The influence of Mount Merapi eruption on the water balance in Kali Kuning sub-watershed

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Abstract. The national park area has a function in conserving the water in the catchment area. This study aimed to compare the changes of the water balance before and after the eruption and to analyse the drought index. This study uses Thornwaite and Mather water balance analysis by calculating the amount of water input and output. The results showed that the water balance in the Kali Kuning sub-watershed was surplus in the wet months, namely January-April and November-December. Meanwhile, the deficit occurs during the dry months, namely May-October. The condition of the water balance in the Kali Kuning sub-watershed before and after the eruption changes but was not significant due to factors of land use, rainfall and temperature before and after the explosion did not change significantly. Before the outbreak (2006-2010), the drought index tended to decrease due to high rainfall every year, while after the explosion (2011-2019) it tended to increase due to changes in land use conditions. Mount Merapi eruption resulted some part of the forest in the Kali Kuning sub-watershed turned into open land.

1. Introduction
Mount Merapi National Park (TNGM) is a unique conservation area. Apart from supporting the most active volcanoes in Indonesia, the forest ecosystem in TNGM is a water catchment area for the Province of Central Java and Yogyakarta Special Region, habitat for various protected species of flora and fauna, pockets of diverse potential germplasm, and social and religious functions. The TNGM forest area is an essential and strategic state forest area because it functions as a good water catchment area for the surrounding area and is a tropical forest type with a very active volcanic condition. Administratively, TNGM is located in two provinces, namely the Special Region of Yogyakarta with an area of 1,283.99 hectares and Central Java with an area of 5,126.01 hectares. The TNGM area is located in Central Java Province covering three districts, namely: Klaten, Boyolali and Magelang, while for the Yogyakarta Province National Park area there is only one district, namely Sleman Regency.

The Kali Kuning sub-watershed is a river or stream located 10 kilometres east of the city of Yogyakarta. This river has a length of approximately 40 km, from the upstream at the top of Mount Merapi. This river flows through five sub-districts in Sleman district, namely Pakem, Cangkringan, Ngemplak, Kalasan, and Berbah districts. The Kali Kuning sub-watershed also passes two sub-districts in Bantul district, namely Banguntapan and Pleret which are downstream of Kali Kuning. In 2010, the Kali Kuning sub-watershed was hit by lava which resulted in damage to the river and its surroundings including plants.

In 2010, the lava after the eruption was bigger than the eruption of Merapi in the previous 20th or 21st century [1]. Currently, the area around the Kali Kuning sub-watershed is dominated by Acacia decurrens. According to Suprayogi [2] Land cover by vegetation will affect water flow. This vegetation
can be in the form of natural or regenerated forest, hedgerows, cultivated trees, or monoculture trees. According to Asdak [3], land-use activities that change the landscape in a watershed will affect water yields and water quality. Changes in the composition of vegetation on a large and permanent scale will affect the size of the water yield. According to Marhaent [4], Resort Turi-Pakem and Resort Cangkringan suffered massivedamage. The Kali Kuning sub-watershed is one of the water sources at the Cangkringan Resort, which is used by the local community, animals and plants. Changes in vegetation types caused by volcanic lava that occurred in 2010 will undoubtedly affect water availability in the Kali Kuning sub-watershed. Therefore it is necessary research on the water balance in the Kali Kuning sub-watershed.

The national park area has a function as a water catchment area. Living things such as animals, plants, and communities also use water for survival. In 2010, there was a change of vegetation composition in the Kali Kuning sub-watershed which was caused by lava of Mount Merapi during the explosion. This changes in vegetation composition will affect water availability, so it is necessary to know the drought index of the Kali Kuning sub-watershed. This because water availability is affected by the area's water balance.

The objectives of this study are:

- To compare the water balance before and after the eruption of Mount Merapi in the Kali Kuning Sub-watershed.
- To analyse the trend of the drought index in the Kali Kuning sub-watershed before and after the eruption of Mount Merapi.

