Baseflow separation of some springs in the Jonggrangan karst area, Java, Indonesia

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Abstract. Karst aquifer flow can be divided into diffuse, fissure, and conduit. Diffuse (base) flow plays a role in maintaining the continuity of karst springs. This research was conducted in the Kiskendo underground river, Mudal spring, and Anjani underground river, which is located in the Jonggrangan karst area, to determine variations in the baseflow proportion in the three locations. Water level and discharge data are collected for a year (March 2018-March 2019). The water level and discharge data pairs are then used to create a rating curve to obtain flow hydrographs during the study period. Several flood events are then chosen to calculate the baseflow recession constant. Separation of base flow is automatically carried out to determine the percentage of base flow during the study period. The results showed that all three locations had fluctuating hydrographs that followed the seasons, with many peaks of flood hydrographs occurred following rainfall events. This condition shows that all three locations have developed aquifers. Although this is the case, flows in the three locations tend to be dominated by base flow both during the dry and rainy seasons, which indicates the capacity of aquifers to store groundwater is still good. Besides, the results of the base flow separation show that the percentage increases during the dry season and decreases during the rainy season. The decrease in the percentage of base flow during the rainy season is due to the contribution of direct flow (fissure and conduit) to the karstic aquifer.

1. Introduction

Today, the issue of climate change has become a worldwide concern. Increased air temperatures and reduced rainfall due to climate change have the potential to cause reduced water resources in some areas [1]. The condition makes the study of the sustainability of water resources more important, as evidenced by the increase in research related to groundwater resources in the last few decades [2]. Furthermore, [3-5] states that the karst area is expected to have an important role in efforts to mitigate the effects of climate change, one of which relates to groundwater resources stored in karst aquifers [6]. The great potential of groundwater resources in karstic aquifers is also stated by [7], where about a quarter of the world's population depends on groundwater derived from karstic aquifers.

Karst aquifers are known to have non-uniform porosity that is controlled by the karstification process. The porosity includes intergranular porosity, fracture, and conduit [8-9]. Consequently, the nature of groundwater flow in karst aquifers is also not uniform, but rather follows the medium in its path [1]. The nature of groundwater flow in karst aquifers can at least be divided into two, namely slow flow and quick flow [8, 10]. [11] mentions other names for these two streams with diffuse flow and conduit flow, respectively. Furthermore, [12] adds that there is an intermediate flow, which is the transition between...
diffuse flow and conduit flow, namely, fissure flow. Conduit flow is a flow that passes through limestone voids, measuring $10^2$ mm to $10^4$ mm or more [12] and is characterized by fast and turbulent flow properties [13]. The conduit flow is recharged by surface runoff entering karstic aquifers through sinkholes [14], and only takes place shortly after a flood due to rain. Meanwhile, diffuse flow flows through a limestone void measuring $10^3$ - $10$ mm [12], which is characterized by slow and laminar flow [13]. This flow is recharged by water stored in the epikarst zone [15]. Diffuse flow is often also identified with the base flow or dependable flow [16].

Since ancient times, springs have an important role in the lives of people who live in karst areas, especially to meet their domestic needs [17]. This diffuse flow is responsible for maintaining the flow of springs in the karst region, especially during the dry season [11, 18]. Thus, the diffuse flow or base flow is a flow that can be relied upon by people in a karst region. This research was conducted in some of the largest underground springs and rivers in the Jonggrangan Karst region, namely the Kiskendo underground river, Mudal Spring, and Anjani underground river. The three locations are the largest water resources in the Jonggrangan Karst Area, which are used intensively by the surrounding community to meet their domestic needs. Accordingly, the purpose of this study was to determine the spatial and temporal variations in the proportion of base flow at the three locations.

2. Methodology

2.1. Research Location

This research was conducted in the Kiskendo underground river, Mudal Spring, and Anjani underground river which is part of the Jonggrangan Karst area (Figure 1). Physiographically, the Jonggrangan Karst region is located at the peak of the Menoreh Mountains, which [19] is called the Oblong Dome. The Menoreh Mountains are formed by a complex process, namely volcanism, submergence, and finally, is updoming [20]. The Jonggrangan Karst area developed in the Jonggrangan Formation deposited in the early Miocene to the late Miocene above the Old Andesite Formation [21]. This formation consists of marl tuff, limestone, and sandstone with lignite inserts, sedimented limestone, and reef limestone [22]. According to [23] the Jonggrangan Formation has a thickness of 250-400 m. The location of the Jonggrangan Karst region at the top of the mountains makes it has relatively high rainfall. The Jonggrangan Karst area has an average annual rainfall of 2601 mm and a mean temperature of 24.1 °C [24].

