An estimation of water economic value of the karst area of Jonggrangan (case study: catchment area of Mudal, Kiskendo, and Anjani Caves)

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Abstract. The Jongggrangan Karst Area is one of the karst areas whose potential data inventory has not been well studied through studies of spatial and temporal variability. Research on the potential economic data of the Jongggrangan Karst Area is useful as a basis for making decisions on the management. The objectives of this study are: 1) to know the availability of water in the Jongggrangan Karst Area; 2) to know the estimated economic value of water that can be produced by the Jongggrangan karst Region. The primary data used is flowrate as measured by the velocity area method, and water level data along with rainfall recorded automatically by a logger. Secondary data used are water price data obtained from relevant agencies. The results of the study indicate that the study area has abundant resource potential. The availability of water in the study location reached 23,825,512.4 m³/year from the Mudal Cave spring and the underground river of Kiskendo Cave and Anjani Cave. The value of the availability of water produced is able to meet the needs of water for a decent human life of 14,890 people per year and with an economic value of IDR 47,651,024,980.00 per year.

1. Introduction
The karst area is the result of a solution or dissolution process with a distinctive physical appearance. The karst area is a terrain with hydrological characteristics and landforms caused by a combination of soluble rocks and well-developed secondary porosity [1]. The karst area is estimated to function as a large reservoir and become the fourth largest water storage place after volcanic, alluvial, and coastal plains [2].

The existence of the karst region is very strategic, because it has high scientific, economic and human values. Karst also has a meaningful value with its existence as a water supply for the socio-economic life of the community and the development of the surrounding area. As a natural resource, the karst area is non-renewable, even the karst region is identical as an ecosystem that is vulnerable to damage and if it has been damaged it is difficult to repair [3].

The karst area is one of the most explored landscapes today and its existence can be found on almost every island in Indonesia. The area of Indonesia's karst area reaches almost 20% of the total area [2] or around 140,000,000 km² [4]. One of the karst areas in Indonesia is the Jongggrangan Karst Area, which is located in two districts of two different provinces, some are located in the district. Kaligesing, Kab. Purworejo, Central Java Province and some are also located in Kec. Girimulyo, Kab. Kulonprogo, Yogyakarta Province. Jongggrangan Karst Area is a karst region that has not been widely studied for its...
potential either through studies of spatial and temporal variability. The availability of incomplete data can make exploration work without considering the physical and environmental aspects to the preservation of the karst area. Estimates regarding basic data such as those relating to the characteristics and economic value of karst areas are important variables to be known and considered before conducting exploration or determining policies related to the management of the karst area.

The study of the economic valuation of the karst region can be one of the start of data inventories which later can explain the characteristics of the area from the availability of water. The estimated economic value for potential water resources alone can be calculated using the benefit transfer approach. Benefit transfer method or approach is a technique that is widely used to estimate the economic value of environmental benefits when original assessment studies are not possible because of time and budget constraints. Benefit transfer can be a screening tool for the early stages of policy analysis [5].

Economic valuation of the availability of water will result in a mechanism for water trading which in general has become an economic good that has been widely traded in several regions. This will certainly have a major influence in the future as an inventory of data that can be used as a reference for decision making related to the use or utilization of exploration and management of the Karst Jongrangan area.

This study has the objectives: 1) to know the availability of water in the Karst Jongrangan area; 2) to know the estimated economic value of water that can be produced by the Karst Jongrangan Region.

2. Methodology

2.1 Description of Study Area

The research sites are administratively located in two districts of two different provinces namely Kulonprogo Regency, Yogyakarta Province and Purworejo District, Central Java Province (Figure 1). It’s also geographically located at 110°05’28”–110°10’33” BT and 07°42’57”–07°49’04” LS.

The research location is one of the results of the solution or karstification process and is located in the Jonggrangan Formation with an estimated thickness of around 150 m and is estimated to exist in the age of lower myocene range [6]. The location of the study is stratigraphically located above the Kaligesing Formation which has a water-resistant rock so that it can cause water entering the soil not to flow deeper into the soil, but will reappear to the surface as a spring [7].

