

Characteristics of kalisirah karst subterranean stream sub-district of buayan, kebumen, central java with tracing test

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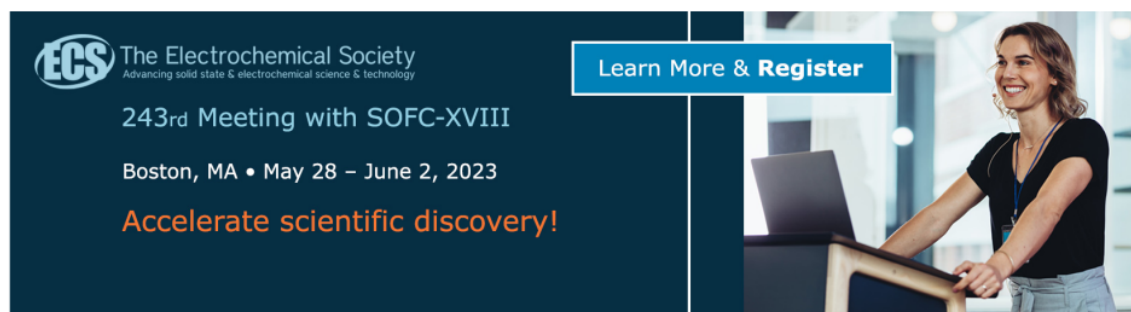
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Characteristics of kalisirah karst subterranean stream sub-district of buayan, kebumen, central java with tracing test

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Abstract. The Karst Landscape Region (KRL) Gombong is an area that has developed subterranean stream and provides abundant water resources. The Kalisirah spring supports thousands of surrounding communities, especially for domestic needs, fisheries and agriculture. The karst area is an area that is sensitive to change so it is necessary to know the character of a developing subterranean stream system, so that groundwater resources can be maintained in terms of quality and quantity. The method used is a tracing test with a qualitative and quantitative approach to obtain detailed information about the characteristics of the karst aquifer flow. Release of trace substances is carried out in Goa Pucung and the fluorometer is placed in the Kalisirah Springs. Release on September 23, 2018 at 9.57 p.m and September 24, 2018 at 3.25 p.m. Fluorometer records an increase in fluorescent concentration. Connection of Goa Pucung-Kalisirah through 2 karst windows (Kalijeblosan and Kaliwinong) that are visible in plain view. The concentration of released tracer substances can be recovered 26.18% in the Kalisirah springs, with discharge recovery reaching 4493%, which indicates a divergence and convergence of the Kalisirah subterranean stream aquifer system. Flow volume from the subterranean stream system of Goa Pucung-Kalisirah reached 23,403,064.49 liters with an average residence time of 24.11 hours. The cross-sectional area is 12.19 m² and the diameter of the Flow-Channel reaches 3.94 m, and with hydraulic depth from the Flow-Channel 3.09 meters.

1. Introduction

Karst and hydrogeology are two things that are inseparable from one another. Karst is the result of the work of water and the dynamics of water that make up karst are controlled by geological factors, such as geological structure, rock type, mineral composition, and stratigraphic arrangement [1]. Limestone is one of the main types of rocks that make up karst because its rock composition is dominated by minerals that are easily soluble by water. The karst area forms a distinctive and dynamic landscape, meaning that any changes that occur in the karst region will affect the existing order, especially the water system that is strongly influenced by rainfall, topography, and development of karstification and human activities on it, therefore it is considered necessary to carry out this research.

The location of the study included the villages of Sikayu and its surroundings, the District of Buayan, Kebumen Regency, Central Java, the object of particular concern is the Kalisirah spring which has a fairly large discharge and flows every season. This area is one of the sub-regions in Gombong Karst that has not yet been designated as a geological protected area or commonly known as a karst landscape (KBAK) through the ESDM Ministerial Decree 3873K/40/MEM/2014. Kalisirah Springs is one of the largest springs used for daily household, agricultural and fisheries purposes, especially by



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the community of Sikayu Village and has been taken by Regional water company of Kebumen for areas outside Sikayu Village. This research was conducted in September 2018, when this region has entered the dry season.

