

RESEARCH ARTICLE

OPEN ACCESS

Riset Journal of Geology
Mengkarang (2026) Vol. 01, No.
1, 25-32

DOI: <https://doi.org/10.22437/jogm.v1i1.53583>

Keywords:

karst aquifer
spring discharge
fracture-controlled flow
Sodong Spring
sustainable water resources

Article history:

Received: 25 Feb 2026
Revised: 03 Mar 2026
Accepted: 08 Mar 2026

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Analysis of Spring Discharge Quantity in a Fractured Karst Aquifer of The Klapanunggal Formation, Ligarmukti Village, Bogor Regency, West Java

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Abstract

Indonesia has karst areas spread across Sumatra, Java, Sulawesi, Nusa Tenggara, Maluku, and West Irian. On Java Island, there is one of the main karst areas, namely the Klapanunggal Formation in Ligarmukti Village which is our research area. Karst areas are able to store and drain water (aquifer zones) due to the dissolution process in carbonate rocks that have the potential to be a source of spring water. There are several karst media aquifer springs in the study area, one of which is Sodong Spring which drains water through fracture media. The existence of Sodong Springs can meet the raw needs of the surrounding community and become a source of income from the tourism sector. In connection with this, this study was conducted to test the quantity of discharge in Sodong Spring which can always meet the needs of the community until now even in dry conditions. The conduct of this research aims to develop the use of Sodong Springs which supports the lives of the surrounding community. In this case, the community will more effectively utilize the source of Sodong Spring. The method to be carried out in this study is a quantitative method based on hydrogeological observations. Sodong spring water will be able to be developed for utilization because of the very high discharge. The results of this research will later become an indicator of the development of water use in the Ligarmukti Village area that can be used sustainably.

Citation:

Zhafirah, A., Haurissa, M. N., & Terloit, I. M. (2026). Analysis of Spring Discharge Quantity in a Fractured Karst Aquifer of the Klapanunggal Formation, Ligarmukti Village, Bogor Regency, West Java. *Journal of Geology Mengkarang*, 1(1), 25-32. <https://doi.org/10.22437/jogm.v1i1.53583>

1. Introduction

The government's provision of clean water across rural and urban areas is uneven, particularly in karst areas, where water services remain inadequate. Areas with karst topography have hydrological systems heavily influenced by secondary porosity resulting from the dissolution of carbonate rock material (Cahyadi, Pratiwi, & Fatchurohman, 2013). Karst areas may appear dry on the surface, but they have the ability to capture or trap water beneath the surface.

Ligarmukti Village is located in the Klapanunggal Formation karst area, which is rich in springs with varying discharge rates, capable of meeting the village community's raw water needs. The spring with the largest discharge in Ligarmukti Village is Sodong Spring, which is used for water and tourism purposes, and most of its water is distributed outside the Village through the Regional Water Company (PDAM) (Maria, Purwoarminta, & Lubis, 2016).

Approximately 93% of the residents of Ligarmukti Village use springs and dug wells for their domestic water needs (Hartana et al., 2014). Even during the dry season, the Sodong spring consistently supplies the community's needs. This demonstrates that the resilience of Ligarmukti Village's water resources depends heavily on groundwater flow and quality.

The Sodong spring in Ligarmukti Village has characteristics that require quantitative analysis, including spring discharge, water availability continuity, drainage system, and distance to homes. These spring characteristics form the basis for determining the clean water network that supports water resource availability (Maria et al., 2017).

This research was conducted to improve the utilization of the Sodong spring, which supports the livelihoods of the surrounding community, and to facilitate proper management of its water supply. It is hoped that the results of this study will provide input for the government and community in maintaining the potential of water resources so that the Sodong spring can continue to meet the raw water needs of Ligarmukti Village.