The location of the study in more detail is in the Kiskendo underground river, Mudal Spring, and Anjani underground river. The Kiskendo underground river has a catchment area of 6.9 km$^2$, with the headwaters coming from Semar Cave, which is 600 m northwest of the Kiskendo Cave [25]. Mudal Spring has the largest catchment area, which is 7.1 km$^2$, and the flow originates from Nguwik Cave which is about 400 m northwest of Mudal Spring. Meanwhile, Anjani underground river has the smallest catchment area of 3.7 km$^2$ and is influenced by three sinking streams, namely Cebong River, Setro River, and Jumbleng Sawah [25].

2.2. Method

Data flow collection is carried out in a year from March 2018 to March 2019. Two water level loggers (HOBO U20L-01) are installed at each location with recording intervals every 15 minutes. Flow velocity measurement by the velocity area method is carried out ten times, which includes the discharge when the water level conditions are low, medium, and high. The pair of discharge data with water level has then performed a regression to obtain a water level vs discharge relationship curve or stage-discharge rating curve. The obtained curve equation is then processed to generate a hydrograph discharge over one year.
Next, in the discharge hydrograph for one year, several flood events were chosen to calculate the baseflow recession constant ($K_b$). The criteria for selecting flood events are floods with a long recession period [26], which in this study is more than 20 hours. The recession constant is calculated based on the recession equation [27]:

\[ Q_t = Q_0 e^{-\alpha t} \]  

where $Q_t$ is the flowrate at time $t$, $Q_0$ is the initial discharge of the recession segment, $e$ is the exponential number ($2.718$), and $\alpha$ is the recession coefficient. The variable "$e^{-\alpha}$" in equation three because it is constant, it can be replaced with "$k$" or called the recession coefficient or depletion factor [7, 16]. Also, [28] suggested that the range of baseflow recession constant values ($K_b$) ranged from 0.93 to 0.995.

To separate the base flow from the total flow, the recursive digital filter method is carried out, based on the equation stated by [29]:

\[ f_k = \alpha f_{k-1} + \frac{1+\alpha}{2}(y_k - y_{k-1}) \]  

\[ b_k = y_k - f_k \]  

where $f_k$ is the quick flow at time $k$, $y_k$ is the flowrate at time $k$, $\alpha$ is the base flow recession constant, and $b_k$ is the base flow at time $k$. The process of separating the base flow is carried out with the help of BFI software developed by [30], with input data is the time series of discharge and the baseflow recession constant.
3. Results and discussion

3.1. Stage-discharge rating curve and discharge hydrograph

The results of discharge measurements at the Kiskendo underground river, Mudal Spring, and Anjani underground river during the study period resulted in a stage-discharge rating curve along with the equation shown in Figure 2. The three locations show the relationship of discharges with different water levels, where the Kiskendo underground river and Mudal Spring show an exponential relationship, while Anjani underground river shows a linear relationship. This difference reflects different river cross-sectional conditions [31]. Kiskendo underground river and Mudal Spring have a river cross-section that tends to be a "U" shape, while SBT Gua Anjani has a cross-section that tends to be square.

![Figure 2. Stage-discharge rating curve: (a) Kiskendo Cave; (b) Mudal Spring; dan (c) Anjani Cave](image)

Furthermore, the discharge hydrograph in the Kiskendo underground river, Mudal Spring, and Anjani underground river during the study period is shown in Figure 3. In general, the discharge hydrograph in all three locations has the same pattern, which indicates that all three are affected by rain with relatively similar characteristics [32]. This condition is likely due to the distance of the three locations that are not too far away, and are still in the same morphology. The discharge Hydrograph in all three locations also shows fluctuating patterns that follow the rainfall events. This fluctuation indicates the aquifer's response to rain that relatively quickly. Furthermore, this indicates that all three sites have developed aquifers [10]. Although generally the same, in detail, the three hydrograph discharges have different shapes. Mudal Spring has a slower form of hydrograph compared to Kiskendo and Anjani underground river, which means it shows the slowest flow response. Meanwhile, Anjani underground river has the highest and most sharp peak flooding among other locations, showing the fastest flow response. The slowest flow response in Mudal Spring is caused by the widest catchment area, as well as the thickest limestone layer [33]. Large catchments cause large deposits of water [7], whereas thick limestone layers cause infiltrated water to enter the aquifer to take a long time to reach the karst spring. The fast flow response on Anjani underground river is caused by the sinking stream that has taken part that recharges the Anjani
Cave aquifer. The existence of sinking streams causes when the event of rain, the surface flow can enter concentrated to increase the discharge quickly.

