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Water resource sustainability in the coastal-karst area of Paranggupito Sub-district, Wonogiri, Indonesia

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[2]Graduate Program of Environmental Science, Graduate School, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126, Central Java, Indonesia
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Abstract. *Aryanto AEP, Herbowo ACF, Aftsari AI, Maharani MP, Worokinkkin SPDA, Setyawan AD. 2024. Water resource sustainability in the coastal-karst area of Paranggupito Sub-district, Wonogiri, Indonesia. Indi Pac j Ocean Life 8: 94-100.* The karst region, with its unique geological landscape characterized by barren limestone hills, presents a significant challenge for the local population in processing clean water. Therefore, sustainable water source management is of utmost importance. This study aims to examine the community's perception of water sources, the communal management of water sources, water source management regulations, and the sustainability of water sources in three coastal-karst villages of Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia, namely Gunturharjo, Gudangharjo, and Paranggupito. The method used in this research is a descriptive-qualitative approach. Primary data were obtained from interviews, questionnaire, and surveys conducted in the three coastal karst villages. While, secondary data on regulations on water source management were obtained from the Indonesian Law 17 of 2019 on Water Resources. This study shows that in the three coastal-karst villages most water sources are heavily influenced by the seasons. Based on interviews, 46% of the community obtains water for daily needs from communally managed water sources, while the remaining 54% manage their water or rely on privately owned dug wells. Otherwise, the regulations or applicable rules have not yet been implemented, so the management and sustainability of water resources are at risk. In terms of sustainability, the management of water resources can meet daily water needs for the next few years. Still, it does not guarantee the sustainability and quality of water, especially for drinking purposes.

Keywords: Coastal, karst, Paranggupito, springs, sustainability, water management

INTRODUCTION

Water is a vital resource for human life. According to Sulistyorini et al. (2016), water has many benefits, including being used by microorganisms for chemical reactions in the metabolic process and as a medium for transporting nutrients or metabolic waste. For humans, water is essential to meet biological needs, particularly for survival. Additionally, water is used for cooking, washing, irrigation, and even in industrial sectors. Thus, humans and other living beings cannot survive without water.

One concern regarding water resources is water security, which has emerged as a significant area of international academic interest (Jiang 2015). Water security is maintaining water-related hazards within reasonable bounds for human, environmental, and economic needs while providing an adequate amount and quality of water for human health, survival, and economic activity (Liu 2021). It is the fundamental component of the global objective of water and the key idea of sustainable development goals. All living creatures must carry out water management as an essential effort for survival (Yustikasari and Lulofs 2022). Periodic water management aims to prevent contamination of water sources.

An important area of concern in water resources management is the karst and coastal area. Karst is characterized by carbonate rock formations such as limestone, which change due to urban development. The fragile karst geological environment and rapid urbanization threaten the karst ecosystem, especially in areas close to urban centers (Tang et al. 2024). The karst region is hydrologically very complex (Pulido-Bosch 2021). Karst cavities formed by dissolution processes allow contaminants to seep directly into the groundwater system (Buckerfield et al. 2020). Karst aquifers have significant potential as a source of drinking water due to the substantial storage capacity they acquire with the breakdown of carbonate. The complex behavior of these aquifers concerning surface and subsurface flow is also caused by the breakdown of carbonate and the ensuing formation of preferential pathways (Cardoso de Salis et al. 2019). The thin soil in karst regions limits the natural filtering of contaminants from the surface to subsurface levels. Microorganisms are common contaminants in karst areas (Kaiser et al. 2023). Contamination can occur due to runoff from agriculture and livestock, and industrial activities may cause leaks from water pipes, septic systems, wastewater, stormwater runoff, and others. The formation of karst landforms, the scarcity of water resources, and their challenging use are the primary causes of the shortage of water resources in karst locations (Peng et al. 2021). Besides, coastal areas face many freshwater issues, including limited access, saltwater intrusion, and climate change. Climate change causes irregular rainfall or long

dry seasons and increases the frequency of floods and droughts, which can worsen water pollution. These problems can have significant environmental and socio-economic consequences (Mukarram et al. 2023).

Water is the essential source of life for all living beings, including animals, humans, and plants. Water has many benefits, such as being a solvent, facilitating chemical reactions in metabolic processes, and serving as a medium for transporting nutrients and metabolic waste. For humans, water fulfills biological needs and is used for various purposes, such as cooking, drinking, washing, irrigation, and other necessities. Although water covers 70% of the earth's surface, the usable water supply is limited. It is not only the quantity that matters but also the quality of water, which must meet certain standards for specific uses. As population growth increases, so does the water demand, which impacts environmental quality.

