The Distribution of Flood Hydrograph Recession Constant of Seropan Underground River for Karst Aquifer Characterization

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Abstract. This research was conducted in the Seropan underground river in the Gunung Sewu karst, Gunung Kidul Regency. This study aimed to identify some of the flood hydrograph properties of the Seropan underground river to characterize the karst aquifer. A water level data logger is installed to detect underground river water level fluctuations during the recording period. In addition, time series discharge measurements at minimum, average and maximum flow are carried out to formulate a stage-discharge rating curve. Thus, the hydrograph of the underground river during the measurement period can be determined. After that, several flood hydrographs were selected to calculate the diffuse flow recession (Kb), fissure flow (Ki), conduit flow (Kc), time to peak (Tp) and time to base flow. The analysis results show that the Seropan underground river responds fairly quickly to rain events (Tp = 3.5 h). Then, the calculation results show the value of the recession constant (Kb = 0.995; Ki = 0.863; Kc = 0.666), which means that the Seropan Cave underground river still has a large enough base flow deposit with a fairly slow release (Tb = 45.3 h). This base flow deposit is reflected in the minimum discharge during the dry season above 300 ltr/second.

Keywords: Hydrodynamic · Karst Aquifer · Recession Curve · Underground River

1 Introduction

Karst area is an area that has unique hydrological characteristics. This area is a landform formed from rocks with a high degree of dissolution [1]. The dissolution process then causes extreme conditions in which tunnels and holes are formed on the surface so that most of the overland flow directly enters the underground flow [2]. Karst [3] is also defined as a landscape formed due to the reaction of the contact between water and carbonate rocks and changes in water conditions as a solvent agent, which are the most influential factors on the formed landform.

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Karst is an aquifer with abundant potential for groundwater resources [4]. Karst provides an essential groundwater resource for many areas worldwide [5]. Karst aquifers have heterogeneous-anisotropic properties that distinguish them from non-karst aquifers, causing the hydrogeological conditions of karst aquifers to be complex. The complexity of the karst hydrological system is shown by the dualism in the karst hydrological system, which includes the dualism of the recharge mechanism (allogenic and autogenic). The two affixes are properties or ways of water entering the aquifer system. Allogenic is groundwater recharge into aquifers outside the karst area; however, autogenic is groundwater recharge from karst areas [1]. The complexity of the karst hydrological system also includes infiltration dualism (dispersed and concentrated), as well as porosity/flow dualism (conduit and fracture) [5]. These various conditions make understanding the characteristics of karst aquifers very important to support better water resource management.

The emergence of karst springs in the last few decades [6] is the key to understanding the characteristics of karst aquifers in releasing their flow components. Karst springs are natural groundwater flows from karst rock fissures that appear to the surface or below the surface like springs from a cave [7]. The natural characteristics of the karst aquifer can be identified through the hydrograph analysis of the springs. The result aligns with the opinion [8], which states that hydrograph analysis can present data representing karst aquifers' natural characteristics. Flood hydrograph analysis by sorting out several flood events is needed to determine the time to peak (Tp) and time to base (Tb). In this study, an analysis of the recession curve was carried out where the influence of the rainy and dry seasons is very influential so that the recession curve can be considered to reflect the characteristics of the release of flow components in a karst aquifer system [9, 10].

The method of releasing water storage components from an aquifer was first proposed by [11], who considers that aquifers are water storage media that, after the absence of rain, will gradually release these storage components according to a function of time. The discharge reduction in a hydrograph is constant for each flow component the aquifer releases. After that, [11] divided the recession constant on the flood hydrograph into three types, namely the channel recession constant (Kc), the interflow recession constant (Ki), and the baseflow recession constant (Kb). In line with the concept of flow components in karst aquifers by [12], which are divided into diffuse, fissure, and conduit flows, all of which have different characteristics, recharge and storage conditions. In this case, the conduit can be equated with channel recession, fissure as interflow recession, and diffuse as the baseflow recession. Figure 1 shows a curve that releases flow from a large void faster than the release of component flow from a smaller void.

