A groundwater tracing investigation to determine Kalisirah Karst Springs catchment area, Kebumen Regency, Central Java

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Abstract. Water tracing was conducted at Karangbolong Karst as a rapid assessment of the Kalisirah spring hydrological characteristics. This study was conducted to determine the movement of underground flow and the estimation of the Catchment Area using the Todd Nomogram and field observations. The results of flow tracing tests conducted in Pocung Cave indicate that there is underground river network connectivity between Pocung Cave, Jeblosan Sinkhole and Kalisirah Springs. Based on topographic survey and flow tracing test, the calculation of the estimated area of the Kalisirah catchment area is 180 Ha. The results were also validate using other parameters, namely flowrate and rainfall in the research location using Todd Nomogram. The estimated area of the Kalisirah catchment area with the Todd Nomogram is 189.2 Ha. The calculation of the estimated area of Kalisirah catchment area based on topographic survey and water tracing is relevant with the estimated area with Todd Nomogram. Groundwater tracing investigation can be used to determine karst spring catchment area, as a preliminary study to understanding the karst hydrology.

1. Introduction
Karst is a landscape characterized by a lack of surface flow and frequent subsurface flow, also characterized by a unique hydrology [1, 2]. According to [1], as much as 20% - 25% of the world's population depends on clean water stored by karstic aquifers. Karangbolong karst is one of karst areas of Java typified by conical karst morphology [3, 4]. Water stored in the karst aquifers released both as spring and underground river system [5]. In Sikayu Village, Karangbolong Karst Area, Kebumen Regency, the community is entirely dependent on karst springs to meet their clean water needs. The main karst springs in this area is Kalisirah. Karst aquifers in this area have the threat of damage caused by limestone mining activities, agriculture, and infrastructure development. In Indonesia, conflicts over the use of limestone and conservation of water resources often occur [6]. Meanwhile, waste from human activities (agriculture and domestic) threatens the water quality because karstic aquifers have a characteristic response to rapid recharges [7].

The Ministry of Energy and Mineral Resources (ESDM), Republic of Indonesia established Minister of Energy and Mineral Resources Regulation No. 17/2012 on “Establishing Karst Landscape
Areas to protect karst areas in Indonesia”. This regulation defines protected karst areas as landscapes that have unique exokarst-endocarst characteristics and hydrological functions.

Water tracing is an appropriate method to be used in rapid assessment of the karst aquifer hydrological characteristics. This method can provide information about the movement of water in rock cracks that are not accessible [8]. Flow tracing combined with field observations can be used as a basis for determining the catchment boundary of a karst spring [9, 10, 11].

This study intends to find out the boundary of catchment area from Kalisirah spring located in the Karst Gombong Region, Kebumen Regency, Central Java Province. The method used was the flow tracing test and field observation, that validated using Todd Nomogram. This study is a preliminary study in research related to karst hydrology.

2. Methods
2.1 Field observation
Field observations were carried out by visiting all existing exokarst-endokarst formations from previous research information and new information from the public. The coordinates were recorded using a GPS (Global Positioning System). Documentation in the form of photos and videos was also done.

2.2 The community involvement and participation in tracking trials
The community was fully involved in the process of water tracing. The involvement includes the initial coordination before carrying out the traceability test, the process of pouring the tracer at each injection point, as well as monitoring the point where the tracer is released.

2.3 Water tracing
The water tracing method is carried out using continuous sampling and integrative sampling techniques [12]. Continuous sampling is a tracer capture method that was done automatically (every 5 minutes in this study) using a fluorometer. Figure 1 (a) presents the fluorometer logger tool used in this study, namely FL-30 and FL-24 [13]. Integrative sampling is a passive / qualitative method that only shows a tracer substance detected or not detected (positive / negative). This method was carried out by installing charcoal bags in several observation areas (Figure 1b). Charcoal bag analysis was then carried out in the laboratory using a FL-30 fluorometer (Figure 2).

Tracer substances that are used were artificial tracers which had conservative properties so that they were not harmful to the environment [12], as can be seen in Table 1. This study used tracers in the form of uranine and sulforhodamine B. Both have soluble properties, are harmless, and are easily detected. Uranine has green characteristics while sulforhodamine B is red when dissolved in water.