2. Material and method

Data collection in the field was carried out on 18-26 November 2019 in the Kali Kuning Sub-watershed, the Cangkringan resort of Mount Merapi National Park. Data were collected for each type of land use. The materials needed in this study include: monthly rainfall data for Mount Merapi National Park 2006-2019 (Gondang / Resort Cangkringan), monthly air temperature data for 2006-2019, contour maps, administrative maps, soil type maps, usage maps TNGM land and altitude map. The tools used in this study include hoes, plastic bags, trowels, label paper, stationery, cameras and computers with ArcGIS software.

![Figure 1. Map of data collection](image)

Soil samples were taken for each type of land use with the disturbed method, namely by taking the soil for each type of land use using a shovel and then putting it into the plastic. Secondary data needed in this study are TNGM monthly rainfall data for 2006-2019 and 2006-2019 monthly air temperature, contour maps, administrative maps, soil type maps, land use maps, and altitude maps. The method used to determine soil texture is the pipette method in the laboratory. Each air-dry soil sample was analyzed using the pipette method so that the texture class could be determined using the USDA texture triangle.
Soil texture is determined by the ratio of sand, clay and clay content, so the naming of soil texture is also determined by these three elements [5].

The rainfall data used is the average monthly rainfall data for the entire region concerned using two rainfall stations in different years.

Air temperature data is generally difficult to find: therefore it can be estimated with temperature data that is available somewhere. The formula used is:

\[ \Delta T = 0.006 \times (X1 - X2) \times ^\circ C \]  

\( \Delta T \) = The difference in air temperature between location 1 and location 2 (° C)

\( X1 \) = The height of the place where the air temperature is known (meters)

\( X2 \) = The height of the place where the air temperature is predicted (meters)

\( T1 \) = air temperature in a location where the weather is unknown

\( T2 \) = available air temperature

2.1. Potential evapotranspiration (ET\(_p\))

After it is known the amount of rainfall in an area from the calculation of the rain distribution, then calculate the amount of evapotranspiration using the Thornthwaite and Marter methods [6].

The water balance calculation is carried out in the following stages:

- Calculating the difference between rain and evapotranspiration
- Calculating accumulated potential water losses (APWL)
- Calculating soil moisture storage (St.)

\[ St = Sto.e^{APWL} / Sto \]  

\( e \) = napier number

\( St \) = value of soil moisture storage

\( APWL \) = Iaccumulation potential water loss value

\( Sto \) = Water Holding Capacity value

2.2. Calculate \( \Delta St \) for each month where \( St \) in the month \( i \) minus \( St \) in the previous month

\[ \Delta St = St_i - St_{(i-1)} \]  

2.3. Calculate actual evapotranspiration (EA)

For a Wet month (P> Ep), then Ea = Ep

For Dry months (P<Ep) aka Ea = P + [-\( \Delta St \)]

2.4. Measure surplus water (S)

if P> Ep, then \( S = (P - Ep) - \Delta St \)  

2.5. Calculating the water deficit (D)

\[ P < Ep, then \ D = Ep - Ea \]  

Estimation of Run off (RO) is done by obtaining a surplus value. 50% of the surplus will be run off and the rest will enter the ground and will be run off in the following month. The run off value is calculated by the formula:

\[ RO = (50\% \ previous \ month + this \ month) \]  

The drought index formula, according to Thornwaite and Mather [6] in Soedjoko [7] is as follows:

Ia = \( x \times 100\% \)

Information:

Ia = Drought index
3. Results and discussion

In the Kali Kuning sub-watershed, there are five types of land use, namely upland forest, open land, *Acacia decurrens* forest, shrubs and mixed forest. This soil sample was tested in the soil laboratory of the Faculty of Agricultural Technology, Gadjah Mada University. The results showed that most of the soil in the Kali Kuning River Basin was loamy sand, except for the land use type of upland forest where the texture of the soil was not known. This because researchers were unable to obtain soil samples due to several constraints, namely Mount Merapi is in a state of alert, and difficult access to land use types of highland forest. According to Rahayu [8], the soil in the Merapi area has Entisol soil types, namely soil with a loamy sand texture, while based on the TNGM soil type map, it shows that the Merapi area is dominated by grey Regosol and Lithosol complex soils.