Environmental degradation occurs when people pay little attention to environmental aspects, such as converting forest areas, which can cause erosion and sedimentation, thus directly or indirectly affecting water sources. According to Indonesian Law No. 17 of 2019, water resources include water, water sources, and energy. A water source is a natural or artificial reservoir found on, above, or below the ground surface. A spring is a groundwater that naturally emerges to the surface and can be influenced by seasonal changes, with quality similar to deep groundwater. Water emerges from the ground in a spring, typically in mountainous or highland areas. The formation of springs usually involves rainwater seeping into the ground and then emerging at the surface through cracks or fissures in the rock.

Geological and hydrological conditions influence the formation of springs in karst regions. Karst aquifers are considered extremely difficult to understand due to their unique features, like lines and flowing channels. Nonetheless, this aquifer system is highly diverse and dynamic, making it a valuable water conduit globally (Hillebrand et al. 2014). The dissolution process causes surface water to penetrate underground through cracks of various sizes quickly. From a chemical perspective, hard soil can neutralize acidity due to its alkaline nature. However, regarding its characteristics, water that enters the ground in karst areas cannot be retained because of the specific nature and gradation of karst soil.

Paranggupito is a sub-district in Wonogiri District, Central Java Province, Indonesia about 55 km from the capital city of Wonogiri District. The southern part of Wonogiri is a karst hilly region of the Gunung Sewu karst hills. This area spans three provinces, from Gunung Kidul in the Special Region of Yogyakarta to Wonogiri in Central Java and Pacitan in East Java. The karst region is a unique geological landscape characterized by barren limestone hills (Aprilia et al. 2021). Consequently, this morphology is considered to cause difficulties for the local population in accessing freshwater. The scarcity of freshwater arises due to the formation process and the dissolution pattern of limestone, which results in dry karst surfaces. According to Sudarmadji et al. (2014), more than 60% of Wonogiri District is prone to drought, indicating a clean freshwater crisis during the dry season, affecting the Paranggupito Sub-district. Three villages in this sub-district face the ocean, adding to the difficulty of providing clean fresh water.

This research aims to determine the community's perception of water sources, the communal management of water sources, water source management regulations, and the sustainability of water sources in Paranggupito Sub-district, Central Java, Indonesia especially in coastal villages of Gunturharjo, Gudangharjo, and Paranggupito.

MATERIALS AND METHODS

Study area

This research was located in three coastal-karst villages of Gunturharjo, Gudangharjo, and Paranggupito in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia (Figure 1).

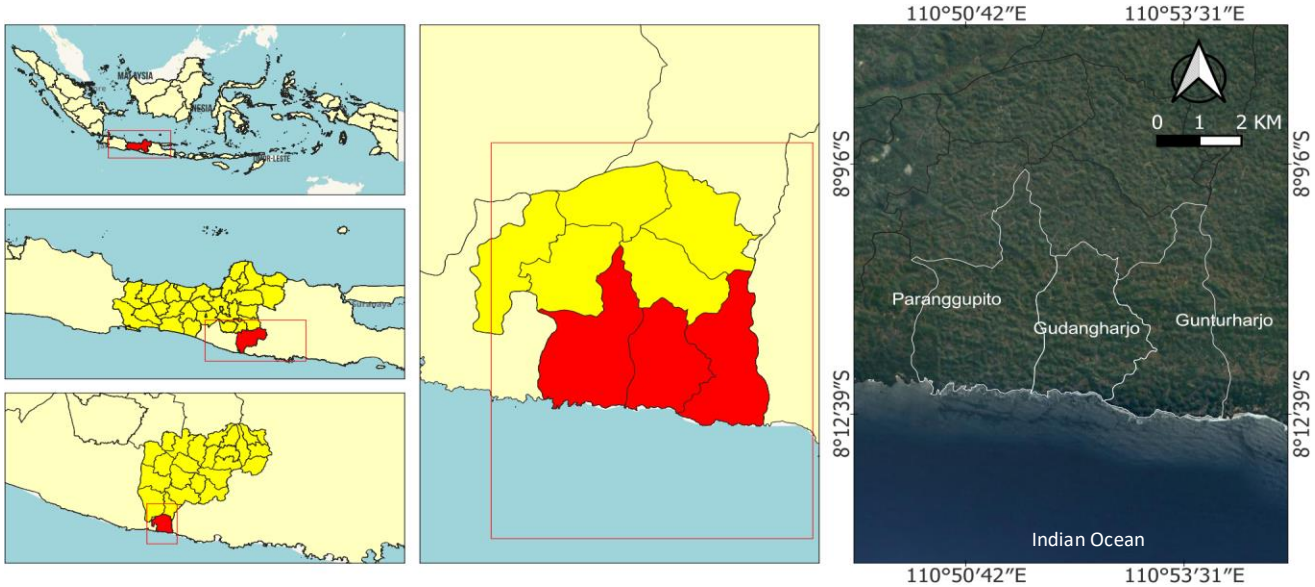

Figure 1. Location of coastal karst area of Paranggupito, Gudangharjo, and Gunturharjo Villages, Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