2. Method

The research method used is a qualitative and quantitative approach. Speleological surveys to reach and record subterranean conditions in Goa Pucung A qualitative approach is intended to determine the distribution of tracer substances in springs through monitoring, while the quantitative approach is intended to understand the flow characteristics in aquifers in detail including conduit topology, flow geometry, to flow properties. The difference between qualitative and quantitative methods is largely one of mathematical analysis and interpretation based on a more comprehensive sample-tracing program [2]. Quantitative methods are carried out because qualitative search results do not precisely establish subsurface connections [3], so to obtain detailed information about topology characteristics and models, research must be carried out with quantitative approaches, but qualitative methods are still needed to support the results of quantitative approaches.

2.1. Correction of background

Indeed, every water has a natural fluorescent content even in low concentrations, but it will affect the results of recording or sampling. Therefore the natural fluorescent content in water must be corrected so that the measurement results replace the actual results without any background effect.

$$C_{if} = C_{ii} - C_b, [2] \text{ where} \tag{1}$$

$$C_b = 1/n \sum C_{bi} [2] \tag{2}$$

C_{if} is corrected concentration, C_{ii} is the fluorometer water recording concentration, dan C_b is initial concentration.

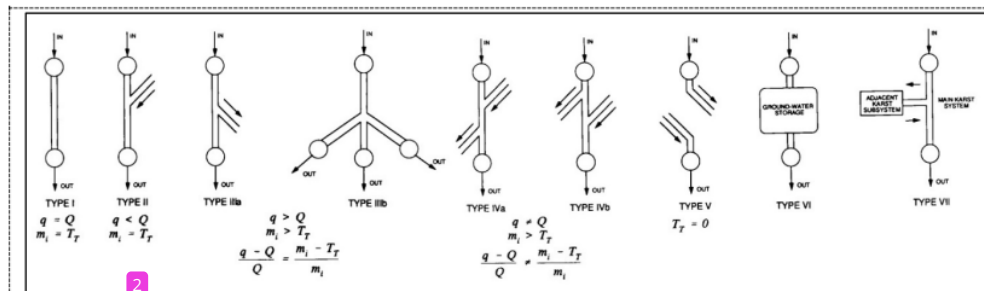


Figure 1. Seven simple karst network types that describe tracer migration in karst conduits. Any of these networks influence influence tests between the point of inflow (IN) and the point of outflow (OUT) in a karst system. The discharge into the conduit is q , the discharge out of the conduit is Q , the tracer mass is injected into the conduit is m_i , and the tracer mass recovered is T_T . Note: Any one of these types of networks may be interconnected with any of the others. [2]

2.2. Recovery of concentration and type of karst conduit network topology

Recovery of tracer concentration is the number of concentration samples that can be captured by an automatic sample recorder, or the results of manual sampling taken at any given time interval (Δt) and discharge fluctuations during the study. Calculation of recovery utilizes ms. excel tabulation formulas to make it easier, where the basic calculation of recovery is the equation:

$$C_o = \int_0^{\infty} C(t) \text{ adopted from [6]} \tag{3}$$

And the calculation of the total trajectory of all downgradient receptors is estimated according to the equation:

$$C_T = \sum C_o \text{ adopted from [6]} \tag{4}$$

with assumption $C_{in} = C_o$

Breakthrough curve describe several thing following the time that elapses after the tracer injection. The characteristics related to Breakthrough curve analysis are [7]:

- T_L , elapsed time to the arrival of the leading edge of the BTC at a sampling point.
- T_p , elapsed time to the peak concentration C_p of the BTC at a point.
- T_c , elapsed time to the centroid of the BTC at a point.
- C_p , highest concentration recorded in springs.
- T_s , the time of the first appearance of the tracer until the last appearance of the tracer in the springs.
- T_t , elapsed time to the trailing edge of the response curve at a point.

