Baseflow index assessment and master recession curve analysis for karst water management in Kakap Spring, Gunung Sewu

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Abstract Karst terrain occurs in combination of high solubility rock and well developed secondary porosity. Over the time, groundwater resources have not been well managed including karst aquifers. Karst aquifers formed in a very complex hydrological system. Developed in fracture media and soluble rocks have led karst aquifers into various porosity types and aquifer properties. Karst spring hydrograph is an essential element for water resource management. The form of karst spring hydrograph reflects the aquifer characteristics. The shapes of flood discharge hydrographs represent aquifer responses to recharge and contain information about the interior condition of karst drainage basin. Every year, Gunung Sewu karst area is suffering severe water scarcity. The development of sub-terrain drainage networks lead into the minimum surface water resources. Kakap Spring is perennial gravity spring that located adjacent to the border of Gunung Sewu and the alluvial formation of Baturetno. Kakap spring play vital role regarding water supply in Giriwoyo sub-district as the spring fulfill most of the water needs in Giriwoyo sub-district. Kakap Spring utilized by the local authorities as the main source for pipeline water and distributed to the households. Water level data series obtained using automatic water level data logger and then correlated with manual discharge measurement to generate stage-discharge rating curve. The stage-discharge rating curve formula for Kakap Spring calculated as $y = 14.504e8.9763x$ with $r^2$ value $=0.8582$. From the MRC result, flow regimes formula determined as $+ 400 (1-0.005t) + 700 (1-0.01t)$, indicated that the aquifer dominated by turbulent flow regime. From the MRC formula, the degree of karstification in Kakap Spring classified at eighth scale. The average baseflow index in Kakap Spring calculated using recession curve analysis with the BFI index$=0.7485$.

1. Introduction
Karst is an international terminology that widely known to describe a distinctive landscape type controlled by dissolution processes. Karst landform characterized by extensive subterranean drainages, caves, and closed depressions. Karst terrain is particularly developed in soluble rock such as carbonate rocks, evaporates and quartzite [8] [16] [15]. Approximately, more than 20 % of the world’s ice free land occupied by karst rock. Despite lack of surface water availability, karst areas contain abundant groundwater resources. Karst groundwater resources reside as underground rivers beneath the earth surface or emerge as karst springs. About 20-25% of the world’s population depends on karst water resources. Most of the biggest springs in the world are located in karst area. Therefore, karst aquifers play an important role for human water supply and one of the most significant aquifer formations. [7] [15] [18].

Gunung Sewu karst area is one of the largest karst areas in Indonesia with distinctive sinusoidal conical hills. Several karst springs emerge with various discharge rate and characters. Karst springs play an important role as potable water sources in Gunung Sewu karst area that considerably lack of surface water resources [1] [3]. Every year, Gunung Sewu karst area is suffering a severe water scarcity. Through the sinkholes and epikarst layer, the surface waters enter the saturated zone as allogeneic and autogenic systems. The development of sub-terrain drainage networks leads into the
minimum surface water resources. The most dependable surface water resources in karst area are karst springs and doline ponds/telaga [17] [2].

Kakap spring is located in Giriwoyo sub-district, Wonogiri Regency, Central Java. Kakap Spring located in the north-eastern part of Gunung Sewu (figure 1). Kakap Spring is perennial gravity spring that located adjacently to the border of Gunung Sewu and the alluvial formation of Baturetno. Kakap spring play significant role regarding water supply in Giriwoyo sub-district as the spring fulfill most of the water needs in Giriwoyo sub-district. Kakap Spring utilized by the local authorities as the primary source for pipeline water and distributed to the households in 4 villages. Kakap Spring also utilized for irrigation purposes for 340 hectares agricultural area [4].

