Characterizing flow release from the aquifer of Guntur Spring in Gunungsewu Karst Area, Indonesia

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Abstract. Karst aquifers have three flow components, namely conduit, fissure, and diffuse. This research was designed to characterize the flow release from the karst aquifer of Guntur Spring. It is part of the hydrogeological system Panggang Block, part of Gunungsewu Karst Area, Gunungkidul, the Special Region of Yogyakarta. The water level and discharge data from May 2018 to May 2019 were processed to create flow hydrographs. Two different methods were applied to measure discharge variation in one year, namely sudden injection in dry seasons and velocity area in rainy seasons. While baseflow separation analysis was employed to calculate the percentage of baseflow, recession constants computation was used to derive the three flow components of the karst aquifer. The recession constants, \( K_b \) (diffuse flow), \( K_i \) (fissure flow), and \( K_c \) (conduit flow), were calculated from nine selected flood events. From the hydrograph analysis, this research found that the average discharges in rainy and dry seasons were 56.7 l/s and 13.25 l/s, respectively. These relatively small flows are mainly because Guntur Spring is an epikarst spring with layers of limestone or thin aquifer. The recession constants were \( K_b = 0.998 \), \( K_i = 0.933 \), and \( K_c = 0.500 \), meaning that Guntur Spring has three flow components, including diffuse, fissure, and conduit. Although the baseflow separation analysis found that the diffuse flow prevailed (93.07%), the influence of conduit and fissure flows was apparent, especially during rainy seasons. The Guntur Spring hydrograph analysis revealed that the average time to baseflow (\( T_b \)) and time to peak (\( T_p \)) was rather prolonged. Supporting this finding was the mean value of \( K_c \) that categorized the recession as medium and signified that the conduit fractures developing in Guntur Spring were not extensive. As a conclusion, diffuse flow mainly characterizes the discharge of Guntur Spring with some indications of growing fissures and conduits.

1. Introduction
Guntur Spring is situated in Gunungsewu Karst (Figure 1.1) and bordered by Baturagung Hills to the west and north. Gunungsewu Karst has an east-west axis and limestone as its primary constituent [1]. It is a plateau formed due to the uplift in the Pleistocene. During this process, the sea terrace on land rose and formed Baturetno Basin, a landform composed of limestone with a low level of karstification [2]. Because the configuration of the valley and cone parameters in Gunungsewu Karst has highly detailed variations, this plateau does not entirely belong to kegelkarst [3].
Karst aquifers are a soluble rock formation that stores and transmits groundwater [4]. Characterization of its flow discharge components is critical in determining the extent of change or widening in karst tunnel or cave systems. The procedure can include identifying recharge properties, typology of cave networks, groundwater storage capacity, outflow’s response to recharge, and flow characteristics [5].

These aquifers occupy roughly 10% of the world area, and around 25% of the global population relies on them for drinking water supply [6]. For this reason, karst groundwater must be considered as a potential aquifer for meeting basic needs of life [7]. However, karst is heterogeneous with a lot of secondary porosity and describing the distinctive features of its aquifers is relatively more difficult than characterizing other aquifers [8]. These features vary depending on the karst hydrogeology [9]. Also, karst aquifers are very susceptible to pollution [10].

The process by which karst aquifers release their flow components can be identified through analyzing the characteristics of the flow. An example is the open karst system, i.e., a type of conduit-controlled stream that disappears underground and then emerges to the surface as a spring [8]. Recession constant and baseflow percentage are two approaches with which the discharge of flow components can be representatively characterized [11]. With the recession constant, the flow component analysis can describe the development of karst aquifers, namely diffuse, fissure, and conduit [12].

Figure 1. The Location of Guntur Spring in Gunungkidul, the Special Region of Yogyakarta, Indonesia.

Guntur Spring, based on its hydrogeological system, is part of Panggang Block, Gunungsewu Karst area. Panggang Block has a maximum elevation of >200 m above mean sea level and bedrocks <100 m deep below the ground surface [1]. Among the other blocks, Panggang has the most widespread springs [1].