2.3. Quality of tracer recovery

Calculation of tracer recovery quality (AI) using equation (5), the calculation result will be $-1 \leq AI \leq 1$. $AI = 0$ shows a perfect search experiment, positive AI shows more injected mass than is recovered, while negative AI shows more recovering mass than injected. When AI moves farther from 0 the quality of the search experiment gets worse. Calculation of tracer recovery quality (A_i) using equation (6), the calculation result will be $-1 \leq A_i \leq 1$. $A_i = 0$ shows a perfect search experiment, positive A_i shows more injected mass than is recovered, while negative AI shows more recovering mass than injected. When A_i moves farther from 0 the quality of the search experiment gets worse.

$$A_i = \frac{c_{in} - c_T}{c_{in}} \text{ adopted from [8]} \quad (5)$$

2.4. Mean residence time

Calculation of average residence time in karst aquifers uses equation (6), and the standard deviation obtained is estimated by equation (7).

$$\bar{t} = \frac{\int_0^{\infty} t c(t) Q(t) dt}{\int_0^{\infty} c(t) Q(t) dt} \quad [2] \quad (6)$$

$$\sigma_t^2 = \frac{\int_0^{\infty} (t - \bar{t})^2 c(t) Q(t) dt}{\int_0^{\infty} c(t) Q(t) dt} \quad [4] \quad (7)$$

2.5. Skewness and kurtosis residence time

Skewness is the slope of the curve that results from recording data at the recording station, which is calculated using equation (8). Skewness is calculated to determine the slope of the curve, whether the curve is symmetrical, leaning right or leaning left. Whereas kurtosis is the degree of deterioration of the BCT curve, which is estimated using equation (10).

$$\gamma_t = \frac{\int_0^{\infty} (t - \bar{t})^3 c(t) Q(t) dt}{\sigma_t^3 \int_0^{\infty} c(t) Q(t) dt} \quad [4] \quad (8)$$

$$K_t = \frac{\int_0^{\infty} (t - \bar{t})^4 c(t) Q(t) dt}{\sigma_t^4 \int_0^{\infty} c(t) Q(t) dt} \quad [4] \quad (9)$$

Mean transfer velocity

Calculation of average tracer speed is estimated using equation (10) which is a function of the division between the distance traveled by tracer and the average residence time calculated. The distance traversed by the tracer (x_s) can be determined from drawing a straight line from the injection location to the recording location in the spring, then multiplying it with Sd as a function of sinuosity because the straight line is considered unrealistic and must be corrected. Equation (11). The standard deviation or standard deviation of the average velocity estimate is estimated by equation (12)

$$\bar{v} = \frac{x}{(t - t_{inf})} \quad [9] \quad (10)$$

$$\bar{v} = \frac{x t_{inf}}{(t - t_{inf}) t} \quad (11)$$

$$\sigma_v = \sqrt{\frac{\int_0^{\infty} \left[\left(\frac{x_s}{t - \frac{t_2}{2}} - \frac{x_s}{\bar{t} - \frac{t_2}{2}} \right)^2 c(t) Q(t) dt \right]}{\int_0^{\infty} c(t) Q(t) dt}} \quad (12)$$

2.6. Longitudinal dispersion

The longitudinal dispersion coefficient is a measure of the degree to which concentrated tracer mass spreads along the flow path [4]. This is defined as the rate of temporal change in tracer cloud variants [10].

Non-reactive traces which dissolve then are released into the flow, behaving in the same way as actual water particles. Therefore, the size of the movement of the tracer and its dispersion characteristics will be a measure of the movement of the fluid element in the flow. It can be further noted that the dispersion and mixing of the traps in the receiving stream occur in all three dimensions, although vertical mixing usually occurs before lateral mixing, depending on flow characteristics and speed variations. Longitudinal dispersion, continues indefinitely and is a dispersion component of the main principle [8]. Longitudinal dispersions for karst channels are estimated by equation (13).

$$D_L = \left(\sigma_t^2 - \frac{t_2}{12} \right) \frac{v^3}{2x_s} \quad [11] \quad (13)$$

2.7. Geometry of flow-channel

Flow-channel volume is generally an integral function of the discharge for each recording time interval, or when the discharge is stable as in the Kalisirah Springs. Aquifer volume is calculated based on the multiplication of the discharge with the average residence time as in equation (14).

$$V = \int_0^{\bar{t}} Q dt \quad [12] \quad (14)$$

The cross-sectional area is a division function between the volume of the system and the distance traveled by the tracer or according to equation (15).