![Figure 1. The sitemap of Kakap Spring.](image)

Karst aquifer receives, stores, and transmits more water compared to all surface streams. Karst springs are known as the world’s largest springs with the highest discharge rates compared to springs from other aquifer types. Among the largest water sources in the world, karst springs ensure that their importance for water supplies is widespread [19]. Karst spring hydrograph is an essential element for water resource management. The form of karst spring hydrograph reflects the aquifer characteristics. The shapes of flood discharge hydrographs represent aquifer responses to recharge and contain information about the interior condition of karst drainage basin. Hydrograph is generally more stable during the recession period and represents hydraulic and geometrical characteristics of the aquifers [14]. Besides, recession curve of karst spring hydrograph describes the significant progress when the maximum discharge recorded until the next consecutive pulse. Each part of the single flood hydrograph curve will represent the contribution of different porosity types [10]. Karst spring hydrograph analysis especially focused on recession curve data possibly provides valuable information in order to identify some characteristics of the karst aquifer and water resources management [9] [15] [24].

Recession curve analysis provides essential information to interpret the hydrological significance and characterize specific parameters of the springs. The main advantage of analyzing spring recession
curves is that the drainage mechanisms in the aquifer and its quantitative parameters will be able to be estimated [5] [20]. Recession curve analysis plays an important role in determining the geological and storage characteristics of the karst aquifer. However, the rising limb of the hydrograph must have been analyzed to determine the karstification degree of the aquifer [22]. Karstification degree is very useful in the application of karst river basin management and deciding protection zone for karst aquifer. Groundwater management and protection zone in karstic aquifer can be based on the determination of karstification degree. According on those issues, this study focused on spring hydrograph analysis to provide general information of the aquifer systems in karst drainage basin within Gunung Sewu karst area. The objectives of this study were to determine the characteristics of recession curves of Kakap spring; Assess the karstification degree and the Baseflow Index of Kakap Spring as for karst water resources management.

2. The Methods
The main material of this research is hydrograph data series that measured using HOBO automatic water level logger. The HOBO water level data logger sensor measure the water pressure with operation range from 0 to 400 kPa (0 to 58 psi); approximately 0 to 30.6 and fully compensated with barometric pressure and logged with 30 minutes interval. Manual discharge measurements conducted using area velocity method, in this case surface float. After several discharge data obtained from numerous measurements, stage-discharge rating curve generated to determine linear regression between water level and stream discharge. The rating curve’s regression function was used to convert the measured water level data into hydrograph series data. After hydrograph series created, the master recession curve (MRC) constructed. MRC construction was done by assembling several recession curves using semiautomatic tool called RC 4.0 that included in HYDROOFFICE software. MRC is also the main input to determine the karstification degree.

The determination of karstification degree in Kakap Spring is adapted form [20]. [20], introduced a methodology for karstification degree determination using a 10-degree scale, from the 1st degree for the lowest karstification, and 10th degree for best developed karstic behavior. The number of flow sub-regimes that presence in MRC used as the main consideration in determining the karstification degree. Typical recessional equations used to describe recessional types that characterized by the existence of different flow sub-regimes.

The baseflow separation [11] introduced automatic technique for hydrograph separation using digital filtering method. Separation of total discharge into two components, baseflow and direct runoff performed using recursive digital filtering as expressed in Eq.1.

\[ b_k = \frac{(1-BF_{imax})aqb(i-1) + 1 - aBF_{imax}}{1 - aBF_{imax}} \]

This filter parameter describes baseflow recession function that expressed as an exponential equation, indicating recession periods without groundwater recharge. BF_{imax} value that based on preliminary results have been suggested to minimize the subjective influence.

3. Result and Discussion
Kakap Spring located in the north-eastern flank of Gunung Sewu. Kakap Spring is perennial gravity spring that located adjacent to the border of Gunung Sewu and the alluvial formation of Baturetno. Kakap spring play very important role regarding water supply in Giriwoyo sub-district as the spring fulfill most of the water needs in Giriwoyo sub-district. The study at Kakap Spring considered as initial research since this location has not been studied before, especially for hydrograph monitoring. The water level observation at Kakap spring that used for this research as obtained during March 2014- April 2015. However, the water level data series that used for the analysis in this study only from March 2014-April 2015. A couple of automatic water level data logger and barometric pressure were
installed with 30 minutes interval. Stage-discharge rating curve of Kakap spring generated from eleven manual discharge measurements. The water level-discharge correlation of Kakap Spring expressed in Eq.2.

\[ y = 14,504e^{8.976x} \]  

(2)

Where \( y \) is discharge (liters/second) and \( x \) is water level (meters). The stage-discharge rating curve of Kakap Spring can be seen in figure 2.