Most of the population in these areas works as farmers and livestock breeders, which makes water a critical "ingredient" for carrying out their work. This region is located in the hills where the land is a karst area, a distinct kind of landscape that develops on top of highly soluble materials like gypsum, marble, and limestone (Zerga 2024). This area also borders directly on the Indian Ocean. Water resource vulnerability is one of the main problems in this coastal karst area (Cahyadi et al. 2017).

Sampling/data collection and data analysis

The method used in this research is a qualitative descriptive study, which is a research method aimed at describing and understanding social phenomena related to water. This method is presented through a single case study analysis. The data sources for this research come from both primary and secondary data. The primary data were obtained through field surveys, interviews, and descriptive questionnaires in the three villages. Interviews were conducted with 100 respondents. Respondent characteristic data only includes age and residence, to ensure that respondents are adults and live in the research villages. Several assessment criteria were used to evaluate (i) the community's perception of water sources, (ii) the communal management of water sources, (iii) water source management regulations, and (iv) the sustainability of water sources. Secondary data were obtained from Indonesia Law Number 17 of 2019 on Water Resources. The primary data collected were then analyzed using a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to assess water-related criteria in these three coastal-karst villages.

RESULTS AND DISCUSSION

The Community's perception and utilization of water sources

Based on the data obtained (Table 1), most (61%) of the population living in the study area still have water sources in the form of springs near their homes, but not all of it is used to meet daily needs. In terms of their origin, springs are groundwater that naturally emerges to the surface, with an output quality that is the same as deep groundwater. According to the interview, most of the spring quantity in the research area is highly influenced by seasonal changes (91%). Wells tend to dry up during the dry season and have water during the rainy season. Even so, the quality (96%) and quantity (100%) of the water are sufficient to meet their needs. However, the increasing population has led to a surge in water demand, necessitating the exploration of alternative water sources to meet domestic, agricultural, and commercial needs (Sulistyani and Irianto 2018).

Table 2 shows the utilization of the water supply system in the study area (Gunturharjo, Paranggupito, and Gudangharjo Villages, Wonogiri District). Residents close to springs, usually dig wells (36%) or draw the water using pipes provided by themselves (*Independent piping*) if the location is some distance from the house (10%). Besides that, people seek other alternatives for gaining access to water, such as purchasing water from trucks with tank systems, using drilled wells for very deepwater sources, and relying on *Sistem Penyediaan Air Minum* (SPAM) and *Perusahaan Daerah Air Minum* (PDAM). The local government manages PDAM, while private entities manage SPAM, which provides and distributes clean water to the community. Water is distributed through pipes connected from reservoirs and delivered to households. Based on Table 2, the majority of the community in the study area uses water sources from SPAM/PDAM (46%). Some residents who live near water springs prefer to use SPAM/PDAM because it is easier and more secure to operate than using dug wells or independent pipes.

The other alternative to access water sources is using Rain Water Harvesting (RWH), which is used in 2 households. It is a technique for collecting and storing rainwater for future use. RWH uses different methods, all of which demonstrate adaptability to local conditions. In Brazil, rainwater is collected in tanks that are partially buried in the ground to prevent contamination by other substances and to maintain water quality (WAW Foundation 2024). In Thailand, rainwater is stored in jars that can hold 100-3000 liters per jar, a system used in areas with a six-month dry season (CSE 2023). In Indonesia, RWH has been implemented in Gunung Kidul, using storage tanks made of cement/concrete, brick walls, or plastic drums, which can supply clean water to communities during the dry season (Pujiati et al. 2018).