$$A = \frac{V}{x_s} \quad [2] \quad (15)$$

Assuming a cylinder flow channel, it is possible to estimate the flow channel diameter of BTC, because the volume of the system has been estimated, the calculation of flow diameter uses equation (16).

$$D_C = 2 \sqrt{\frac{A}{\pi}} \quad [2] \quad (16)$$

If an open channel flow is assumed to occur in a flow channel, then the hydraulic depth can be estimated by equation (17), which is a function of division between the cross sectional area of the channel and the diameter of the flow channel.

$$D_H = \frac{A}{D_C} \quad [2] \quad (17)$$

Empirical fluid dynamics

The pecllet number is a dimensionless number which is the ratio of the rate of advection of physical quantity by flow to the diffusion rate of the same quantity and driven by the appropriate gradient. The pecllet number below 0.4 indicates diffusion control; 0.4-0.6 shows that diffusion and advection are in transition; and when pecllet > 6.0 indicates advection control [13]. In most examples of media from transporting solutes in karst channels, the Peclet value will be greater than 6.0 [2].

$$Pe = \frac{\bar{v} x_s}{D_{xs}} \quad [2] \quad (18)$$

This equation is commonly used to explain flow behavior, and Reynolds number provides a means to determine whether the flow is laminar or turbulent, the smaller the Reynolds number, the more obstacles to flow, meaning the smaller the Reynolds number, the flow is turbulent. While Froude numbers are used to determine whether the flow is subcritical or supercritical. If $N_f < 1$, then the flow is

said to be sub critical (slow, calm), for the price of $N_F = 1$, then the flow is said to be critical, if the price is $N_F > 1$, then the flow is called super critical (fast) [14].

$$N_R = \frac{\rho \bar{v} D_C}{\mu} [2] \quad (19)$$

$$N_F = \frac{\bar{v}}{\sqrt{g D_H}} [2] \quad (20)$$

3. Result and discussion

3.1. Qualitative observations

The trace substances used in the tracing test consisted of 2 types, Rhodamin B, and Tinopal, 150 grams and 250 grams respectively in powder form. This fluorescent powder can be used in the study area because the discharge condition is above the minimum threshold [15]. Rhodamin B is used to facilitate qualitative monitoring because the colors are easily detected by the human eye, while Tinopal is used specifically in quantitative analysis. Both are recorded by a Fluorometer installed in the Kalisirah Springs. Tracer injection is carried out directly into the subterranean stream of Goa Pucung on Sunday, September 23, 2018 at 21:55 WIB for Tinopal respectively, and 22:05 for Rhodamine B. The solvent has different purity and sometimes not according to the purity stated on the packaging of tracer substances in the market. Then from 250 grams of Tinopal to be injected it only has a purity of 60% of it which is 150 grams, the next mixed into a container and dissolved with 10L of water into a solution with a concentration of 15 grams / l, or 15000 mg / l.

A qualitative tracer test is positive if a dye is detected at one or more monitoring points [15]. Water discoloration occurs only in 3 observation points, namely in the subterranean stream in Goa Jeblosan, the Kaliwinong Karst stream, and the Kalisirah spring. This information explains the connectivity between the three objects and the subterranean stream in Goa Pucung. Observations in Goa Jeblosan show that the red color is evenly distributed in the main stream of subterranean streams which shows a direct connection between the subterranean stream in Goa Pucung and Goa Jeblosan. Observation in Goa Kaliwinong shows that the red color coming out of one of the incoming sub-streams fills the main stream, this indicates that there are other affixes that fill the main stream leading to the Kalisirah Springs.

Tabel 1. Objects and results of visual observations of water tracing

No	Karst Phenomenon	Observation	Information
1	Candi Cave	Negative	-
2	Jeblosan Cave	Positive	Observed at 1.30 p.m.
3	Kaliwinong Cave	Positive	Observed at 5.00 p.m. in sub-flow, not main stream
4	Jumbleng Spring	Negative	-
5	Kalisirah Spring	Positive	Observed at 5.30 p.m.
6	Krowokan Spring	Negative	-
7	Teleng Spring	Negative	-
8	Ledeng Spring	Negative	-
9	Kalirong Spring	Negative	-
10	Sukun Spring (1,2,3)	Negative	-

