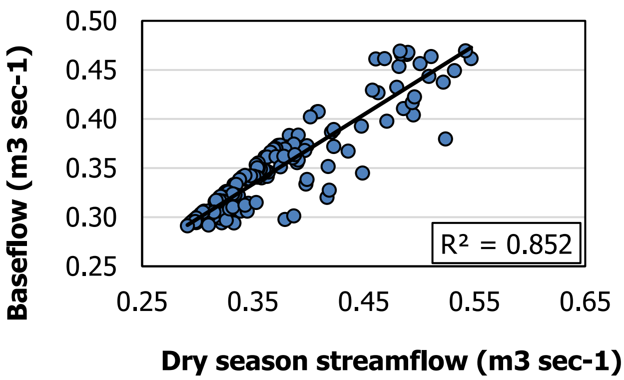

Figure 3. Comparison of discharge and baseflow in the dry season (June–November) Cobanrondo Sub watershed

The parameter filter value in this research was k=0.925 [8]. According to them, the acceptable filter parameter value is between 0.90–0.95. Figure 1 shows the results of the RDF filter parameter calibration during the dry season (June–November). The coefficient of determinant in Figure 1-3 is $r^2>0.5$, meaning, the RDF filter with One Parameter Algorithm filter result (k=0.925) was satisfying.

3.2. Proportion evaluation of baseflow contribution on total river flow

Figure 4-6 and Table 3 show the baseflow analysis results on overall river flow

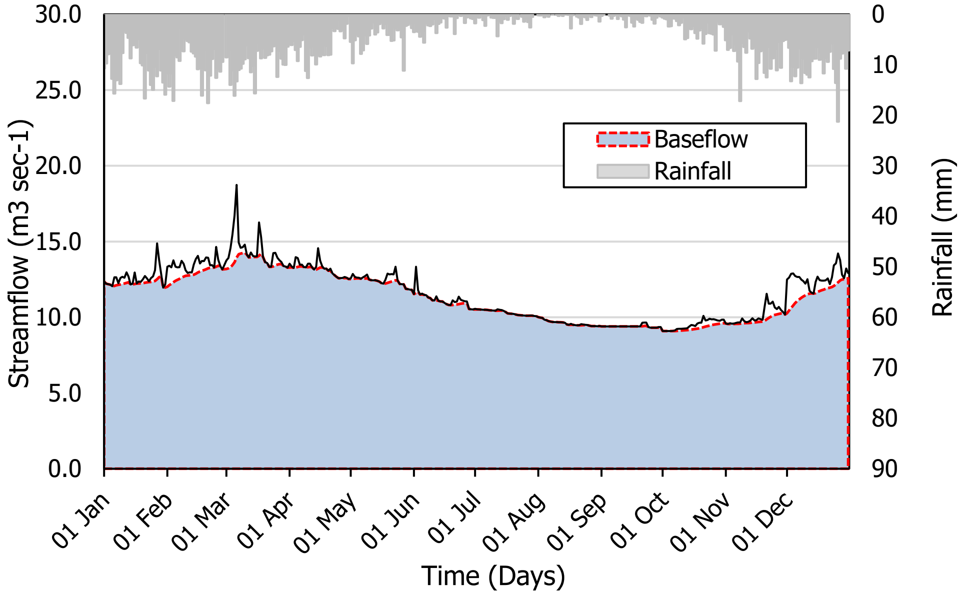

Figure 4. Streamflow, baseflow, and average rain (2004–2018) in Bango-Sari Sub watershed,