Administratively, Guntur Spring is located in Girijati Village, Purwosari District, Gunungkidul, the
Special Region of Yogyakarta. It receives a regional rainfall of 1787 mm/year [13], which at this rate likely affects the amount of its discharge. Also, its catchment area is as wide as 30.7 ha [14]. Flowing throughout the year (perennial), Guntur Spring is available for domestic use by the 166 local families. However, the spring discharge drops in dry seasons, leaving many villagers of Girijati with a water crisis.

2. Methods

The water level was recorded for one year from May 2018 to May 2019, with an interval of 10 minutes using an automatic water level logger (Hobo U-30). The discharge was measured 26 times by two methods, namely sudden injection in dry seasons and velocity area in rainy seasons. Each measured discharge was connected to the corresponding water height or stage to produce a rating curve’s equation. Meanwhile, the method used to characterize water releases from the karst aquifer is described in the following details.

2.1. Recession Constant

The recession constants were derived from selected flood hydrographs that had sufficient period of recession [15]. For Guntur Spring, nine flood hydrographs were chosen, and the recession constant for each flood event was computed using

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

where \( Q_t \) is flow discharge at time \( t \), \( Q_0 \) is initial streamflow at a recession segment, and \( e^{-\alpha} \) or \( k \) is the recession constant. The recession constant has been used frequently as an indicator of baseflow continuity [16].

2.2. Baseflow Separation

A baseflow separation is an approach to separating the baseflow component from the hydrograph. In this study, this analysis employed the recursive digital filter developed by Lyne and Hollick (1979). This technique uses the following equation [17],

\[
\begin{align*}
    f_k &= \alpha f_{k-1} + \frac{(1+\alpha)}{2} (y_k - y_{k-1}) \\
    b_k &= y_k - f_k
\end{align*}
\]

where \( f_k \) is the quick flow at time \( k \), \( y_k \) is flow discharge at time \( k \), \( \alpha \) is the baseflow recession constant, and \( b_k \) is baseflow at time \( k \).

3. Results and Discussion

3.1. The Stage-Discharge Relation

The discharge measurement was carried out 26 times from May 2018 to May 2019 (Table 4.1). It included low, medium, and high flows to ensure that the data were representative enough to produce a rating curve equation, which in this study had an exponential pattern (Figure 4.1). An exponential equation is used for natural channels or cross-sections [19], such as Guntur Spring. The rating curve has \( R^2 = 0.964 \), and with \( R^2 \) approaching 1, the obtained equation can accurately convert the water stage of Guntur Spring into discharge [20].

| No | Dates   | Water Level (m) | Discharge (l/s) | No | Dates   | Water Level (m) | Discharge (l/s) |
|----|---------|----------------|----------------|----|---------|----------------|-----------------|
| 1  | 5/5/18  | 0.17           | 25.00          | 16 | 1/29/2019 | 0.32           | 41.29           |

Table 1. The Results of Discharge Measurements at Guntur Spring.
3.2. The Flow Hydrograph of Guntur Spring

The hydrograph, which relates discharge to time (Figure 4.2), showed that Guntur Spring had a fluctuating release, indicating the influence of laminar and turbulent flow. In the rainy season, there was a cluster of flood events from November 2018 to March 2019. This finding proves that Guntur Spring is perennial.

Figure 2. The Rating Curve of Guntur Spring.
Guntur Spring has varying discharge (Table 4.2). The lowest release was 1.24 l/s on October 13, 2018 (the end of the dry season), while the largest one was 125.58 l/s on March 17, 2019 (the end of the rainy season). The average discharge in the rainy season was 56.7 l/s, which decreased to 13.25 l/s in the dry season. In one year (May 2018-May 2019), the spring discharge was averagely 27.63 l/s. On March 17, 2019, the water release of Guntur Spring far exceeded its mean value due to the effects of Savannah Cyclone.