Source: Results of participatory data collection, September 24, 2018

3.2. Analysis of breakthrough curve from tracing test

Recording concentration data on fluorometer using a certain time interval. Fluorometer installed in Kalisirah Springs records both types of tracer substances injected into the subterranean stream Pucung Cave, but in quantitative analysis the researchers only used concentrated data recordings from Tinopal because of more pouring concentrations. The fluorometer is set to record periodically every 5 minutes, but because of the large amount of concentrated data for a relatively long time, the data will be presented at longer intervals of 15 minutes, in a period of 57.75 hours. The data presented starts at the same time as the injection, at 9.55 p.m. Tinopal concentration data recorded by fluorometer has ppb units (parts per billion), then it will be converted into mg / l to facilitate calculations. Concentration of data recording or sampling must coincide with measurement of discharge, to anticipate fluctuating

discharge, except for springs which have a constant discharge. Kalisirah springs have a constant discharge, and from several measurements obtained a discharge of 269.58 l / sec. The results of fluorometer recording are presented in Figure 3..

3.3. Background correction

All field measurements need to be improved by reducing the initial concentration of the measured concentration. So from the initial data fluorometer must be corrected first to produce accurate concentration data. The concentration of this initial tracer is obtained from doing some water sampling and the average concentration of natural fluorescent contained in water from some of these samples. In this study, the initial concentration data obtained from the results of recording the initial concentration of fluorometer until injection of tracer substances, namely from 5.20 p.m. -9.50 p.m. there are 25 times the concentration recording, and the average value of the initial concentration is 0.00001 mg / l.

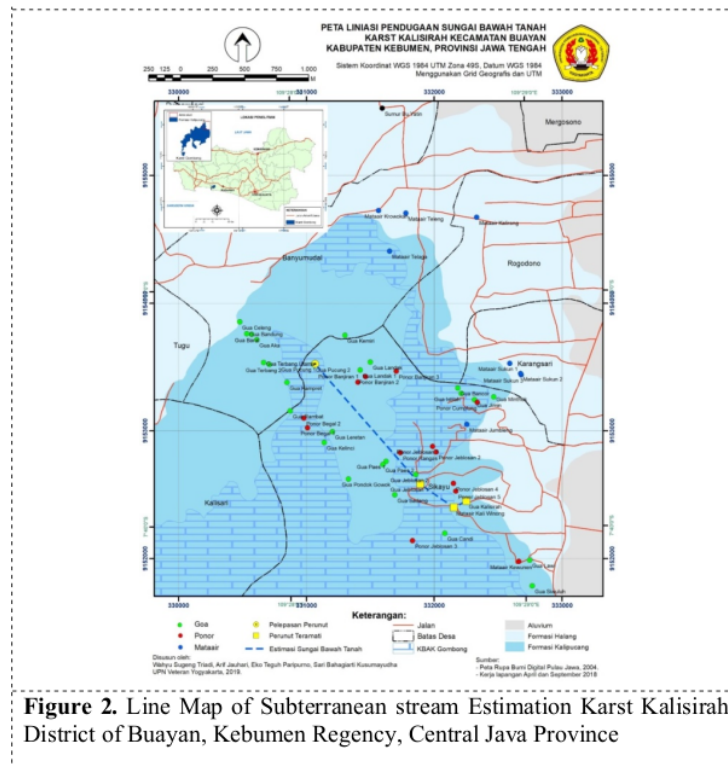
3.4. Tracer concentration recovery

The calculation results obtained from the concentration concentration recorded by the fluorometer in the Kalisirah spring at 3.926.35 mg / l from the Tinopal concentration which is injected into the Goa Pucung subterranean stream which is 15,000 mg / l, meaning that Tinopal's concentration recovery reaches 26.18%. From these results it can be concluded that the subterranean stream channel of Kalisirah has divergence or separation of conduit aisles resulting in flow separation. Assuming that concentrations that are not fully recovered reflect the same amount of mass in units of weight.

The total recovery of tracer concentration is calculated using equation (4), and the same value is obtained by estimating the recovery of concentration tracer in the Kalisirah springs. The total recovery of tracer concentration cannot be maximized because in this study only recording on one downgradient receptor or one recording station. Therefore the recovery of the total tracer does not reach 100% or the tracer that comes out in another spring cannot be recorded in its entirety. This also affects the quality of tracer recovery. Total recovery (M_T) is the same as recovery in the Kalisirah (M_O) spring, which is 26.18%.