This study aims to identify several characteristics of the flood hydrograph in the Seropan underground river (Fig. 2), which can then reflect the character of the karst aquifer. This location was chosen because the flow is relatively stable throughout the year, and the availability of discharge, which is used to meet the population's clean water needs, especially during the dry season. In addition, there is a lack of specific research on karst aquifers in the Gunungsewu karst area, so this research is expected to contribute to the development of hydrological science, especially regarding the characteristics of karst aquifers and as a comparison with aquifer conditions in other karst tropical areas on Java Island.

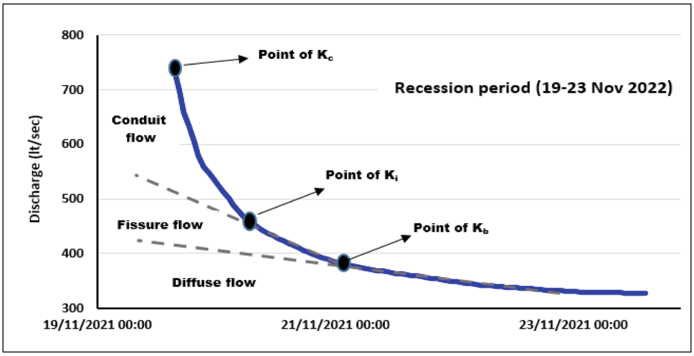

Fig. 1. An example of a selected flood hydrograph recession curve when the aquifer releases its flow component in the Seropan underground river

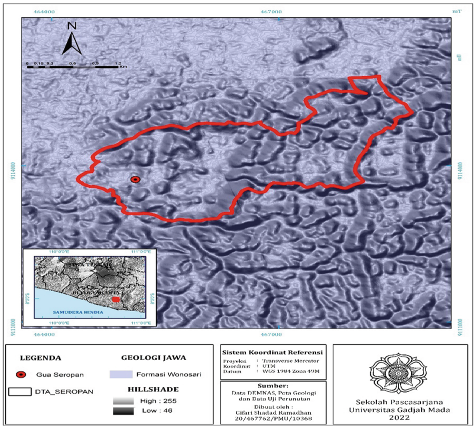

Fig. 2. Research location of Seropan underground river

2 Methods

At the initial stage, the Hobo Water Level tool was installed, and the discharge measurement was carried out to obtain a discharge hydrograph between November 2021 to July 2022. The water level logger was installed in the Seropan underground river, recording every 15 min during the study period. After all the hydrograph time data were available, several floods were sorted out with a long enough recession and reached the base flow at the end of the recession period. Then, the recession constant of each conduit, fissure, and diffuse flow component is calculated by the formula [13] as follows:

$$\mathrm{Q(t) = Q(t_0)e^{-k(t-t0)}} \tag{1}$$

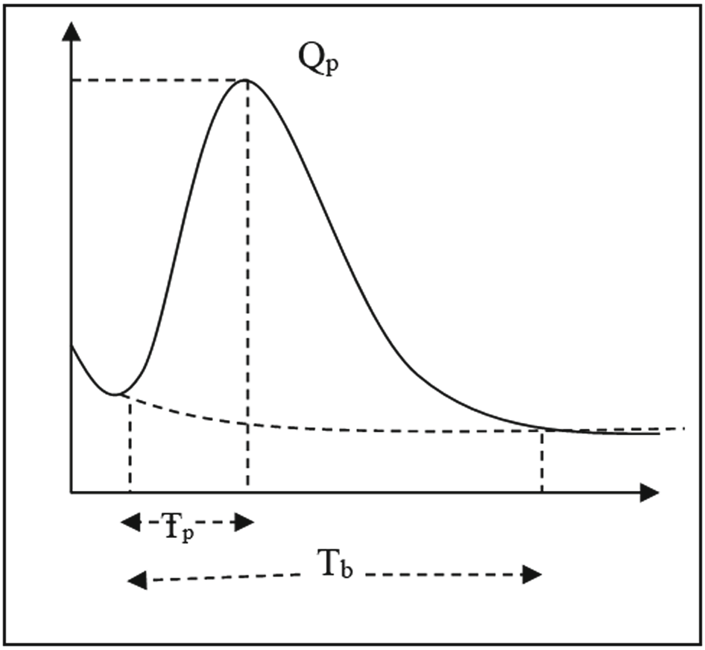

Fig. 3. Flood hydrograph period and its parameters

where k is the recession constant in the aquifer system, t is the release time at t, and t_0 is the time at the initial release of the recession period. On a semi-log scale, the consideration of the formula becomes linear, then:

$$\mathrm{In}\,Q(t) = -k(t - t_{0\_} + \mathrm{In}\,Q(t_0) \tag{2}$$

$$K = -I/t - t_0\,\mathrm{In}(Q_1/Q_0) \tag{3}$$

In addition, to obtain an overview related to the release of deposits from the karst aquifer, the time to peak (Tb) and time to base (Tp) calculations are carried out during the flood event period, as presented in Fig. 3.

3 Result and Discussion

The discharge hydrograph in the Seropan underground river during the measurement period is presented in Fig. 4.

In general, the discharge fluctuates according to the season. Usually, the discharge will show a recession period in the dry season and experience flooding in the rainy season. Discharge in Seropan fluctuates, which is quite visible in the dry and rainy seasons. The minimum discharge recorded on the hydrograph is 307 L/second, while the maximum is about 850 L/second. During this period, the Seropan underground river experienced 17 different flood events.

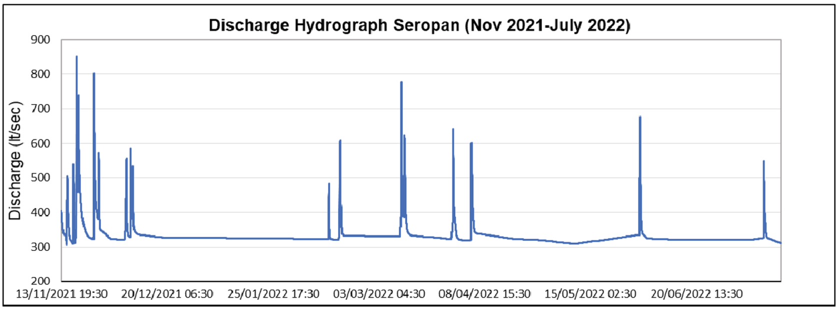

Fig. 4. Discharge hydrograph in the Seropan underground river during the measurement period

The characteristics of the release of flow components from storage in the aquifer to the Seropan underground river can be determined by calculating the recession constants for diffuse flow (K_b), fissure (K_i), and conduit (K_c). First of all, several flood events were selected that met the requirements for calculation, namely floods with a discharge that allowed them to be analyzed using flood hydrograph parameters in the form of peak discharge (Q_p), time to peak (T_p), and time to baseflow (T_b). In this study, there were six selected floods shown in Fig. 5. The results of the calculation of the value of the recession constant and the hydrograph parameters (T_b) and (T_p) are summarized in Table 1.

In general, according to [14], the range of recession constant values for conduit (K_c) is 0.2–0.8, interflow (K_i) is 0.7–0.94, and baseflow (K_b) ranges from 0.93 to 0.995. Based on the table above, the Seropan underground river has a constant value of diffuse flow (K_b), fissure (K_i), and conduit (K_c), which varies in each flood event. The K_b value ranges between 0.989 and 0.999 with an average of 0.995, the Ki value ranges between 0.731 - 0.943 (average = 0.863), and the Kc value ranges between 0.535–0.782 (average = 0.666).