3.2. Baseflow recession constant (Kb)
During the period between March 2018 and March 2019, the Kiskendo underground river, Mudal Spring, and Anjani underground river experienced at least 32 flood events. From 32 flood events, then 10 flood events were chosen with a large adequate discharge and a recession period long enough to calculate the baseflow recession constant (Kb). Furthermore, the results of Kb calculation of selected flood hydrographs from the three locations are shown in Table 1.

Table 1. Value of Kb for each flood event in the Kiskendo underground river, Mudal Spring, and Anjani underground river during the study period

|             | Kiskendo   |             |             | Mudal      |             |             | Anjani     |
|-------------|------------|-------------|-------------|------------|-------------|-------------|------------|
| Date        | peak discharge (l/s) | Kb  | Date        | peak discharge (l/s) | Kb  | Date        | peak discharge (l/s) | Kb  |
| 03/19/18    | 1573.33    | 0.995       | 03/16/18    | 1011.70    | 0.999       | 11/09/18    | 295.64     | 0.993 |
| 11/10/18    | 2209.03    | 0.962       | 11/09/18    | 534.91     | 0.997       | 11/11/18    | 1322.14    | 0.986 |
| 11/28/18    | 2045.85    | 0.991       | 11/11/18    | 993.41     | 0.997       | 11/14/18    | 565.00     | 0.995 |
| 11/29/18    | 874.56     | 0.993       | 11/28/18    | 1328.63    | 0.995       | 11/22/18    | 304.70     | 0.995 |
| 12/08/18    | 2141.16    | 0.984       | 12/08/18    | 821.87     | 0.991       | 11/28/18    | 1405.89    | 0.993 |
| 25/12/18    | 1079.16    | 0.995       | 12/10/18    | 615.64     | 0.997       | 12/08/18    | 1287.06    | 0.990 |
| 01/03/19    | 4739.70    | 0.981       | 01/03/19    | 865.06     | 0.997       | 12/25/18    | 429.19     | 0.996 |
| 01/18/19    | 3025.63    | 0.992       | 01/18/19    | 771.02     | 0.997       | 01/03/19    | 967.90     | 0.992 |
| 01/23/19    | 1364.51    | 0.991       | 02/08/19    | 640.73     | 0.998       | 01/11/19    | 562.74     | 0.995 |
| 02/08/19    | 937.91     | 0.995       |             |            |             | 02/02/19    | 540.10     | 0.995 |
|             |            |             |             |            |             | 02/08/19    | 850.20     | 0.996 |
|             |            |             |             |            |             | 02/20/19    | 362.42     | 0.997 |
|             |            |             |             |            |             | 02/24/19    | 708.73     | 0.995 |
| Average     | 0.988      |             |             | 0.996      |             | 0.994       |
In general, all three locations have relatively slow diffuse flow releases ($K_b > 0.9$). This condition indicates that the three aquifers, despite having a developed voids system, still can store good water. Mudal Mata has the largest diffuse flow recession constant among the three locations. This condition shows that the aquifer in the Mudal Springs releases the slowest diffuse flow. The slow release of diffuse flow in the Mudal Spring aquifer is probably due to its thick aquifer layer and its most extensive catchment. The thick aquifer layer causes water that moves vertically through the fissures takes a long time to reach the underground river, while the extensive DTA causes the volume of water received when it rains more, so it takes a long time to be released.