The value of recovery quality in Kalisirah Springs is 0.98 indicating that the recovered tracer is less than the injected injector, and the AI value that is farther away from 0 indicates that the recovery quality is relatively poor, this is because the trace concentration that can be recovered is only a small part of the total substance Tracer injected.

Discharge recovery calculations are also important for knowing the characteristics of karst conduits. From the results of measurements of discharge in Goa Pucung or location of injection tracer substances of 6 l / s and the measurement of discharge in Kalisirah Springs as a monitoring outlet of 269.58 l / s, the recovery of discharges in the Kalisirah Springs is 4493%. From the very large recovery value it was concluded that the Kalisirah subterranean stream channel had convergence of flows or the influx of flow from different systems to the Kalisirah subterranean stream.



Karst Kalisirah subterranean stream network type is based on discharge and tracer recovery is type IV (Figure 1). This type IV karst network has convergence and divergence in flow in karst networks, this is in line with the **1** approach to recovery of concentration and recovery of **1** concentrations. The karst networks of Type IVa and IVb further complicate the determination of flow because of the significant loss of dye and the identified exit points will have a discharge level that may be less than, greater than, or equal to the inflow point [2].

3.5. Mean residence time

Tracer substances which are inserted into subterranean streams have a residence time before being monitored to the spring, the estimated average residence time of tracer in the aquifer is calculated by equation (6) and the value of 86813.06 seconds or 24.11 hours is obtained. Estimates obtained of course must be calculated the standard deviation (deviasi standard) because in this analysis using the sampling method. Standard outline is the most common statistical distribution measure, or in other words the standard deviation measures the average distance of data deviations from time points measured from the average value of the residence time of the tracer. The standard deviation is estimated by equation (7) and the value is 0.182 hours, or 86813.06 seconds.

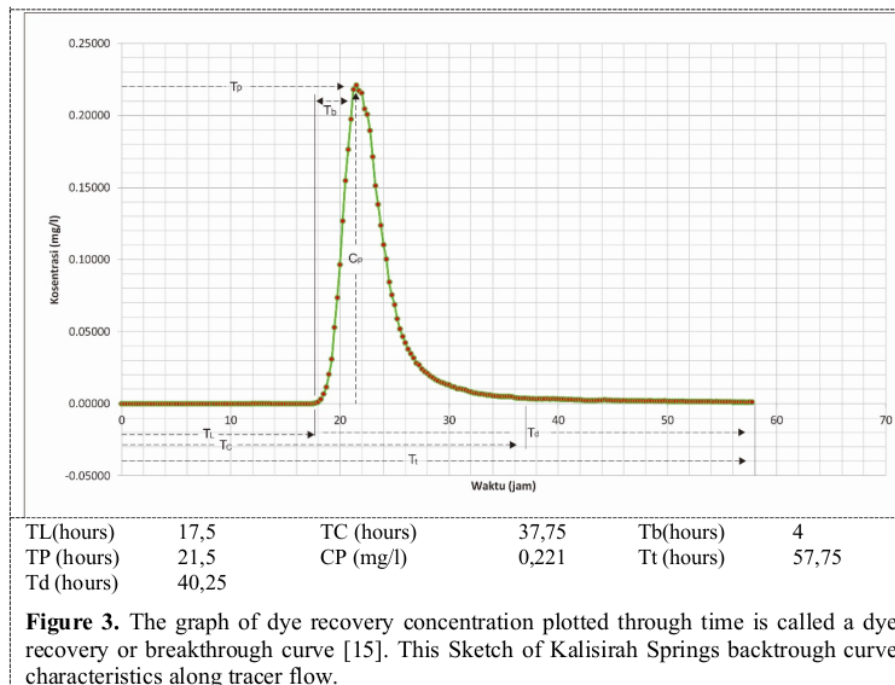


Figure 3. The graph of dye recovery concentration plotted through time is called a dye recovery or breakthrough curve [15]. This Sketch of Kalisirah Springs backtrough curve characteristics along tracer flow.