Water holding capacity (Sto) according to Thorntwaith and Mather in Wijayanti [9] is the ability of the land to hold water. Sto is influenced by two factors, namely soil texture and land use. In the Kali Kuning sub-watershed the soil texture has not changed, but the land use has changed. Changes in land use and land cover are the result of various anthropogenic activities, namely tree cutting and conversion of forest land to agricultural land or human settlements. This disrupt budgets for biodiversity, water and radiation, affect trace gas emissions and other processes that cumulatively affect climate and biosphere [10].

However, in the Kali Kuning sub-watershed, changes in land cover occurred due to the eruption of Mount Merapi, which resulted in the loss of part of the existing forest. The land change will affect the runoff, total water yield, trend of lateral water decline, groundwater flow and actual evapotranspiration [11]. Before the eruption, the Sto value of the Kali Kuning sub-watershed was 291 mm then decreased after the explosion in 2011-2015, namely 192 mm due to forest destruction. In 2016-2019 the Sto increased by around 260 mm but had not reached WHC before the eruption. This increase occurred because the condition of the forests in the Kali Kuning sub-watershed began to improve.

3.1. Water balance

Water balance is the ratio between input and output of the water. In this study, the water balance was calculated from 2006-2019. Processing the water balance itself requires some data, namely the type of land use, rainfall, temperature, and soil texture. The eruption that occurred in 2010 at Mount Merapi will certainly affect the availability of water in the area. This is due to forest destruction and silting of rivers. Kali Kuning sub-watershed is one of the sub-watersheds that have been affected by the eruption of Mount Merapi.

D = Deficit
Ep = Potential evapotranspiration

| No | Drought Index (%) | Drought Level                  |
|----|-------------------|-------------------------------|
| 1  | 0 - 16.7          | Little or no water shortage   |
| 2  | 16.7-33.3         | Moderate water deficiency     |
| 3  | > 33.3            | Severe water deficiency level |

Table 1. Drought levels according to Thornwaite and Mather [6]
Figure 2. The Example of the Water Balance Before Erupsion (a) and After eruption (b)

The method used to analyze the water balance in the Kali Kuning sub-watershed is the Thornwaite Mather method. Thornwaite Mather can be used to determine the condition of water in quantity every month of the year, in this case, the water condition is experiencing a water surplus or deficit, as well as knowing the monthly runoff, to determine water loss through surface runoff [12]. The Thornwaite Mather method requires input data including rainfall, temperature (air temperature), evaporation, land cover data and soil conditions from field observations [13].

The water balance in the Kali Kuning sub-watershed is seen if the rainfall exceeds the potential evapotranspiration (P > Ep), there will be an increase in groundwater so that enough water is available even if the land experiences excess water or surplus (S), and vice versa if the rainfall is less than the potential evapotranspiration. (P < Ep), will reduce the water content in the soil and can even reach a state of deficit (D) [14]. The water balance in the Kali Kuning TNGM sub-watershed is as follows.

Before the eruption period (2006 - 2010). In Figure 2 (a). It can be seen that the highest rainfall in 2006 occurred in January around 633 mm, and the lowest was in July, namely 1 mm, while in August and September there was no rain event. January-May and November-December are in a surplus condition, this can be seen based on the P > Ep chart. Meanwhile, June-October is a dry month or deficit as seen on the P < Ep Graph, so that in 2006 there were seven wet months and five dry months. The highest runoff in 2006 was in February and did not experience a runoff in July-August because in that month there was little or no rain.

After the eruption period (2011-2015). The highest rainfall in 2011 occurred in November, around 465 mm, and the lowest was in June, namely 33 mm, while in August-September there was no rain. In Figure 3 (a). It can be seen that in January-May and then in October-December, it was included in a surplus condition, this can be seen based on the P > Ep chart. Meanwhile, June-September is a dry month or deficit as seen by the P < Ep Graph. Therefore, in 2011 there were 8 wet months and 4 dry months. The highest runoff in 2011 was in April while the months of July-October did not experience a runoff because in that month there was little or no rain.

After the recovery period (2016-2019). In 2016, the highest rainfall occurred in November, namely 837 mm, and the lowest in August, namely 171. Based on Figure 4 (a). It can be seen that in January - it was included in a surplus condition, this can be seen based on the P > Ep chart so that in 2016 there was no dry month or deficit seen based on the P < Ep Graph. In 2016 there were 12 wet months without dry months. The runoff in 2016 occurred throughout the year, and the highest runoff occurred in March and November, this was because it rained throughout the year.