2. Materials and methods**Regional Geology**

Physiographically, Van Bemmelen (1949) divided West Java into five physiographic zones:

1. Jakarta Coastal Lowland Zone
2. Bogor Zone
3. Bandung Zone
4. Bayah Mountains Zone
5. South West Java Mountains Zone

In research area, which includes Ligarmukti Village in the Klapanunggal Formation, is included in the Bogor Zone. This Bogor Zone encompasses the areas of Rangkasbitung, Bogor, Subang, Sumedang, and Bumiayu. The study area is classified as part of the Bogor Basin Mandala, which changed throughout the Tertiary-Quaternary era (Martodjojo, 1984). During the Oligocene-Miocene, increased volcanic activity occurred, leading to the first depositional cycle, characterized by the spread of volcanic material aided by gravity flow. Then, during the Middle Miocene, shallowing occurred in the Bogor Basin, leading to the deposition of local turbidite facies due to the presence of slopes to the south of the basin in the Late Miocene. Unconformably, alluvial deposits of Quaternary volcanic rocks and alluvium are deposited on the upper part.

The study area is composed of limestone of the Klapanunggal Formation, as well as marl and intercalated clay and quartz of the Jatiluhur Formation. The Klapanunggal Formation is of the same age as the Lengkong and Bojonglopang Formations in the southern mountain belt and intersects with the lower Jatiluhur Formation, which is of Early Miocene age. The hilly areas consist of limestone of the Klapanunggal Formation, while the inland areas consist of clay deposits of the Jatiluhur Formation.

Describe where and how you obtained your data. Explain the criteria and methods used for selecting samples. List any tools or instruments used to collect data.

Outline the overall design of your study. Detail the step-by-step procedures followed during the experiment. Mention any software tools or programs used for data analysis. Discuss any potential limitations or biases in your study. Cite any established methods followed.

The geological structures developing in the study area include faults, folds, lineaments, and joints found in Oligocene-Quaternary rocks. The faults encountered are strike-slip and normal faults, generally trending north-south, southwest-northeast, and northwest-southeast. In addition, there are anticlines trending southwest-northeast and northwest-southeast. Two structural patterns resulting from Late Miocene tectonic activity are uplift and andesite intrusion.

Methods

In conducting research on the Sodong Spring in Ligarmukti Village, the discharge measurement data were obtained from literature sources and the Class A Irrigation Unit (UPT) Region I. The discharge measurements were carried out by the Class A Irrigation Unit (UPT) Region I using a current meter at the sluice gate of the Sodong Spring. This approach was adopted because direct access to the undisturbed spring source was not possible, resulting in the use of secondary data for discharge analysis.

In addition to discharge data, rainfall data from the Klapanunggal area were collected to analyze the relationship between spring discharge and rainfall variations during the rainy and dry seasons. The overall research procedure, including literature review, secondary data collection, data processing, and analysis stages, is summarized in the research flowchart presented in Figure 1.