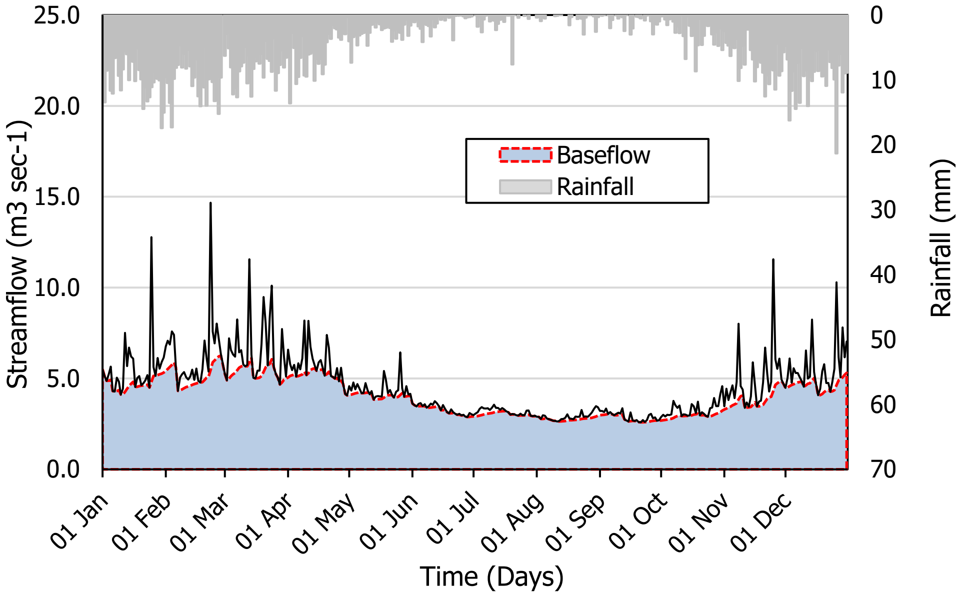

Figure 5. Streamflow, baseflow, and average rain (2004–2018) in Brantas Hulu Sub watershed

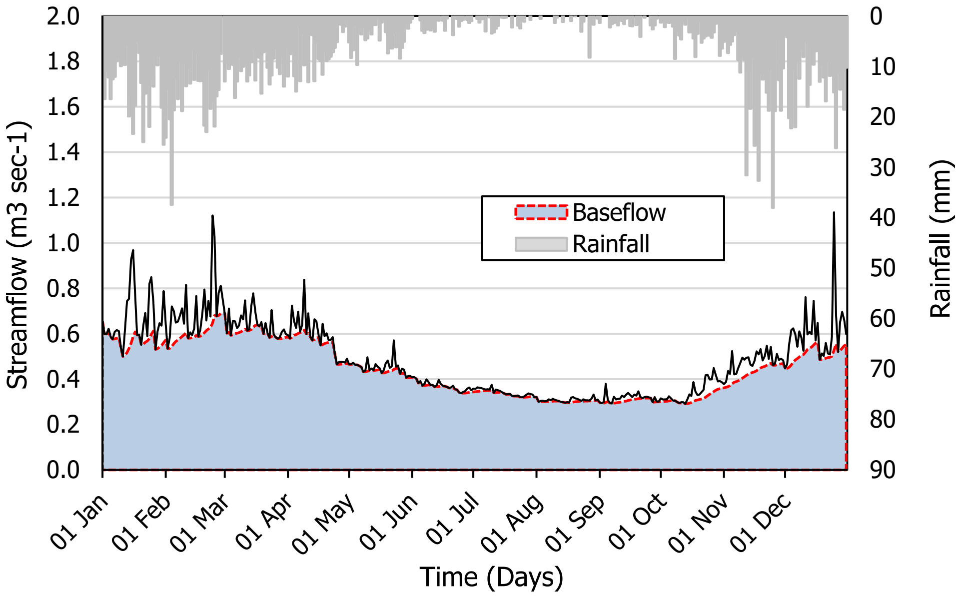

Figure 6. Streamflow, baseflow, and average rain (2004–2018) in Cobanrondo Sub watershed.

Table 3. The parameter contribution of baseflow to river flow in each sub watershed

Sub watershed	Baseflow Index (BFI)	Q90/Q50
Bango-Sari Sub watershed	0.97	0.80
Brantas Hulu Sub watershed	0.87	0.68
Cobanrondo Sub watershed	0.92	0.67

3.3. Proportion Evaluation of Baseflow Contribution on Total River Flow

The correlation between gross rainfall on baseflow can be seen in Figure 3. Figure 3 shows that the rain had a 30% contribution to the baseflow, and the remaining portion was influenced by other factors. Figure 3 also presents the positive correlation between rain and baseflow, meaning the more significant the rain, the higher the baseflow created. A similar pattern was achieved by several researchers such as Rumseya et al. and Ouyang et al. The increase in baseflow due to precipitation occurred when precipitation becomes the primary source for groundwater recharge [7]. Silt loams are grouped at infiltration rates and moderately rapid recharge classification.