The study was conducted for one year from March 2018 to March 2019. The research location of the Jonggrangan Karst Region was chosen because the area has abundant potential water resources, indicated by the presence of springs and underground river that are found throughout the year, including during the dry season. However, this potential has not been widely studied for its economic availability and value, so that management and use and maintenance cannot be optimized and run continuously. Specifically water availability in this study was measured at three different locations and based on catchment areas which were quite representative to describe the availability of water that accumulated in a certain area, such as the Mudal Cave catchment area of 1,705,751 m², Kiskendo Cave of 3,693,902 m² and Anjani Cave of 803,072 m². Mudal Cave Water Catchment is geographically located in the southern part of Jonggrangan Karst (Figure 2a), Kiskendo Cave is in the middle of Jonggrangan Karst (Figure 2b) and Anjani Cave is in the north of Jonggrangan Karst (Figure 2c), the three catchments certainly have the characteristics and ability to provide different water resources to one another.
2.2 Methodology

This study uses primary data and secondary data. Primary data used are flow, rainfall, and temperature characteristics. Secondary data used is a map of the Earth's geological map and water prices. Calculation of the availability of water itself uses a different formula like these below.

2.2.1 Availability of water on springs and underground rivers

The availability of water in this study is calculated from automatic water level data and flowrate data directly in the field. Water level data is obtained by using an automatic water level logger tool, commonly called a water logger and the recording is set every 15 minutes with consideration of being able to record fluctuations occurred.

Springs flow and underground river are obtained through direct measurements in the field by recording water level and measurements using the velocity area method both with current meter and
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buoys that are adjusted to the conditions of the current discharge measurement. The results of measuring the flow velocity with the current meter are processed by the formula [8].

\[ V_{\text{water}} = a + bn \]  

Information:
- \( a \) and \( b \) = regression coefficient
- \( n \) = the number of rotating turns divided by time

while the wet area itself can be calculated by the mean section method. The flow velocity can be calculated using the buoy itself then processed by the formula [8].

\[ Q = A \times k \times U \]  

Information:
- \( Q \) = flow (m\(^3\)/s)
- \( U \) = buoy speed (m/s)
- \( A \) = wet cross-sectional area (m\(^2\))
- \( k \) = buoy coefficient

The results of the flow and recording of water level are then processed with a rating curve and flow hydrograph to produce the availability of water for springs and underground rivers. Equation rating curve used to produce flow discharge based on constants as follows:

\[ Q = \alpha (H - H_0)^b \]  

Information:
- \( Q \) = Flow (m\(^3\)/s)
- \( \alpha, b \) = Constant
- \( H \) = Automatic water level recording
- \( H_0 \) = Zero flow height

The availability of total water itself is obtained from the results of the conversion of \( Q \); \( Q \) (m\(^3\)/s) => \( Q \) (m\(^3\)/year)

2.2.2 Estimated Economic Value of Water

The availability of water in springs and underground river and also the availability of meteorological water determine the economic value of water in the Jongggrangan Karst Area. Water economic assessment is carried out by the method of transferring benefits with formulas.

\[ NE = \sum \text{Water} \times 2,000 \]  

Information:
- \( NE \) = Economic Value
- \( \sum \text{Water} \) = Availability of Total Water
- 2,000 = Renewable prices on the free market

2.3 Research Flow Chart

Research includes the stages of preparation, data collection, data processing, and descriptive synthesis analysis. The results of the analysis become the basis of the recommendations given in the study. The stages of research can be seen in Figure 3.
3. Results and Discussion

The availability of water is a quite important variable to know and estimate its amount or reserves, especially for the Jongggrangan Karst Area which is still developing and has not been explored much for economic purposes. The Jongggrangan Karst Area is one of the areas that has a potential water supply with its own uniqueness in terms of providing water resources. The existence of springs and
underground river that are spread evenly until the variety of plants that can thrive around the area shows the large potential of water availability owned by the Jonggrangan Karst Region. In general, as explained [2], the karst region is expected to also function as a large reservoir and become the fourth largest water storage place after volcanic, alluvial, and coastal plains.