![Figure 1](image-url)  
**Figure 1.** (a) (b) Fluorometer GGUN-FL24 and FL30 and (b) Installation of Charcoal Bags in Springs
Figure 2. Charcoal Analysis in the Laboratory

Table 1. Characteristics of Various Tracer Substances

| Group        | Tracer name (CAS RN) | Detection limit | General problems                              | Specific problem          |
|--------------|----------------------|-----------------|-----------------------------------------------|---------------------------|
| fluorescent dyes | Uranine (518-47-8)   | $10^{-3}$μg/L   | Sensitive to light and strong oxidants.       | -                         |
|              | Eosin (17372-87-1)   | $10^{-2}$μg/L   | Ecotoxicological concerns                     | -                         |
|              | Amidorhodamine G (5873-16-5) | $10^{-3}$μg/L | Analytical interferences between fluorescent dyes or similar optical properties. | -                         |
|              | Sulforhodamine B (3520-42-1) | $10^{-3}$μg/L | -                                             | -                         |
|              | Rhodamine WT (37299-88-8) | $10^{-3}$μg/L | -                                             | -                         |
|              | Pyranine (6358-69-6) | $10^{-1}$μg/L   | -                                             | -                         |
|              | Naphthionate (130-13-2) | $10^{-1}$μg/L | -                                             | -                         |
|              | Tinopal CBS-X (27344-41-8) | $10^{-1}$μg/L | -                                             | -                         |
|             | Sodium (only cations) | with ICP-MS     | Analytical (optical)                          | Biodegradable             |
|             | Potassium            | (Sr>K>Na>Li)    | Ecotoxicological concerns                     | Genotoxic                 |
|             | Lithium              | $10^{-3}$-0,1μg/L| Sorption of cations                           | Analytical (optical)      |
|             | Sisronium            |                 | Variable and sometimes                        | Interferences with DOC    |
|             | Chloride             | With IC (cations and 0,1 mg/L) | high natural background, particuly for NA and Cl |                           |
|             | Bromine              |                 | Can form toxic compounds                      |                           |
|             | Iodide               |                 | Bio-chemically unstable                       |                           |
|             | Fluorescent microspheres |             | Detection of single particles                | Analysis within 24h       |
|             | Bacteria             |                 | Analysis is relatively time consuming         | -                         |
|             | Bacteriophages       |                 | Prone to filtration                           | -                         |

Source [12]

2.4 Delineation of the spring catchment area

Determination of the catchment area in the karst region was based on a subsurface flow and surface flow system. The outlets of the catchment area are streams that come out of underground springs or rivers. The flow system in question was analyzed based on water tracing carried out in the cave / ponor / sinkhole. Delineation of the catchment area boundaries was then based on the appearance of the igir or karst hill that borders it.

Catchment area validation was carried out using Todd Nomogram [14]. Todd Nomogram can be used to determine the extent of catchment area using the concept of the relationship between discharge at an outlet (spring) with an annual rainfall affix (RC). Table 2 shows the annual affix value based on its geological formation. The area of the catchment was obtained by plotting the rainfall with the nomogram (Figure 3). Research on the validation of the karst springs catchment area using a Todd Nomogram) in Indonesia has been carried out including [15] and [16].
3. Result and Discussion

3.1 Characteristics of exokarst and endokarst

Field observations that had been done show that there were 15 exokarst and endocarst formations around the study area. The formation consisted of five springs, eight caves, and two ponors. The absolute location of each of these formations is shown in Table 3.