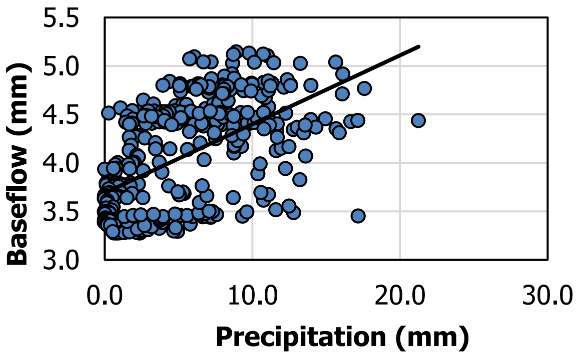

Figure 7. Correlation between annual rainfall (precipitation) on baseflow in Bango Sub watershed

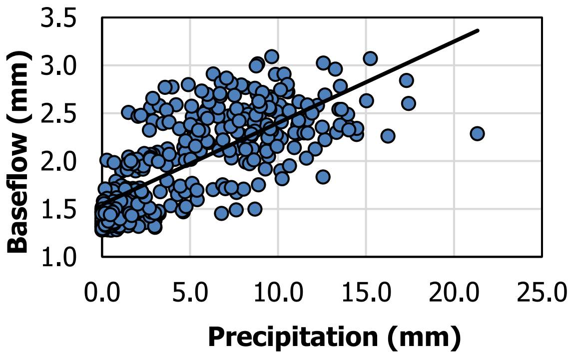

Figure 8. Correlation between annual rainfall (precipitation) on baseflow in Sumber Brantas Sub watershed

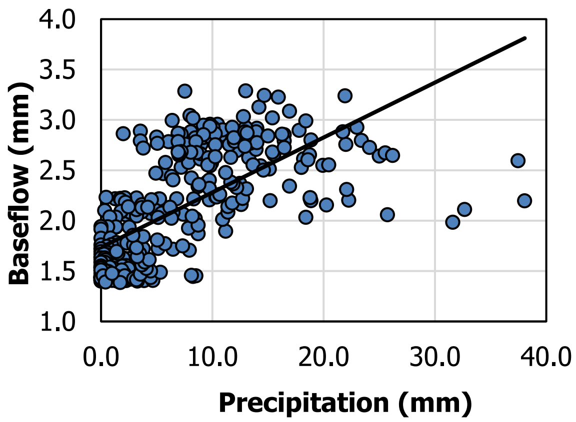

Figure 9. Correlation between annual rainfall (precipitation) on baseflow in Cobanrondo Sub watershed

The negative and essential effect on the change of baseflow is influenced by factors such as changes in the forest area, followed by agriculture and settlement. Meadows, badlands, and shrubs did not produce a significant impact [5]. Changes in the forest land use and its relation with changes in evapotranspiration, infiltration, and groundwater recharge in a watershed could influence baseflow [11]. The decrease of rain contribution on the baseflow with large forest area percentage is predicted due to the canopy density which causes increased loss of rain due to interception, stemflow [15], and evapotranspiration so that the infiltration and recharge of groundwater decrease.

3.4. Baseflow dominance evaluation

The FDC method resulted in a curve outside Q50 mark with relatively flat curve that shows a significant contribution from baseflow. In other words, baseflow dominates the river in each sub watershed. This occurrence was caused by the land characteristics in research location that was silt loam and is a part of the land with a moderately rapid infiltration rate and recharge.

3.5. Stability evaluation of streamflow

If the variation in annual flow (Q) is small, the flow condition (Q) year after year does not change much. In another side, if the yearly flow (Q) is high, the flow condition (Q) year after year will experience changes, which shows the unstable watershed/sub watershed. The cause is the change in land use and or water use in watersheds, such as El Nino and La Nina. Table 4 shows the value of CV in Bango Sub watershed (18% area) that is 64.83%, Brantas Hulu Sub watershed (23% area) that is 31.98%, and Cobanrondo Sub watershed (59% area) that is 29.67%. Hence, the more percentage of forest area generates smaller CV, which means that the flow (Q) year after year in watershed with forest area percentage above 60% is more stable compared to a basin with forest area below 30%.

The high Coefficient of River Regime represents the high Qmax and Qmin; or, the range of runoff values in the rainy season (flood) that occurs is high, while in the dry season the flow of water that happens is minimal or shows drought. Indirectly, this condition indicates that the ground absorption ability in watershed unable to save or store the rain and the runoff water continues to enter the river and is discharged into the sea so that the availability of water in the watershed during the dry season is little. Based on Table 4, the KRS value is less than 50, which means the stability.