![Figure 2. Stage-discharge rating curve of Kakap Spring.](image)

After the stage-discharge rating curve equation determined, the water level data series converted to hydrograph data. Based on the hydrograph result, major recessional period at Kakap Spring occurred from March-December. The minimum discharge recorded at 38,239 liters/second. Intensive flood periods started in December and the discharge periodically increase as the rainy season has begun. The maximum discharge at Kakap spring recorded at 3314, 24 liters/second, five times larger than the average discharge rate at 600,087 liters/second. Based on the hydrograph data series, 42 flood events were recorded with various magnitude. The hydrograph data series of Kakap Spring shown in figure 3.

![Figure 3. The hydrograph of Kakap Spring.](image)

3.1. Master recession curve of Kakap Spring

The discharge fluctuation of Kakap Spring is relatively high, especially in the rainy season. A long recessional period occurred from March-December with very minimum precipitation events. Basically, several small precipitation events were occurred during that time but didn’t give significant
impacts to the hydrograph. Therefore, the hydrograph were adjusted with the removal of linear segments and insignificant flood pulses. The huge flood period started in December and periodically increase as the season entered the peak of rainy season.

Based on automatic recession curves filters, 26 flood events were identified and 23 events analyzed. The selection of ideal recession curve based recession length and the inclination of the recession limb. Subsequently, each recession curve was calibrated with the appropriate flow model, based on the shape and inclination of the recession limb. The shape of each recession curve is unique and differ representing the aquifer response to the precipitation intensity. After each recession curve has calibrated, all the recession curves subsequently combined to generate Master Recession Curve. The shape of calibrated MRC in Kakap Spring shows the combination of two turbulent flow regimes and one laminar flow regime as it presented in figure 4. The advantage of using MRC for hydrograph analysis is because of its ability to easily identified flow regimes. Flow regimes identification from MRC is relatively more accurate than from combined single recession curves. The determination of karstification degree from flow regimes identification is a powerful tool for scientific adjustment before formulating management actions in karst area [12].

![Figure 4. Master Recession Curve of Kakap Spring.](image)

These results indicate that the aquifer feeding Kakap’s stream is complex and formed by the combination of pores, micro-fractures, fissures, and conduits. However, based on the MRC shape this mixed type aquifer also strongly influenced by the conduit channel. This indication convinced by the fact that the falling limb steepness is relatively high with short periods to baseflow condition. Rapid discharge responses in Kakap Spring also indicate the domination of concentrated flow in the conduits as the stream turns turbid several 2-3 hours after the rain events. Example of various discharge conditions in low flow period and flooding period presented in figure 5.

From the hydrograph presented in figure 4, it can be seen that most of the flood pulses shape is relatively steep, either in rising limb or falling limb. This condition indicates a short residence time of quick flow in the aquifer [6]. However, discharge response to rain events also affected by several factors. [23] stated that after infiltrating through the catchment’s surface-soil, the rainwater recharges two portions of the catchment. The storage-rate of water in particular portion of the spring catchment depends on its permeability and the volume of water stored in particular portion of the spring depends on its storage capacity. Based on this justification, it is concluded that the maximum volume of water in shorter time will be stored in the portion with highest permeability and capacity. Conversely, the portion with highest permeability will deplete earlier in comparison to catchment portions with low permeability.
Based on those findings, it is clear that the role of conduit channel feeding the stream is significant, especially during the rainy season. Fast depletion time in falling limb indicates that the aquifer with high permeability play an essential role feeding the stream during rainy season with quick flow characteristics. Based on the MRC of Kakap Spring, falling time of quick flow period occurred at the first five hours after the peak flow. Subsequently, the recession period took four more hours to reach the low flow condition. The presence of more turbulent flow in the aquifer proofs the domination of developed karstic networks in the aquifer formation.