Table 3. Absolute Location of Exokarst and Endokarst Formations in the Vicinity of the Study Area

| No | Types of Exokarst / Endokarst Formations | Name     | X     | Y     |
|----|----------------------------------------|----------|-------|-------|
| 1  | Spring                                 | Kali Sirah | 332243 | 9152457 |
| 2  | Spring                                 | Jumbleng | 332253 | 9153052 |
| 3  | Spring                                 | Rangas   | 331740 | 9152834 |
| 4  | Spring                                 | Sukun 1  | 332674 | 9153449 |
| 5  | Spring                                 | Sukun 2  | 332589 | 9153511 |
| 6  | Cave                                   | Pocung   | 331032 | 9153523 |
| 7  | Cave                                   | Candi    | 332069 | 9152182 |
| 8  | Cave                                   | Jeblosan | 331887 | 9152601 |
| 9  | Cave                                   | Sugiharjo | 331746 | 9153500 |
| 10 | Cave                                   | Banteng  | 331846 | 9153517 |
| 11 | Cave                                   | Banteng Kecil | 331969 | 9153437 |
| 12 | Cave                                   | Banteng Kelapa | 331990 | 9153365 |
| 13 | Cave                                   | Cocor 1  | 331850 | 9153225 |
| 14 | Cave                                   | Cocor 2  | 332185 | 9153335 |
| 15 | Ponor                                  | Banjiran | 331468 | 9153424 |
| 16 | Ponor                                  | Sumur Bor | 331475 | 9153351 |

Source: Field observation (2019)
Pocung Cave is located in Jeblosan Hamlet, Sikayu Village, Buayan District. Pocung Cave is located in the upper reaches. Pocung Cave is a vertical cave that is still active with a perennial spring at the bottom. The use of land around the Pocung Cave is as a garden.

Jeblosan Cave is located in Sikayu Village, Buayan District. In Jeblosan Cave, there are springs that come from underground streams and come back to the surface (resurgence). The spring in Jeblosan Cave is a spring that flows throughout the year and is connected to the Kalisirah Spring. Jeblosan Cave is located in the form of residential land use. Water from Jeblosan Cave is used to meet the domestic needs of the surrounding residents. Water retrieval in Jeblosan Cave is done by using pipes and water pumps which are then channeled to people's homes.

Kalisirah spring is located in Jeblosan Hamlet, Sikayu Village, Buayan District. Kalisirah spring is located near the residential area. This spring flows throughout the year / perennial with a fairly large discharge. Water conditions tend to be clear throughout the year and turbid during floods. Kalisirah springs are used by the surrounding community as a source of clean water for meeting domestic needs and agricultural irrigation. Kalisirah springs are also used as a water source for PDAM Sikayu.

3.2 Traceability test for Pocung Cave - Jeblosan Spring - Kalisirah Spring
Traceability test is one method that can be used to determine aquifer characteristics. [18] states that tracing tests carried out in caves or ponors can explain underground river systems that are inaccessible to humans. Trace test results are curves called breakthrough curves or hydrocemograph tracking tests. Hydrocemograph is a curve that shows the relationship between the concentration of tracer substances to the time that can reflect the condition of the karst aquifer.

Water tracing is done by pouring tracer substances in the form of uranine and sulforhodamine B in Pocung Cave. The pouring of sulforhodamineB (red) was carried out on June 15, 2019 at 23.45 West Indonesia Time, while the uranine (green) substance in Pocung Cave was carried out on June 16, 2019 at 00.05 West Indonesia Time. The results of water tracing show that there is connectivity or connection between the underground flow from the Pocung Cave to Jeblosan Springs. The water tracing curve with uranine is shown in Figure 4, while the water tracing curve with sulforhodamine B is shown in Figure 5.

Figure 4. Water Tracing Results Curve with Uranine Substance

Figure 5. Tracing Results Curve with SulforhodamineB

Fluorometer installation is used to record the tracer set with a recording interval of 5 minutes. Fluorometer at Mataair Jeblosan is on on June 15, 2019 at 16:40 WIB and is released or turned off on June 20, 2019 at 12.25 WIB. The results of water tracing in the Pocung- spring Jeblosan-Mata Kalisirah Cave system are shown in tables 4 and 5. Map of the flow direction of the Kalungah Pocung-Springs based on the tracing results is presented in Figure 11. Fluorometer was also installed in one of the Nogoraji wells. The results show that there is no underground flow connectivity from the Pocung Cave to the well according to Figure 6.
**Table 4.** Characteristics of Tracer Substances Appearance in the Pocung-Kalisirah System

| Parameter                      | Unir | Uranine | SulforhodamineB |
|-------------------------------|------|---------|-----------------|
| First detected                | minute | 450     | 450             |
| Time to the top (Tp)          | minute | 120     | 125             |
| Time recovered (recession)    | Day   | 3       | 3               |