Table 2. The Flow Discharge of Guntur Spring.

| No | Parameters                  | Discharge (l/s) | Periods                               |
|----|------------------------------|-----------------|---------------------------------------|
| 1  | Discharge in Dry Season      | 13.25           | May 2018-October 2018 & April 2019-May 2019 |
| 2  | Discharge in Rainy Season    | 56.70           | November 2018-March 2019              |
| 3  | Minimum Discharge            | 1.24            | October 13, 2018                      |
| 4  | Maximum Discharge            | 125.58          | March 17, 2019                        |
| 5  | Average Discharge            | 27.63           | May 2018-May 2019                     |

With a range of 1.24 to 125.58 l/s, the discharge of Guntur Spring is smaller relative to other hydrogeological sub-systems, for instance, Wonosari-Baron Block yields more than 1,000 l of water per second [1]. Aside from the limestone layer or thin aquifer [21], the small discharge is because Guntur Spring is an epikarst spring [2]. Petoyan, another spring in Panggang Block, also has a low release, i.e., <100 l/s [22]. This finding is in line with Kusumayudha (2005), which claims that Panggang Block has a high distribution of springs but a small discharge, under 100 l/s [1].
3.3. The Recession Constants of Guntur Spring

Each of the selected flood events gave variation to the recession constants (Kr) of Guntur Spring, as seen in Table 4.3. The recession constant for diffuse flow, Kb, was between 0.994 and 0.9998 with an average of 0.998. Meanwhile, the fissure flow constant (Ki) was 0.887-0.995 with an average of 0.933, and the conduit flow constant (Kc) was 0.250-0.740 with an average of 0.500. These results affirm the ranges of Kc, Ki, and Kb identified in Nathan & McMahon (1990), namely Kc= 0.2-0.8, Ki= 0.7-0.94, and Kb= 0.93-0.99 [16].

| No  | Dates       | Qp (l/s) | Kr Diffuse (Kb) | Kr Fissure (Ki) | Kr Conduit (Kc) | Tp (Hours) | Tb (Hours) |
|-----|-------------|----------|-----------------|-----------------|----------------|------------|------------|
| 1   | 28/11/2018  | 29.54    | 0.998           | 0.932           | 0.374          | 12.1       | 65         |
| 2   | 23/12/2018  | 62.50    | 0.994           | 0.916           | 0.712          | 7.2        | 37         |
| 3   | 2/1/2019    | 61.85    | 0.998           | 0.980           | 0.627          | 6.9        | 61         |
| 4   | 17/1/2019   | 75.98    | 0.995           | 0.938           | 0.462          | 8.0        | 60         |
| 5   | 23/1/2019   | 74.88    | 0.999           | 0.919           | 0.550          | 7.2        | 41         |
| 6   | 1/3/2019    | 68.97    | 0.998           | 0.887           | 0.742          | 4.4        | 18         |
| 7   | 8/3/2019    | 68.23    | 0.999           | 0.906           | 0.506          | 7.0        | 46         |
| 8   | 16/3/2019   | 95.11    | 0.998           | 0.924           | 0.250          | 6.2        | 29         |
| 9   | 17/3/2019   | 125.58   | 0.999           | 0.995           | 0.278          | 5.1        | 175        |
| Mean|             | 73.63    | 0.998           | 0.933           | 0.500          | 7.1        | 59         |
| Max.|             | 125.58   | 0.999           | 0.995           | 0.742          | 12.1       | 175        |
| Min.|             | 29.54    | 0.994           | 0.887           | 0.250          | 4.4        | 18         |

The recession constants represent how karst aquifers release their flow components. Guntur Spring had a high Kb, 0.998, signifying the prevalence of diffuse flow. Kb>0.98 shows that an aquifer can store groundwater well [16], which is evident from never-drying springs (perennial). The recession constant Ki (0.933) was also considered high, indicating the influence of the fissure system yet not as dominant as diffuse flow. Although the recession constant Kc was only 0.5 (medium) with a minimum value of 0.25, it proved that conduit flow had developed in the observed karst aquifer. Kc<0.5 means that the flow component is released fast [23]. These theories suggest that the diffuse system dominates the flow components of Guntur Spring and forms reliable groundwater storage, but there are signs of fissures and conduits that have begun to shape. Rahmawati (2018) [24] and Adji (2016) [25] claim that while diffuse flow mainly feeds Guntur and Ngeleng Springs in Panggang Block, the groundwater supplies also run through developing conduit and fissure systems. These assertions support the results of this study.