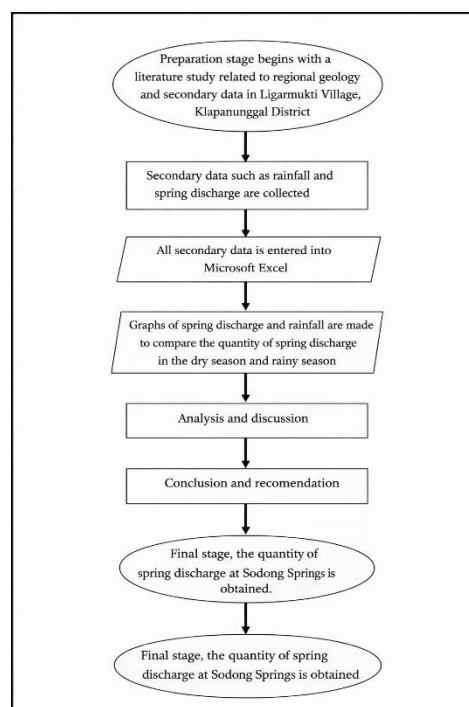


Figure 1. Research Method Flowchart

3. Results and Discussion

Sodong Spring discharge data from 2011 to 2019 are presented in Tables 1 and 2. Table 1 shows monthly discharge values from January to June, while Table 2 presents discharge data from July to December. These data indicate temporal variations in spring discharge related to seasonal rainfall patterns. The Sodong spring water meets the basic needs of the Ligarmukti Village community. Furthermore, the spring water is used for agriculture and tourism, and is distributed to the water company (PDAM) located outside Ligarmukti Village. Based on the geology of the study area, Ligarmukti Village is composed of Early Miocene Klapanunggal Formation limestone. Dissolution of the limestone by meteoric water (rainwater) forms secondary porosity. Furthermore, fractures in the study area increase rock permeability. The geomorphological unit consists of karst hills with residential and plantation land cover.

Rainfall data for the Klapanunggal District from 2011 to 2019 are summarized in Tables 3 and 4. Table 3 presents rainfall during the January–June period, while Table 4 shows rainfall from July to December. These data were used to analyze the relationship between rainfall intensity and Sodong Spring discharge. The data obtained include Sodong spring water discharge and rainfall in the Klapanunggal area, both measured by relevant parties. The Sodong spring water discharge measurements were conducted by the Class A Irrigation Technical Implementation Unit (UPT) Region I, and the rainfall data were obtained from the Central Statistics Agency of Bogor Regency. Based on these two data points, a comparison can be made between the Sodong spring water discharge during the rainy and dry seasons. The Sodong spring's water discharge is measured daily, but an average calculation is performed every 15 days. This discharge measurement takes place at the Mercur Water Gate. This measurement is conducted before the Sodong spring's water is distributed to residential areas, the agricultural sector, the tourism sector, and the surrounding PDAM.

Table 1. Sodong Spring Water Discharge January-June 2011-2019

Tahun	Jan (L/s)	Feb (L/s)	Mar (L/s)	Apr (L/s)	Mei (L/s)	Jun (L/s)
2011	1450	750	975	1075	625	400
2012	1750	575	1375	900	1075	500
2013	1450	700	1450	850	850	650
2014	1550	875	1325	900	750	775
2015	1350	650	525	325	700	450
2016	–	–	–	–	–	–
2017	–	–	–	–	–	–
2018	–	–	665	720	878	–
2019	950	1243	1030	2847	665	422

Note:

– = data not available

Table 2. Sodong Spring Water Discharge July-December 2011-2019

Tahun	Jul (L/s)	Aug (L/s)	Sep (L/s)	Oct (L/s)	Nov (L/s)	Dec (L/s)
2011	575	575	500	650	1500	800
2012	450	800	450	1450	800	1450
2013	850	550	725	1175	1600	1100
2014	1075	775	1050	3500	3875	4225
2015	350	475	875	1500	1375	1050
2016	–	–	–	–	–	–

Tahun	Jul (L/s)	Aug (L/s)	Sep (L/s)	Oct (L/s)	Nov (L/s)	Dec (L/s)
2017	–	–	–	–	–	–
2018	513	357	166	154	170	761
2019	432	2847	877	–	–	–

Note:
– = data not available

Table 3. Rainfall in Klapanunggal District, January-June 2011-2019

Tahun	Jan (mm)	Feb (mm)	Mar (mm)	Apr (mm)	May (mm)	Jun (mm)
2011	165	108	81	313	245	146
2012	370	287	115	493	307	92
2013	–	–	–	–	–	–
2014	1334	672	467	701	474	552
2015	324	398	411	298	367	70
2016	308	505	500	534	269	456
2017	363	502	301	442	366	222
2018	283	423	366	347	176	145
2019	345	225	291	471	186	–