Table 1. Community perception of water source management

Questions	Yes (%)	No (%)
Are there any springs around your residence?	61	39
Is the water source sufficient to meet your needs?	96	4
Is there a difference in water flow during dry season?	91	9
Is the water of good quality and suitable for use?	100	

Source: Primary Data, 2024

Table 2. The utilization of the water supply system

Question	Dug Well	Independent piping	Rainwater harvesting	Tank system	Drilled well	SPAM/PDAM
Community water source	36	10	2	6	1	46
Total			100			

Table 3. Perception of communal water source management in the study area

Questions	Yes (%)	No (%)
Are there any springs managed communally?	25	75
If the springs are managed communally, are you a consumer of that communal water management system?	100	0
Is the management system for the springs well-maintained?	95	5
Are there frequent issues in the management of communal water sources?	15	85
Are the managers responsible for addressing those issues?	100	0

The Communal management of water sources

Some members of the community in Paranggupito Sub-district use clean water managed communally. Table 3 shows that 25% of the springs in the study area were managed communally, while the remaining 75% were managed individually. Communal management involves providing water sources from PDAM or SPAM. According to interview results, the issues faced in the management of communal water sources include occasional interruptions in water flow.

Additionally, the community believes water from wells or groundwater is more precise and cleaner than water from PDAM/SPAM, which contains many calcium compounds. The water from SPAM/PDAM is clear, but some have a salt content that makes it similar to hard water. Water hardness refers to the levels of dissolved calcium and magnesium in the water. There are two types of water hardness, i.e.: temporary hardness and non-carbonate (permanent) hardness (Kiswanto 2022). This water cannot be consumed directly just by boiling; it also needs to be settled. Water with high hardness can cause various issues, such as gray staining on clothes and reduced water flow in distribution pipes (Sahabuddin 2015). This water quality is not ideal for daily consumption. Therefore, the community is encouraged to seek alternative solutions to address this issue, such as desalination or finding better freshwater sources (Wardana et al. 2024).

This aligns with research conducted by Serniati et al. (2021), which shows that some community members prefer using well water because SPAM water contains calcium compounds. Pump lines are connected using a piping system. Corrosion of pipes in drinking water distribution systems is of particular concern because of various problems related to the loss of pipe mass through oxidation to dissolve, which shortens the service life of pipes and increases maintenance costs. Another problem is that scale can accumulate in tubercles, reducing water capacity and thereby increasing pumping costs, which also impacts consumer health (Liang et al. 2014). However, communal water supply from PDAM/SPAM is also considered quite effective as it can serve as a backup during the dry season. Although there are still issues in managing communal water in Paranggupito Sub-district, the managers of communal water sources have been responsible for identifying and resolving these problems.

Water source management regulations

The regulation concerning water source management currently used in Indonesia is Law Number 17 of 2019 on Water Resources. According to this law, the regulation addresses the imbalance between the demand and availability of water, as the quality and quantity of water have declined over time. Furthermore, there is a need to manage water resources that consider social, environmental, and economic aspects to achieve integration in meeting the community's clean water needs. Water is a vital production branch and one of the keys to sustainable living, as the state controls it for the benefit and welfare of the people.

There are two patterns in formulating legislation related to government authority, i.e.: the broad autonomy pattern and the regional autonomy pattern (Wulandari and Ilyas 2019). The broad autonomy pattern gives authority to the central government, while the remainder is under the regional government's authority. In contrast, the limited autonomy pattern primarily grants authority to the regional government in a restrictive manner, with the remainder under the central government's authority. However, the established regulations have not reached remote areas that fundamentally need regulations to manage water sources. Based on interviews conducted in three villages in Paranggupito Sub-district, these villages have not implemented existing regulations. This urgent situation highlights the need for immediate action to ensure the management and sustainability of water resources in these remote areas.

The community in these villages relies solely on the nearest water sources and waits for rainfall to meet their clean water needs. The government has not introduced the residents of Paranggupito Sub-district to the regulations applicable to water resource management, and there is a lack of socialization regarding regulations and local wisdom that should be established for the protection of clean water. However, the implementation of local wisdom is the cultural knowledge possessed by a specific group of people, including cultural knowledge related to the sustainable management and utilization of natural resources, which holds great promise. It reflects the mindset of the community concerning the functions of the environment, nature's responses to human actions, and the relationship between humans and their environment. By promoting and implementing local wisdom, we can bring about a positive change in the water management situation in Paranggupito Sub-district.

The sustainability of water sources

The sustainability of water sources in Paranggupito Sub-district, Wonogiri District, is an issue that must be prioritized. This region often experiences water shortages during the dry season, a situation that significantly impacts the lives of the local communities. Water shortages hinder

water use for agricultural needs, forcing landowners to delay planting and focus on soil preparation while waiting for the rainy season.

The availability of water resources in karst areas differs significantly from that in non-karst regions. Springs in karst areas exhibit uneven water distribution, which is a contributing factor to the water shortages experienced by communities in karst regions. The scarcity of water in karst areas is due to the formation of underground drainage systems, making the surface areas vulnerable to drought (Arida 2022).