Time to baseflow (Tb), or time required by peak discharge to recede to baseflow, is derived from a flood hydrograph with known recession constants. The shortest Tb of Guntur Spring was 18 hours, whereas the longest was 175 hours (mean= 59 hours). This range of Tb is deemed very long compared to Petoyan, another spring in Panggang Block, with Tb= 8.8 hours [12], and also Bribin Underground River in Wonoasari-Baron Block with mean Tb= 36.3 hours [23]. Prolonged Tb indicates that aquifers release the diffuse storage slowly because the fractures in the conduit system are not fully developed [23]. Meanwhile, the time to peak (Tp) of Guntur Spring was 4.4 – 12.1 hours with an average of 7.1 hours, signifying the prevalence of diffuse flow. Founded on this theory, the prolonged Tb (mean= 59 hours) and Tp (mean= 7.1 hours) in Guntur Spring reflects the small to medium-size fractures in its aquifer, or in other words, the dominant flow component is diffuse. However, despite the primary control of the diffuse flow, the discharge of Guntur Spring is attributable to the early development of fissure and conduit systems, as evidenced by the relatively short recession time to baseflow, Tb= 18 hours.
3.4. Baseflow Separation

After separating baseflow from the total flow component, baseflow (diffuse) was found to largely supply the water in Guntur Spring (Figure 4.3), proving that it is a perennial spring. Also, the results demonstrated that the karst aquifer of this spring released not only diffuse but also conduit flow, particularly in rainy seasons. From May 2018 to May 2019, the percentage of baseflow varied from 86.12% and 100% with a total of 93.07% for the whole year (Table 4.4). In other words, baseflow or diffuse is the dominant flow component in Guntur Spring. In the dry season, the baseflow was stable at 100% (for six months), meaning that the groundwater storage is still reliable. Diffuse systems are mostly good at storing groundwater [26]. Meanwhile, at the beginning of the rainy season, the baseflow decreased to the lowest percentage, 86.12% (November 2018), and then slightly fluctuated until the end of the season, illustrating the presence of fissures and conduits beside the diffuse flow in Guntur Spring. Also confirming this finding is Adji (2011), which states that the percentage of baseflow in the dry season lowers in response to direct flow (conduit and fissure)—instead of the diffuse system, and slowly increases in the rainy season [27].

![Figure 4. The Baseflow Separation of Guntur Spring.](image)

| No | Months           | Mean Baseflow (%) | Seasons          |
|----|------------------|-------------------|------------------|
| 1  | May 2018         | 94.37             | Early-Dry Season |
| 2  | June 2018        | 100.00            | Dry Season       |
| 3  | July 2018        | 100.00            | Dry Season       |
| 4  | August 2018      | 100.00            | Dry Season       |
| 5  | September 2018   | 100.00            | Dry Season       |
| 6  | October 2018     | 100.00            | Late-Dry Season  |
| 7  | November 2018    | 86.12             | Early-Rainy Season |
| 8  | December 2018    | 87.08             | Rainy Season     |
| 9  | January 2019     | 90.80             | Rainy Season     |
| 10 | February 2019    | 99.90             | Rainy Season     |
| 11 | March 2019       | 89.75             | Late-Rainy Season |
The aquifer of Guntur Spring has reliable groundwater storage capacity, which is primarily and slowly released through small to medium size fractures. This condition is apparent from the high percentage of baseflow for one year (93.07%) and $K_b > 0.98$. Rahmawati (2018) has also confirmed that the baseflow contributes to 92% of the total flow released at Guntur Spring [24]. It is more significant than the portion of baseflow at Petoyan Spring, i.e., 80.64% [12]. Therefore, combined with the previous studies, the percentage of baseflow shows that the aquifer of Guntur Spring maintains functional groundwater storage with a slow release.