3.1 Availability of water in the Jongggrangan Karst Area

The availability of water in the Jongggrangan Karst Area can be broadly calculated from the availability of water in springs and underground rivereither directly for the entire region or through calculations in some catchments. The value of water availability in underground river and springs is obtained from rating curves and flow hydrographs, which one of it produces an annual discharge (m$^3$/th) of water flowing through cracks and also underground passages to accumulate in an underground river and can come out as a spring.

The overall Jongggrangan Karst Area has an area of around 17,493,690 m$^2$ with the existence of a catchment area that spreads evenly with a certain area. The percentage of water catchment area that is the location of the study of the total area of the Jongggrangan Karst Area is around 72% consisting of the Mudal Cave water catchment area of 29.5%, Kiskendo Cave water catchment area of 23.0%, Gua Anjani catchment area of 19.6% . Each different area of water catchment area is known to be able to save the availability of water in different amounts. (Figure 4). Based on the quantity, the three catchments produce an average monthly water flow that enters class IV (> 10 liters/second) based on the Meinzeir classification in [11]. This condition illustrates the potential of water in the three catchments that are still good enough to be used for various activities or needs.

![Figure 4. Availability of water in the Jongggrangan Karst Area on Springs and Underground Rivers](image)

Source: Processed Primary Data (2019)

3.1.1 Water availability in the catchment area of Mudal Cave

Water availability in the Mudal Cave water catchment area is measured through Mudal Springs which are outlets of the Nguwik-Mudal underground river karst system. Characteristics of Mudal Springs fall into the classification of perennial spring or spring that flows both during the rainy season and the dry season. Based on the flow hydrograph produced (Figure 5), it can be seen that the variation of Mudal Springs flow discharge during the dry season in May-October is <400 liters/second and in the rainy season November-April the flow rate is> 400 liters/second. The total water availability in the Gua Mudal catchment area alone reached 10,379,559.2 m$^3$/year with an average monthly discharge of 329.1 liters/second.
The hydrograph of the Mudal Cave catchment area also illustrates the size of water deposits that are strongly influenced by the physical characteristics of Mudal Springs and geological structures or hydrological systems that develop in Mudal Cave through karstification, while also having high porosity [12]. The amount of water produced by Mudal Springs can be seen from the daily, monthly or annual discharge, as previously explained. [10] The discharge produced by Mudal Springs is one of the largest water discharges from 61 springs which are evenly studied in the Jongggrangan Karst Area. This condition reaffirms the potential for water resources in the Anjani Cave catchment area is very large and potential to be utilized by various activities of the local community.

3.1.2 Water availability in the catchment area of Kiskendo Cave
The availability of water in the Kiskendo Cave catchment area is measured through an underground river which is one of the karst aquifers with extensive and still developing cave characteristics. The Kiskendo Cave underground river also flows as a resurgence of Soemitro Cave. The flow hydrograph produced shows that water availability can be found throughout the year. However, graphically, the water availability shown (Figure 6) is not very large, especially compared to the availability of water available to Mudal Cave spring.