3.3. Baseflow percentage
The baseflow separation that has been done shows that all three locations are dominated by base flow (Figure 4). During the period March 2018 to March 2019, the Kiskendo underground river, Mudal Spring, and Anjani underground river had a total baseflow percentage of 87%, 94%, and 86%, respectively. This percentage shows that although all three locations have developed karst aquifers, all three are still good at storing water, as also shown in the $K_b$ value.
Baseflow percentage values in the three locations tend to show the same pattern, which increases during the dry season and decreases when the rainy season. The baseflow percentage value has slowly increased with the season changing to the dry season (March-April 2018) and reaching its highest value in April-August 2019 (the peak of the dry season). Furthermore, the base flow percentage gradually decreases when entering the beginning of the rainy season (September-October 2018). The baseflow percentage value reaches its lowest value in November 2018 (peak rain). The baseflow percentage then gradually rises again as the season shifts to dry season (December 2018-March 2019). Here, the baseflow percentage is controlled by the presence or absence of direct flow contributions (fissures and conduits) in aquifers [18]. The decrease in baseflow percentage during the rainy season is due to the contribution of direct flow into the aquifer. Surface runoff originating from rainwater enters the aquifer, which is concentrated through sinkholes, which are widely spread in the catchment area in each location, causing a decrease in the proportion of base flow, which is replaced by the dominance of fissure and conduit flow.

Anjani underground river has the most fluctuating baseflow percentage compared to the other two locations, while Mudal Spring shows the most stable pattern (Table 2). High fluctuations in Anjani underground river show the amount of direct flow discharge that recharges during the rainy season. The magnitude of baseflow percentage fluctuations in the Anjani underground river indicates that the aquifer in the Anjani underground river has the most developed voids configuration so that discharges in springs rapidly increase and rapidly decrease (large fluctuations). Conversely, small fluctuations in Mudal Spring indicate that the majority of the flow tends to be released slowly through diffuse (intergranular) fractures. This condition is also in line with research conducted by [34], where Anjani underground river has the highest degree of karstification compared to the Kiskendo underground river and Mudal Spring. In a broader scope, the characteristics of aquifers in releasing baseflow reinforce the results of research in other tropical karsts (Gunungsewu), among others conducted by [35, 18], which states that although the flow throughout the year is dominated by baseflow, but conduit-sized voids have formed in aquifers that are characterized by high conduit discharge during the flood period.

**Table 2.** The baseflow percentage at Kiskendo underground river, Mudal Spring, and Anjani underground river (March 2018 to March 2019)

| Bulan       | Baseflow percentage (%) | Season                     |
|-------------|--------------------------|----------------------------|
|             | Kiskendo     | Mudal | Anjani |                        |
| March 2018  | 89           | 89    | 93     | beginning of the dry season |
| April 2018  | 100          | 100   | 100    | dry season               |
| May 2018    | 100          | 100   | 100    | dry season               |
| June 2018   | 100          | 100   | 100    | dry season               |
| July 2018   | 100          | 99    | 100    | dry season               |
| August 2018 | 99           | 99    | 100    | end of dry season        |
| September 2018 | 94     | 97    | 96     | end of dry season        |
| October 2018 | 89          | 99    | 99     | beginning of wet season  |
| November 2018 | 67         | 67    | 57     | wet season               |
| December 2018 | 87         | 91    | 82     | wet season               |
| January 2019 | 79           | 88    | 74     | wet season               |
| Februari 2019 | 95        | 98    | 94     | end of wet season        |
| March 2019  | 97           | 100   | 94     | end of wet season        |
| **average** | **87**       | **92** | **86** |                         |
Figure 4. The result of the baseflow separation of Kiskendo underground river, Mudal Spring, and Anjani underground river (March 2018 to March 2019)

4. Conclusions
The streams in the Kiskendo underground river, Mudal Spring, and Anjani underground river during the study period were dominated by base flow, with an average percentage of the total base flow of 87%, 92%, and 86%, respectively. This condition shows that although all three aquifers have developed voids, they are still good at storing groundwater. Baseflow percentage values tend to fluctuate according to the season, where the values tend to be high during the dry season and low when the rainy season. The decrease in baseflow percentage during the rainy season is due to the contribution of direct flow in the form of conduits and fissures that contribute to aquifers. By knowing the characteristics of the base flow in this study, it is hoped that it can provide an overview of the groundwater potential in the Jonggrangan Karst region, especially in the Kiskendo underground river, Mudal Spring, and Anjani underground river. Also, the results of this study are expected to contribute to the sustainable management of water resources in the future, especially in a karst area.

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