Source: Data processing (2019)

**Table 5.** Tracing Results of the Pocung Cave System - Kalisirah Springs

| No. | Location of injection | Tracer Substance | Time of Injection | Flat Distance | Information |
|-----|-----------------------|------------------|-------------------|---------------|-------------|
| 1   | Pocung Cave           | Uranine          | 16 June 2019 at 00.05 WIB | Pocung Cave – Jeblosan : 1,3 km, Jeblosan - Kali Winong: 347 m, Kali Winong-Kalisirah : 97 m | Visually seen at Luweng Jeblosan on June 16, 2019 around 08.30 West Indonesia Time, in Kali Winong around 09.30 West Indonesia Time, and at Kalisirah Spring around 10.30 West Indonesia Time. |
| 2   | Pocung Cave           | SulforhodamineB  | 15 June 2019 at 23.45 WIB | Pocung Cave – Jeblosan : 1,3 km, Jeblosan - Kali Winong: 347 m, Kali Winong-Kalisirah : 97 m | Detected at Luweng Jeblosan on June 16, 2019 around 08.30 West Indonesia Time, in Kali Winong around 09.30 West Indonesia Time, and at Kalisirah Spring around 10.30 West Indonesia Time. |

Source: Data Processing (2019)

Monitoring Tracing is not only done by installing a fluorometer device, but also by installing a passive detector using activated carbon. Installation of activated carbon is carried out in Iwil-Iwil spring, Pakis Renda spring, and Karst window Candi-Winong. The three locations of activated carbon installation showed negative results or there was no connection with the Pocung Cave underground flow. The results of the reading of activated carbon are shown in Figures 7, 8 and 9.

![Figure 6. Results of Water Tracing by Monitoring in Nogoraji Well](image)

![Figure 7. Activated Carbon Readings at Iwil-Iwil Springs](image)
3.3 The estimation of catchment area

Limitation of the catchment area in the karst landform needs to pay attention to the distribution of caves, springs, sinkholes, and sinking streams. Figure 10 shows the estimated catchment area boundaries of the Kalisirah Spring based on a topographical approach and tracer test results. The tracing results also show that there is a system difference between Jumbleng Spring and Kalisirah Spring, so that both have different catchment areas. The main system in the Kalisirah catchment area is Pocung Cave which empties the Jeblosan Cave and then reaches Kalisirah Springs. The area of Kalisirah catchment area based on water tracing and topographic survey are 180 ha.
sedimentary limestone / limestone. Table 2 shows the annual affix value based on its geological formation, so that the annual affix value of the study area is 1,701 mm/year.

Topographic catchment area boundary validation and field surveys are carried out using a Todd Nomogram. Todd Nomogram is used with the concept of the relationship between outlet / spring discharge with annual recharge to obtain the area of the catchment. Discharge at Kalisirah spring outlets measured in the field is 89.74 liters/sec. Based on the annual recharge value and flowrate at Kalisirah Springs, the catchment area according to the Todd Nomogram is 189.2 ha (Figure 11). This value does not differ greatly from topographic determination of catchment area and field surveys (180 ha).

![Todd Nomogram to Determine the Size of the Kalisirah Spring Catchment Area](image)

**Figure 11.** Todd Nomogram to Determine the Size of the Kalisirah Spring Catchment Area

4. Conclusion
Trace test results from the Pocung Cave show that there was underground river flow connectivity, namely from the Pocung Cave --- Jeblosan Sinkhole --- Winong Cave --- Kalisirah Spring. Trace test results show that Kalisirah Water Catchment Area originates from Hulu Pocung which empowers Luweng Jeblosan and then reaches Kalisirah Spring. The flow system that was analyzed based on water tracing are then elaborated with topographic surveys to determine the boundaries of Kalisirah Spring catchment area. The area of the Kalisirah Spring catchment area based on calculations that have been carried out and have been validated using Todd Nomogram is 180 ha.

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