The average value of the recession constant for the fissure flow component in the Seropan aquifer is 0.863. This value indicates that the Seropan aquifer reasonably quickly releases storage in medium-sized voids. Furthermore, the diffuse flow component has a

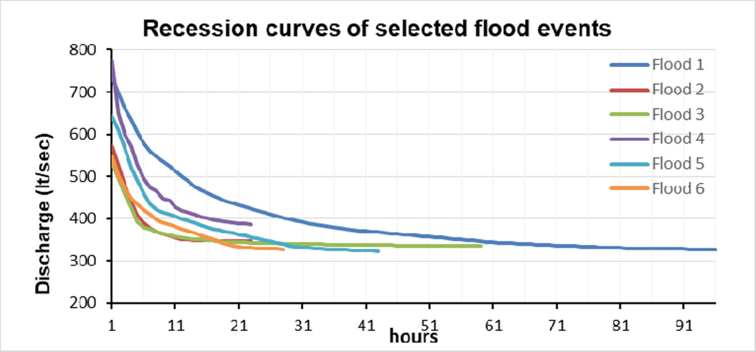

Fig. 5. Recession curves of selected flood events in Seropan underground river

Table 1. Selected several flood events in the Seropan underground river

No	Flood number	Date	Q_p (lt/sec)	Kr Diffuse (K_b)	Kr Fissure (K_i)	Kr Conduit (K_c)	Tp (hour)	Tb (hour)
1	4	19/11/2021 15:30	738.1	0.998	0.943	0.782	1.15	96
2	6	26/11/2021 17:45	572.0	0.999	0.731	0.731	3.45	23
3	9	08/12/2021 08:15	532.8	0.999	0.817	0.649	1	59
4	12	10/03/2022 21:30	777.5	0.990	0.869	0.535	12	23
5	14	28/03/2022 17:30	642.5	0.996	0.898	0.631	2	43
6	17	13/07/2022 20:45	548.6	0.989	0.921	0.667	1.45	28
Average				**0.995**	**0.863**	**0.666**	**3.51**	**45.33**
Max				**0.999**	**0.943**	**0.782**	**12**	**96**
Min				**0.989**	**0.731**	**0.535**	**1**	**23**

high value; this indicates that the Seropan aquifer has a good water storage capacity. In addition, the Seropan aquifer releases diffuse flow quite slowly, supported by the long average time to baseflow (T_b) value of 45 h with the most extended maximum T_b value (96 h). The slow release of this diffuse flow component is probably due to the thick *epikarst* layer and the presence of the majority of small voids. This thick layer causes water that moves vertically through the fracture to take a long time to reach underground streams.

Furthermore, the Seropan aquifer responds quickly to rain events and relatively quickly releases storage in conduit-sized voids. This fact is indicated by the value of time to peak (Tp), which is quite fast, namely 3.5 h. This rapid response may be due to an autogenic flow component from the surface that enters vertically into the underground water surface through sinkholes. The low Kc value also supports this character with an average of 0.666. Based on this, it can be concluded that the aquifer that recharges the Seropan underground river has a conduit-sized void that is sufficiently developed.

4 Conclusion

With the development of science in the field of karst hydrology in the Gunungsewu karst area, this study concludes that the release of diffuse fissures and conduits flow components in the Seropan aquifer indicates the development of karst aquifer voids. From the results of observations in water level measurements during the study period, 17 flood events were found. Then, the analysis results of the six selected flood events were used to determine the mean value of Tp (3.5 h) and Tb (45 h). The average recession constant calculation results for Kb, Ki, and Kc in the Seropan underground river aquifer are 0.995; 0.863; and 0.666, respectively. These figures show that the development of voids in the karst aquifer still has the ability to store groundwater for a long time, although, on the other hand, it has also experienced the development of large voids so that it responds quickly to rain events. The results of this study certainly need to be sharpened by continuous observation of more comprehensive discharge data to find out how the Seropan underground river discharge varies in the following year. In addition, it is necessary to conduct research by applying other methods, such as hydrogeochemistry, cave mapping and karst hydrodynamic modelling.

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