Pre and post explosion comparisons. Before the 2006-2010 eruption. In 2006-2010, the condition of Merapi's land cover was still improving, with the land being dominated by forests so that the WHC before the outbreak was 291 mm. In the period before the eruption, the surplus increased every year because it was directly proportional to the rainfall. The deficit value tends to decrease due to increased precipitation.
At the time before the eruption, the RO value tended to increase. This was influenced by the higher rain each year. If the rainfall is high, the RO will be increased, whereas if the rain is low, the RO will be low as in Figure 5.

During the recovery period, the highest rainfall occurred in 2013 and the lowest was in 2011. Moreover, after recovery, the highest rainfall occurred in 2016 and the lowest was in 2018. In 2011-2015, the land cover of Merapi experienced changes in land cover, namely forests in the Kali sub-watershed. Kuning has decreased, and part of the forest has turned into open land and bushes due to the eruption of Mount Merapi on 26 October 2010. This eruption is one of the most massive outbreaks of Mount Merapi, not only ecological damage but also financial losses. In the recovery condition (2011 to 2015) after the explosion the WHC decreased to 192 mm compared to the WHC condition before the blast, which was 291 mm. In 2016-2019 the WHC value increased again to 260 mm. It is higher than during the recovery period even though it has not been able to return to what it was before the eruption.
In 2011-2019 the highest surplus was in 2016, and the lowest was 2011, when viewed from the figure, the surplus-value after the explosion tends to increase in direct proportion to rain. The highest deficit after the eruption was in 2015 and the lowest deficit occurred in 2016. This because in 2015, although the annual rain was high compared to other years, the rain in the dry month was low so that the deficit was high in that year. Based on the figure in the post-eruption period, the deficit tends to decrease because post-eruption rainfall tends to increase.

![Figure 6. Graph of surplus condition after eruption (2011-2019)](image1)

![Figure 7. Graph of deficit condition after eruption (2011-2019)](image2)

At the time before the eruption, the RO value tends to increase, this because the RO value is directly proportional to rainfall. If the rain is high, the RO will be high and vice versa if the precipitation falls the RO will fall.

![Figure 8. Graph of run off condition after eruption (2011-2019)](image3)

Water balance before and after the 2010 eruption. The calculation of the water balance condition in the Kali Kuning sub-watershed showed that, it is quite good. The deficit in the Kali Kuning sub-basin occurs on average from May to October, while in January-April then in November-December it is included in a surplus condition. This happens because in general January-April then August-December is rainy months and December and January are the peak months of rain. During the dry month, the amount of water in the Kali Kuning sub-basin will of course decrease.

The water balance in the Kali Kuning sub-watershed has changed before and after the explosion. The potential evapotranspiration before the outbreak in 2006-2010 was 4259.3 mm higher than that after the eruption (recovery period) in 2011-2015, which was 4170.3 mm. Groundwater content also experienced changes wherein 2011-2015 it decreased compared to before the eruption (2006-2011) then in 2016-2019 (after recovery) the groundwater content increased again when compared to 2011-2015 but had not been able to reach the level of the groundwater before the eruption. This is because changes in land cover in 2006-2010 (before the explosion) experienced changes in the forest area. This change was due to a change in a forest area in the Kali Kuning sub-watershed due to a massive explosion in 2010. The reduction in forest area was followed by a decrease in evapotranspiration and groundwater content. The wider the forest, the higher the evapotranspiration and groundwater content. If the forest area decreases, evapotranspiration and groundwater content will reduce. According to Anache (2019), a decrease in evapotranspiration and an increase in RO were due to the conversion of forests to agriculture or villages.
Forests can release excess waterpump water into the atmosphere through the evapotranspiration process to keep the hydrological cycle running well. Besides, rain is also capable of storing water in the ground to maintain water availability for living things around it. In 2015-2019 (after recovery) the TNGM area experienced an increase in the forest area. The result showed that it was an increase in groundwater content with a value of 260 mm, but the evapotranspiration was 3344.8 mm. One of the factors that influenced the decrease in evapotranspiration was that the temperature in 2015-2019 was lower than the previous year.