The percentage of baseflow in all flood events was averagely 65.99% (Table 5.5), which is lower than the average in one year. This situation reflects the influence of fissure and conduit flows during the floods [23]. This low percentage is also smaller than the average contribution of baseflow in each flood event in 2017-2018, which was 75.2% [24]. The decreased portion of baseflow is caused by higher recharge or intensity of rain, demonstrating the effects of fissure and conduit [12]. Another study in Petoyan Spring (part of Panggang Block) has reported that compared to Guntur Spring, the mean percentage of baseflow in each flood event is higher (48.78%). Based on the above theories and previous research, the conduit fracture in the aquifer of Guntur Spring has become more developed but not as much as the other karst aquifers that are also located in Panggang Block (e.g., Petoyan Spring).

### Table 5. The Percentage of Baseflow During Flood Events.

| No | Dates               | Peak Discharge (l/s) | Baseflow (%) |
|----|---------------------|----------------------|--------------|
| 1  | November 28, 2018   | 29.54                | 29.19        |
| 2  | December 23, 2018   | 62.50                | 69.12        |
| 3  | January 2, 2019     | 61.85                | 62.48        |
| 4  | January 17, 2019    | 75.98                | 75.16        |
| 5  | January 23, 2019    | 74.88                | 77.06        |
| 6  | March 1, 2019       | 68.97                | 82.34        |
| 7  | March 8, 2019       | 68.23                | 82.65        |
| 8  | March 16, 2019      | 96.11                | 66.43        |
| 9  | March 17, 2019      | 125.58               | 54.02        |
| Mean|                    | 73.74               | 65.99        |

During the nine flood events, the percentage of baseflow varied between 29.19% and 82.65%. The lowest percentage was 29.19% on November 28, 2018, because this flood occurred at the beginning of the rainy season. At this time of the year, the groundwater storage reaches its lowest point because the antecedent condition includes the absence of rainfall and the next rain first supplies the fissure and conduit components of the spring’s aquifer. The largest percentage of baseflow was 82.65%, which was at the end of the rainy season. Nearing the late wet season, the rain intensity decreases and, consequently, the baseflow or diffuse flow prevails [12]. The baseflow component raised from January 17, 2019, until March 8, 2019, and anomalously decreased on March 16-17, 2019. Before and during these two days, the rainfall intensity was the highest in May 2018-May 2019, i.e., up to 148 mm/day (categorized as very heavy rain). This extreme rain was attributable to the occurrence of Savannah Cycle. In this situation, the previously reduced fissure and conduit flows start to increase.

### 4. Conclusion

The flow release from karst aquifers has been characterized from discharge, recession constants, time to baseflow ($T_b$), and percentage of baseflow. The average discharges in the rainy and dry seasons
(56.7 l/s and 13.25 l/s) are relatively small because Guntur spring is an epikarst spring that has limestone layer or thin aquifer. The recession constants for diffuse flow (K_b = 0.994-0.999; mean = 0.998), fissure flow (K_i = 0.887-0.995; mean = 0.933), and conduit flow (K_c = 0.25-0.74; mean = 0.5) indicate the existence of these three flow components. The high recession constants show that the aquifer of Guntur Spring is dominantly fed by diffuse flow and functional as groundwater storage. Supported by the average K_c value, the prolonged T_b (59 hours) and T_p (7.1 hours) indicates that the conduit fractures are not fully developed yet. Based on the total percentage of baseflow in one year (93.07%) and in nine selected floods (65.99%), diffuse flow is dominant in the dry season but less in the rainy season—even lower than fissure and conduit. In other words, while the contribution of diffuse flow prevails in the dry season, there are few influences of fissures and conduits in the rainy season. As a conclusion, the characteristics of the flow release from Guntur Spring are primarily diffuse with signs of developing fissures and conduits.

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