Availability of water on the underground river of Kiskendo Cave during the dry season in May - October has a flow rate of <100 liters/second and in the rainy season November-April has a flowrate of > 100 liters/second. Based on the average monthly discharge, the Kiskendo Cave underground river is 273.5 liters/second, while the total water availability is 8,627,129.4 m³/year. The availability of total water illustrates the potential of water resources in the Kiskendo Cave catchment area is not so large and quite vulnerable to drought, especially when entering the dry season such as October.
3.1.3 Water availability in the catchment area of Anjani Cave

Water availability in the Anjani Cave catchment area was measured by the presence of an underground river within the Anjani Cave which has the characteristics of an active aging system. Water flow on the Anjani Cave underground can be found throughout the year both during the rainy season and during the dry season. The uniqueness of the Anjani Cave water catchment area can be seen from the presence of waterfalls at the bottom of the cave as one of the outputs of the flow of water flowing on the underground river Gua Anjani. The flow hydrograph produced from the underground river Anjani Cave (Figure 7) can illustrate the total water availability in the Anjani Cave catchment area which is far less than the water availability in the Mudal Cave catchment area. Variation of flow discharge on the Anjani Cave underground river during the dry season in May-October <40 liters/second and during the rainy season November-April > 40 liters/second

![Hydrograph of Underground River in Anjani Cave](image)

**Figure 7.** Hydrograph underground river in the catchment area of Anjani Cave
Source: Processed Primary Data (2019)

Based on the average monthly discharge or monthly water availability generated for the Anjani Cave catchment area of 152.8 liters/second, the total water availability is 4,818,823.8 m$^3$/year. The availability of water in the underground river Anjani Cave has the lowest availability compared to the other two catchments. The low water availability in the Anjani Cave water catchment area is quantitatively influenced by the surface water recharge from sinking streams sourced from Cebong River and Jumbleng Sawah. The existence of a sinking stream and a typical dating system makes the conduit flow so dominant that it allows the flow of water to come out one of them as a waterfall. The conduit flow type responds to the Anjani Cave water catchment area to meteorological water input which is one of the other inputs of water other than surface flow or sinking streams which are fast enough to lose water, making available water and one of them flowing in the underground river Anjani Cave more low with a relatively smaller discharge, so that it has an indication of susceptibility to be drought especially when entering dry months.

3.2 Estimated Economic Value of Availability of Water in the Jongggrangan Karst Area

The existence of karst areas such as the Jongggrangan Karst Region has an important role to do with water supply. The ability of the Jongggrangan Karst Region to carry out its main function of storing large amounts of water has its own economic benefits. Water is a major human need that is always needed every day, such as to fulfill domestic water needs [9], nowadays water is widely traded through the mechanism of water trading both by the government and the private sector in a certain area.

The availability of water produced by the three water catchment areas has considerable usefulness for the community around the Jongggrangan Karst Area. The value of total water availability from the three study areas which amounted to 23,825,512.4 m$^3$/year can meet the needs of water for human-worthy living as many as 14,890 people per year, according to the calculation of the Decree of the Minister of Environment No. 17 of 2009 related to water requirements for human decent life of 1,600 m$^3$/year per individual. The value of the availability of water has met the needs of domestic water in a semi-urban scale with a population ranging from 3,000-20,000, based on the classification of the...
Research and Development Center for Irrigation in [13] regarding the criteria for determining domestic water needs. This certainly confirms the greater potential of water resources owned by the Karst Region and the very effective functioning of the Jonggrangan Karst Region specifically in providing water resources.

The estimated economic value of water for the Karst Jonggrangan Area can be known by the benefit transfer method. The use of the benefit transfer method is very possible to do in this study because of the limited time and budget. Benefit transfer can be a screening tool for the initial stages of policy analysis [5]. The price of water that applies in the Jongggrangan Karst Area itself is known to be IDR 2,000 per m³ based on the water price set by one of the water supply providers in Kulonprogo Regency, namely PDAM Tirta Binangun Kulonprogo Regency.