Skewness is calculated to determine the slope of the curve, whether the curve is symmetrical, leaning right or leaning left. From the skewness calculation using equation (8) the value of 94.73 is obtained, which means the curve is leaning to the right.

Kurtosis is the degree of convergence of the BCT curve, which is estimated using equation (9), and it is found that 13274.87 means that the curve is relatively sharp.

3.6. Mean transfer velocity

The calculation of mean transfer velocity gets an estimated average speed of 1,91 km/days, or 79.62 m/hour, or 0.02 m/sec, indicating that the velocity of the tracer is relatively slow, the mean transfer velocity value is normal for karstic aquifers, because the flow velocity for karstic aquifers is usually in the range of 0.2-7 km/day [15]. But the speed must also be corrected by multiplying x by t_{inf} and dividing it by multiplying the difference between t average and t_{inf} with t average, which produces a value of 0, which means that there is no difference at all from the average speed, the deviation standard 0.00012 m / sec.

Estimation Longitudinal dispersion is calculated based on equation (13) and the value is 4.36 m² / hour. This means that the spread of tracer is relatively slow in spreading horizontally in the subterranean stream.

3.7. Geometry of flow-channel

The results of the calculation of the volume of aquifers with equation (14) get a value of 23.403,064.49 liters or 23.403.06 m³. The volume in the Kalisirah karst aquifer can be classified as a relatively large volume.

1. Calculation of estimation of aquifer crossing area with equation (15) is 12.19 m².

Assuming a cylinder flow channel, it is possible to estimate the flow channel diameter of BTC, because the volume of the system has been estimated, the calculation of flow diameter uses equation (16), then the flow diameter (D_C) is generated at 3.94 m and the radius of 1.97 m.

If the open channel flow is assumed to occur in the flow channel then the hydraulic depth can be estimated by equation (17), which is a collateral function between the cross-sectional area and the flow channel diameter, then the value (D_H) 3,094 m

3.8. Empirical fluid dynamics models

In calculating the pecelet number equation (19) a number of 35046.96 is obtained which indicates that flow is more controlled by advection than diffusion [14]. Substitution of peak flow velocity can be considered, but most likely will produce too high a Peclet number [2].

The Reynolds number in the calculation is 18.21, which means that the N_R value gets smaller, the more obstacles to flow, or the flow is turbulent. While the Freud number is 14.45 means $N_F > 1$, the flow is supercritical or the flow flows quickly.

4. Conclusions

From the results of the discussion and analysis that have been presented previously, they are concluded to be several important points, as follows:

- Springs that have a direct relationship with the Goa Pucung subterranean system are the Karst Window Springs Jeblosan, sub-streams from Karst Springs, Kaliwinong Springs, and Kalisirah Springs, which are marked by changes in water color to pink.
- Recovery of tracer concentrations of 26.18% indicates a convergence of the Kalisirah subterranean stream that has not yet been known and recovered as a whole. Discharge recovery in Kalisirah Springs reaches 44.93%, indicating differ to the Kalisirah subterranean stream.
- The Kalsirah subterranean stream is included in the type IV karst network, where there is flow divergence and convergence, from different discharge values from the injection point and monitoring springs, and also the communication of the discharge out in the springs is less than the injected concentration. The injected tracer substance has an average residence time of 24,11 hours, with an average flow rate of 79.62 m / hours, and a longitudinal dispersion speed of 4,36 m² / hours.
- The geometry of the Kalisirahsubterranean stream is estimated to have a flow volume of 23,403.06 m³ with a cross sectional area of 3,34 m, and a hydraulic depth of 3.09 m.
- The pecelet number is estimated to reach 35046.96 which indicates the flow of tracer substances in the Kalisirahsubterranean stream is more controlled by advection than diffusion.
- The Reynolds number is estimated to reach 18.21 which indicates that the flow is turbulent, while the Froude 14.45 number value indicates the flow is supercritical or flows quickly.

5. Recommendations

Based on the results of research using the fluorescent tracing test qualitatively and quantitatively it needs to be done and it is hoped that it can be a reference or recommendation for related parties so that the area around the Kalisirah Springs and its entire network can be included in the Gombong Karst Area (KBAK).

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