Note:
– = data not available

Table 4. Rainfall in Klapanunggal District in July-August 2011-2019

Tahun	Jul (mm)	Aug (mm)	Sep (mm)	Oct (mm)	Nov (mm)	Dec (mm)
2011	238	71	85	265	299	217
2012	38	9	61	250	383	329
2013	–	–	–	–	–	–
2014	321	111	93	65	694	867
2015	61	21	88	39	251	262
2016	348	292	394	534	502	143
2017	338	163	256	417	518	309
2018	–	42	46	179	517	263
2019	–	–	–	56	73	268

Note:
– = data not available

The average fluctuation of rainfall and discharge in the Klapanunggal District from 2011 to 2019 is illustrated in Figure 2. The figure shows that higher rainfall generally corresponds to increased spring discharge, while lower rainfall during the dry season results in reduced discharge. The data show that the Sodong spring's water flow intensity can be influenced by rainfall in the area. When rainfall increases, spring flow rates increase. When rainfall decreases, spring flow rates decrease relatively. Despite the relatively lower flow rate, the area can still meet the community's water needs due to the karst region's secondary porosity, which allows it to store water.

Figure 3 presents the average monthly fluctuation of Sodong Spring discharge from 2011 to 2019. The data show seasonal variability as well as interannual trends, with significant increases in discharge observed in certain years. In analyzing the data, the dry season is represented by August, which saw a decrease in rainfall between 2011 and 2019. The rainy season is represented by April, which saw increased rainfall between 2011 and 2019. Calculations show an increase in the average discharge in March-April from 2011 to 2019. The average discharge in July-August decreased between 2011 and 2018, but increased in 2019.

In 2013, rainfall measurements were not taken due to equipment failure. While rainfall in January 2014 was relatively high, the discharge remained stable. This suggests a possible decrease in rainfall in 2013, which reduced the water reserves in the karst cavities. Therefore, the stability of the discharge in January 2014 was influenced by the decrease in rainfall at the end of 2013 and the increase in rainfall at the beginning of 2014.

Very high discharges were observed in 2014 and 2019. In 2014, the highest average discharge was recorded in December, reaching 4,225 l/s. In 2019, the highest average discharge was recorded in April, reaching 2,847 l/s. The discharges measured in 2014 and 2019 differ significantly from the average discharges measured in other years. This may indicate a pattern of significant increases in average discharge every 5 years.

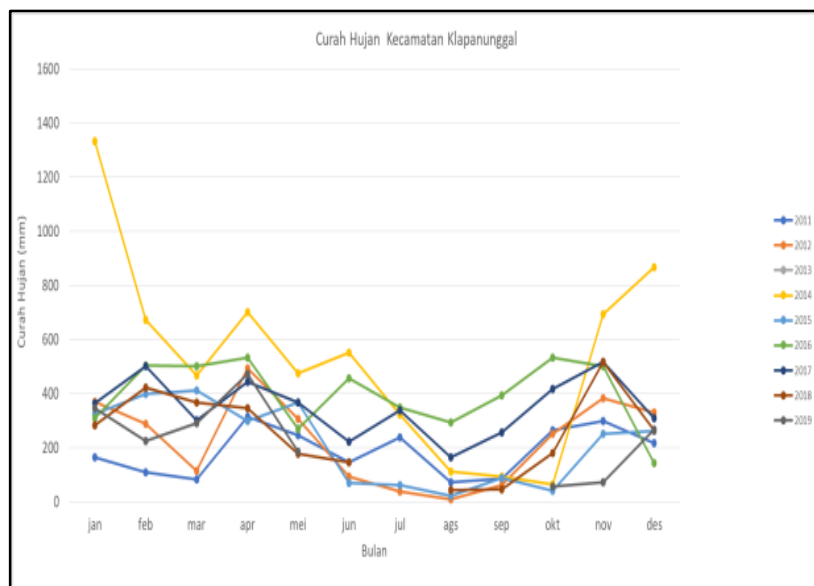


Figure 2. Average Fluctuation of Klapanunggal District Discharge from January to December 2011-2019