Based on the calculation results, the availability of water in the Karst Jonggrangan area through the three water catchment areas, namely in the Mudal Cave, Kiskendo and Anjani, obtained the economic value of water reached IDR 47,651,024,980.00 per year (Table 1). The economic value of water in the Gua Mudal catchment area contributes the largest economic value reaching IDR 20,759,118,400.00 per year, which is very much influenced by its abundant availability with high annual debits, while the lowest economic value of water is generated in the Anjani Cave catchment area which only reaches IDR 9,637,647,600.00 per year which is certainly influenced by fewer availability. Overall the economic value of the water is greater than the economic value of water availability in other karst areas as in the study [3] in the Gudawang Cave Karst area, Kec. Cigudeg produces a water economic value of IDR 1,222,673,877.00 per year or in research [14] for the Pura Tirta region, the economic value of water is IDR 2,314,040,471.00 per year. This confirms the large potential of the economic value of water owned by the Jonggrangan Karst Region which is also the largest contributor to economic value in the Jongggrangan Karst Area.

Table 1. Estimated Economic Value of Water in the Total of Jongggrangan Karst Area

| Water Catchment Area | Availability of Water (m³/th) | Water Prices /m³ (IDR) | Economic Value (IDR) |
|----------------------|------------------------------|------------------------|----------------------|
| Mudal Cave           | 10,379,559.2                 | 2,000.00               | 20,759,118,400.00    |
| Kiskendo Cave        | 8,627,129.4                  | 2,000.00               | 17,254,258,980.00    |
| Anjani Cave          | 4,818,823.8                  | 2,000.00               | 9,637,647,600.00     |
| **Total**            | **23,825,512.4**             | **47,651,024,980.00**  |

Source: Processed Primary Data (2019)

The economic value of water availability in the Jonggrangan Karst region which is large enough can confirm the existence of the region. Based on the Decree of the Minister of Energy and Mineral Resources Number: 17 of 2012, the Jonggrangan Karst Area is categorized as a class I area, which shows that it has sufficient hydrological functions, caves and active underground rivers, and also has the potential to be developed into tourism and cultural objects, so it has a typical flora and fauna content that fulfills the meaning and function of social, economic, cultural and scientific development. The Jongggrangan Karst Area has also been entered into a local protected area where it starts to be protected and cared, one of which is by protecting the caves and springs by the rule that there should be no building activities around the border, which can damage the decoration in the cave (stalactite, stalagmite, flowstone and others other), and polluting the underground river, so that it will affect its potential decline.

The Jongggrangan Karst Area has a large role and potential in providing water resources (water reservoirs). Exploration by various land-use activities that have not been so developed can be an advantage for maintenance steps. In addition, exploration prevention stages that have the potential to damage the environment of the karst region can be immediately considered. The estimated economic value of the Jongggrangan Karst Area should be used as a reference for regional conservation. Preservation of the Jongggrangan Karst Area can also be carried out by financing the increase in the capacity and quality of natural resources as well as human resources around the area. Capital for self-
financing can be obtained from the value of the availability of water and carbon which will be economically more beneficial if included in the global trade scheme. The improvement in the quality of natural resources and human resources is certainly expected to bring about an assumption or an increase in the welfare mindset while continuing to preserve the Jongggrangan Karst Area sustainably.

4. Conclusion
The existence of Jonggrangan Karst has an important role in providing water resources which are the basic needs of living things. The availability of water in the presence of Jonggrangan Karst is very abundant and can be found in the form of springs or flowing as underground river which are widely spread in the region. The total water availability of the three study catchments in the Karst Jonggrangan area reached 23,825,512.4 m$^3$/year of which 10,379,559.2 m$^3$/year came from the Gua Mudal catchment area, 8,627,129.4 m$^3$/year from Kiskendo Cave and 4,818,823.8 m$^3$/year from Anjani Cave.

The value of total water availability from the three study areas in the Jonggrangan Karst Area is capable of meeting the needs of 14,890 people per year or able to meet the domestic water needs of a semi-urban scale. Economically, the availability of water produced has economic value reaches IDR 47,651,024,980.00 per year, which comes from the Mudal Cave spring and the underground river of Kiskendo Cave and Anjani Cave. The economic value can be the biggest contributor to economic value in the Karst Jonggrangan area, which currently its benefits and existence have not been recognized directly by the community.

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