3.2. Karstification degree of Kakap Spring

The karstification degree assessment at Kakap Spring attributed from twenty-three individual recession events. Based on the MRC result of Kakap spring, one laminar sub-regime and two turbulent sub-regimes were identified. The superposition equation of Kakap spring represented in Eq.3.

\[ Q_t = 1400e^{-0.0014t} + 400(1-0.005t) + 700(1-0.01t) \]  

According to the Eq.2, two turbulent flow sub-regimes were identified with a higher \( \beta_2 \) value that indicates a high karstification degree. Based on the superimposed equation of flow regimes, Kakap Spring’s karstification degree classified at eight scales. At this scale, the aquifer considered as highly karstified with a strong domination of conduit channels. The domination of conduit channels represents rapid groundwater transmissions within the aquifer. This type of turbulent flow through conduit channels possibly causes a linear segment in the recession limb [13]. This condition implemented in the Eq.2 that shows the domination of linear equations, representing turbulent flow regimes. A higher value of \( \beta_2 \) at Kakap Spring represents more rapid aquifer drainage that can be associated with conduits draining from the saturation zone.

A rapid recharge responses at Kakap spring also indicates the domination of conduit channels. Short time to peak with the average time two up to three hours and the following turbid water flows that recharges indicates rapid water transmissions within conduit channels. Besides controlled by the internal structures of conduit channels, the response time of karst aquifers also depends on several factors such as the size of catchment area, carrying capacity, and the contribution of allogenic recharge.
and internal runoff [25]. According to [21] water flow in karst aquifer considered as turbulent flow when the value of transmissibility > 5 m/day. While when the k value less than 1 m/day the water flow considered as laminar flow. Rapid temperatures and chemical compounds response to storm pulses also indicates the so called “conduit flow springs”. This type of spring is characterized by highly karstic limestone aquifers that dominated by open cave systems [25]. According to the automatic temperatures recording at Kakap Spring, it shows rapid temperatures response that also indicates the domination of conduit channels within the aquifer. A short time to peak also represents a quick aquifer response to storm events. These quick stream responses respectively followed by rapid temperature responses as it shown in figure 6.

![Figure 6. Rapid temperature responses to discharge and storm events at Kakap Spring.](image)

3.3. Baseflow separation

The main purpose of baseflow separation is to determine the percentage of flow component supplying the spring. Two flow components that separated were direct flow (conduit-fissure) and baseflow (diffuse). According to BFI index calculation, the baseflow index of Kakap Spring varies from 0.1401 to 0.9419 with the average value 0.49. The average value of BFImax used as the main input for baseflow separation as it already described in Eq.1. Baseflow recession constant for Kakap Spring calculated from five major food. The value of baseflow recession constant in Kakap Spring varies from 0.9913 to 0.9995 with average value 0.9914. The baseflow separation result shows the average baseflow percentage during March 2014-April 2015 is 81.20 % from the total run-off (figure 7).

The ratio of baseflow during rainy season in some certain month was relatively smaller compared to the baseflow presentation in the dry season. However, the ratio of baseflow gently increased in the end of rainy season. The average baseflow ratio in December 2014 was recorded at 69.54 % that indicates the role of conduit flow supplying the spring. The ratio of diffuse flow during flood is relatively low compared to the normal flow condition. In the first recorded flood (November 17, 2014), baseflow ratio decreased up to 17.68 %. This fact indicates that the conduit flow dominates the total flow through the large open channel and contributes directly to the spring.
4. Conclusion
The karstification degree of Kakap Spring is classified at the 8th scale, which means that the aquifer considered as highly karstified with a strong domination of conduit channels. The domination of conduit channels represents rapid groundwater transmissions within the aquifer. Low baseflow ratio during flood events also indicates the domination of conduit channel in term of its contribution to the total run-off. Those results show that Kakap Spring catchment area play a big role as water reservoir and must be considered as conservation area. However, according to the base flow separation result, the percentage of base flow is apparently too high for karst aquifer. The default BFI max value that suitable for karst aquifer is 0.25. While in this study, the average BFI value was 0.49. According to the base flow separation, the default BFI max value for karst aquifer is more appropriate than the average BFI max that derived from the study location.

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