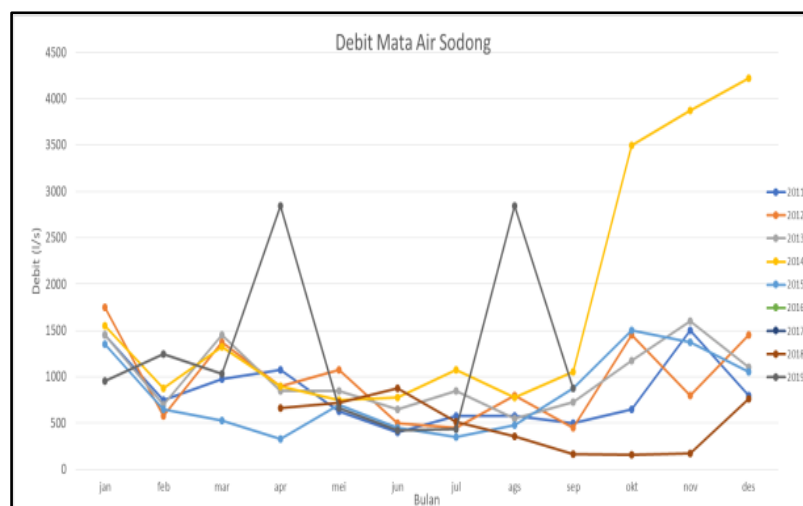


Figure 3. Average Fluctuation of Sodong Spring Water Discharge from January to December 2011-2019

Based on this, the pattern of a significant increase in average discharge every 5 years and karst cavities' ability to retain water could positively impact the development of the agricultural and tourism sectors in Ligarmukti Village. If observed based on the five-year repetition pattern, the average discharge will increase significantly, and a significant increase in the average discharge will likely occur again in 2024. This can be utilized as an opportunity to develop the agricultural and tourism sectors. However, the abundance of the Sodong spring must still be utilized

effectively by distributing water supplies to each household according to the average monthly discharge. Water reserves in Ligarmukti Village must also be considered, as data show that average discharge in 2018 decreased compared to previous years.

4. Conclusions

Calculations of the average discharge of the Sodong spring during the dry season show a fairly stable value with a relative decline. However, throughout the calculations, the average discharge never fell below 100 l/s. This indicates that the Sodong spring's discharge quantity during the dry season remains sufficient to meet the raw water needs of the surrounding community, the agricultural sector, and the sustainable tourism sector.

Special attention is paid to the utilization of the Sodong spring. Although there is a recurring pattern of significant increases in the average spring discharge every five years, the Sodong spring's discharge quantity remains a possibility. Therefore, the government and community of Ligarmukti Village must continue to utilize the Sodong spring effectively by distributing water supplies to each household, the agricultural sector, and the tourism sector according to the average monthly discharge, while also considering the spring's water reserves in Ligarmukti Village. This study shows that the Sodong spring's discharge quantity used to meet the raw water needs of the community, the agricultural sector, and the tourism sector can be determined from the relationship between rainfall data and the average monthly discharge data from 2011-2019. Therefore, for future research, it is advisable to add population and land-use data to determine the maximum amount of Sodong spring water discharge to be distributed to meet the needs of the community, the agricultural sector, and the tourism sector.

5. Competing interests

The authors declare that they have no competing interests.

6. Author's contributions

Auliya Zhafirah conceived the research idea, conducted data collection and analysis, and prepared the original draft of the manuscript. Miranda Nella Haurissa contributed to the research design, field data interpretation, and manuscript revision. Inggri Mirascela Terloit assisted in data processing, result interpretation, and manuscript editing.

All authors read and approved the final manuscript.

Acknowledgments

The authors would like to express their gratitude to the Department of Geological Engineering, Faculty of Exploration and Production Technology, Universitas Pertamina, for academic support and facilities provided during this research. Appreciation is also extended to local communities in Ligarmukti Village, Bogor Regency, for their assistance and cooperation during field data collection.

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