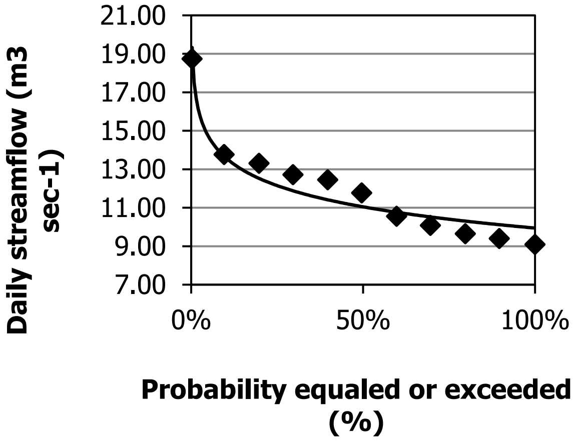

Figure 10. Daily Flow Duration Curve (FDC) in Bango Sub watershed

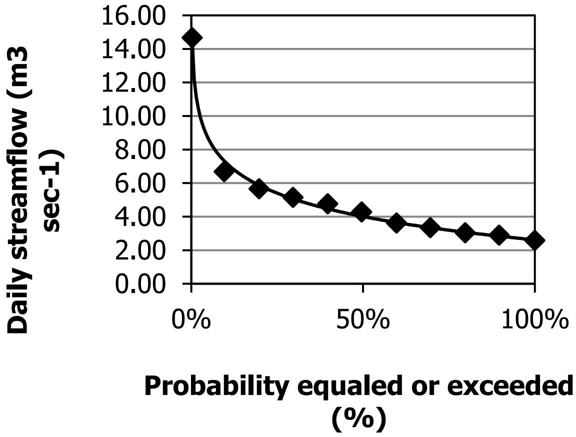

Figure 11. Daily Flow Duration Curve (FDC) in Bango Sub watershed

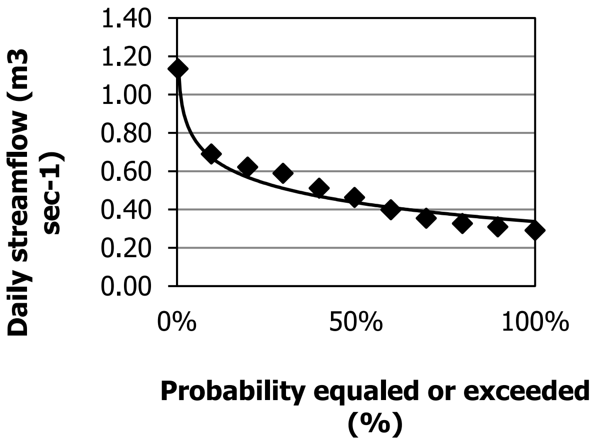

Figure 12. Daily Flow Duration Curve (FDC in Cobanrondo Sub watershed

Table 4. River flow stability

Sub watershed	Coefficient of River Regime (KRS)	Coefficient of Variant (CV)
Bango-Sari Sub watershed	1.53	64.83%
Brantas Hulu Sub watershed	2.24	31.98%
Cobanrondo Sub watershed	2.28	29.67%

4. Conclusion

- This research conducted a study in the change of forest area in tropical island towards baseflow and streamflow characteristics including the RDF filter parameter calibration, baseflow contribution on total river flow based on the Baseflow Index (BFI) and Q90 ratio on Q50, rain contribution on total baseflow, baseflow domination, and streamflow stability.
- Based on the RDF filter parameter calibration with One Parameter Algorithm method, the result showed 0.925 filter parameter value or satisfying calibration.
- The baseflow contribution proportion on streamflow (BFI value) was above 0.80 with ratio Q90/Q50 showed higher than 0.60, which meant that the baseflow dominated the streamflow in the research location.

- There was a positive correlation between rain and baseflow, meaning the higher rain flow generated higher baseflow.
- The result from the FDC method showed the curve outside of Q50 with relatively flat slope, which indicated a substantial contribution from baseflow; or in other words, baseflow dominated the streamflow. This occurrence was caused by the land characteristic in the research location that was silt loam or land with moderately rapid infiltration and recharged.
- The higher the percentage of large forest area, the more stable the condition of streamflow year after year. The absorption ability of watershed area in the research location could withstand and store the rainfall; hence, water availability during the dry season was quite large, which meant river flow stability was excellent, or there was only small gap between streamflow discharge in rain season and dry season.

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