From this analysis, it can be seen that forests have an essential role in the hydrological cycle, if there is a disturbance in the forest area, the hydrological conditions will also change. Apart from the forest area, other factors that influence are rainfall and temperature. More rain and lower temperatures will increase the water surplus and vice versa. As shown in Figure 22, the surplus-value in the Kali Kuning sub-watershed tends to increase due to increased rainfall. The deficit in the Kali Kuning sub-watershed also tends to increase. Even though the annual rainfall is high in the dry months there is little rain to infiltrate. The factor of forest area is reduced due to the eruption, Although in the post-recovery period (2016-2019) the deficit value begins to decline compared to during recovery.

The RO condition in the Kali Kuning sub-watershed tends to increase because the RO value is directly proportional to rainfall. If the rain is high, the RO will be high and vice versa if the rain is low, the RO will also low. Besides that, the decreasing forest area and the increasing open land area caused the WHC to decrease, thus affecting the amount of RO.
The water balance in the Kali Kuning sub-watershed has indeed changed, but changes that have occurred are not significant (> 0.05) this is because the rainfall and temperature in the Kali Kuning sub-watershed have not experienced significant changes. According to Leta [15] climate change has an influence on the water balance, especially changes in rainfall which are more influential than temperature. The effect of climate change on evapotranspiration results is more significant than differences in land cover [16].

3.2. Drought index

Drought is a condition in which water reserves cannot meet water needs. According to Loon and Laaha [17], impact of a drought is generally dependent on the severity of the drought event. The drought in the Kali Kuning sub-watershed are based on the calculation results, that is between 0 to 12.31 % and classified as less water shortage, except for the year 2015 and 2019 are included a moderate deficiency because during these two years the dry months were quite long.

Based on Figures 12 and 13, the drought index in the Kali Kuning sub-watershed before the eruption has decreased, this because the rainfall in that year has increased. However, after the eruption the drought index has increased, this is due to the influence of rainfall and also land use. After the explosion, the land use changes, namely the reduction in the forest area to open land.

Based on Figures 12 and 13, the drought index in the Kali Kuning sub-watershed before and after the blast has increased. This because the Kali Kuning sub-watershed has changed its land cover due to the eruption of Mount Merapi. The reduction of forest in the Kali Kuning sub-watershed affects on the ability to store water. The wider the forest water stored, the higher it will be. The relationship between the drought index and rainfall is inversely proportional, that is, the higher the rainfall, the lower the water shortage and vice versa, the lower the rainfall, the higher the drought index.

Therefore, in the wet months, it is expected to collect water so that during the dry months, the need for water is still met. Or based on Hartanto [18] it is possible to increase the value of water capacity and water storage by expanding the area of land planted with tree crops or reforested on open ground. So it is necessary to do intensive planting and maintenance in the Kali Kuning sub-watershed so that the hydrological function is maintained. In open land and shrubs, banyan and ficus can be planted because these plants are able to store groundwater. It also needs to be replanted with the original Merapi plants.
including the cantigi and puspa. This maintenance will require many parties so that the preservation of forests in Merapi, especially the Kali Kuning sub-watershed, continues to run well. The deficiency index in the Kali Kuning sub-watershed will decrease by 11% -33%.

4. Conclusion
Water balance in the Kali Kuning sub-watershed is a surplus in the wet months, namely January-April and November-December. Meanwhile, the deficit occurs during the dry months, namely May-October. The condition of the water balance in the Kali Kuning sub-watershed before and after the eruption experienced changes but still it was not significant due to factors of land use, rainfall and temperature before and after the explosion in the Kali Kuning sub-watershed did not change significantly.

The drought trend that occurred in the Kali Kuning sub-watershed before the eruption (2006-2010) tended to decrease due to higher rainfall every year, while after the eruption (2011-2019) it tended to increase due to changing land use conditions after the blast of Mount Merapi. An eruption that caused part of the forest in the Kali Kuning sub-watershed to turn into open land. The dry conditions before and after the explosion did not change significantly because the rainfall was almost the same.

Acknowledgment
We would like to thank UGM in supporting the funding for this research through the RTA scheme, the year 2020. Also special thanks to the students who help during the field data gathering.

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