The groundwater conditions in karst areas possess distinctive characteristics. These groundwater conditions depend on the dissolution processes occurring in the limestone of the area. Most of the soil patterns in karst regions consist of cracks or fissures in the rocks, leading to unpredictable water distribution. Generally, groundwater resources in karst areas consist of three types: springs, dug wells, and independent piping systems. Many residents utilize dug wells in this region because there are relatively abundant water resources beneath the ground. However, not all areas have springs or water reservoirs. Springs/water reservoirs are only found in Gunturharjo Village and parts of Gunturharjo. In addition to these three water sources, the community also has Rain Water Harvesting (RWH) systems. The RWH system is a structure around the house that serves as an alternative water storage facility. This RWH relies solely on rainwater, and the surrounding community mainly uses it for agricultural purposes.

Through interviews conducted with residents in the karst area, it was found that the water available for their daily needs is sufficient for several years ahead (Table 1). Still, it does not guarantee sustainability and adequate water quality, especially for drinking. This is also related to the lack of government regulations applied in this area. Regulations and the sustainability of water resources are interrelated and go hand in hand. If there are binding regulations governing water resource management, the sustainability of both water quality and quantity can be maintained and protected collectively.

Recommendations for water management

Water management recommendations for the karst area in Paranggupito Sub-district are determined based on a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. Strengths and opportunities drive good water governance, while weaknesses and threats limit water management. The driving and limiting factors are categorized into internal factors (strengths, weaknesses) and external factors (opportunities, threats); strengths and opportunities can be leveraged to address weaknesses and threats (Rachid et al. 2021).

Based on the SWOT analysis results in Table 4, recommendations for water management in the coastal-karst area of Paranggupito Sub-district include collaboration between the community, government, and companies as CSR implementers. According to Bajec and Krajc (2023), water management through a participatory approach requires active community involvement in conserving water sources to achieve sustainable development and address water scarcity. The potential impact of these CSR programs is significant, offering hope for a future with improved water management. These programs can include outreach to improve human resource quality and community participation in planning and decision-making regarding water management (Caponera and Nanni 2019).

Table 4. Perception of communal water source management in Paranggupito Sub-district, Wonogiri District, Central Java, Indonesia

External \ Internal	Strengths (S)	Weakness (W)
	1. The water sources around the community settlements are available. 2. The groundwater quality is still considered clear and suitable for drinking water. 3. Most springs meet the domestic needs of the community. 4. Most water source locations are close to homes, with a radius of less than 10 meters.	1. Inadequate economic conditions occur in providing water source infrastructure. 2. Lack of supervision and strict regulations in water utilization. 3. Water discharge cannot meet the needs of agricultural systems. 4. Lack of knowledge and awareness about water resource management practices.
Opportunity (O) 1. The opportunity for CSR (Corporate Social Responsibility) was the programs for the provision of clean water resources.	1. Collaboration between the community, companies, and the government managed to implement clean water programs, such as constructing boreholes. 2. Utilize existing springs around community settlements to be managed communally with a more structured governance system.	1. Develop water sources through financing via CSR. 2. Implement applicable regulations and establish agreements/specific rules between managers and the community regarding the utilization of water sources. 3. Strengthen human resource capacity for water source management.
Threats (T) 1. Increased demand and need for water. 2. Climate change. 3. Decreased water availability occurs during the dry season.	1. Create a rainwater harvesting system (RWH) as a backup water source during the dry season. 2. Enhance the water conservation efforts to ensure that needs are met sustainably.	1. Enhance the roles and partnerships in providing clean water. 2. Encourage the research on clean water management in karst areas. 3. Apply the appropriate technology to address clean water limitations.

The government plays a role in implementing regulations that support integrated water management and programs related to providing clean water in Paranggupito Sub-district. The government also plays a crucial role in providing assistance, facilities, and appropriate technology to meet community water needs. According to Angelia and Hakiki (2021), companies or private partners are essential in providing financial assistance; through CSR programs, they can contribute to meeting clean water needs in Paranggupito Sub-district. Based on interviews, there are plans for a CSR program in Gudangharjo Village, but it has not yet been realized. Additionally, research on managing water sources in karst areas is needed. Most scientific applications related to water involve some form of monitoring, but participatory activities such as mapping, modeling, and local data collection are valuable data sources (Walker et al. 2021). Integrating local knowledge can be used for disaster risk reduction at the community scale (Hicks et al. 2019).

The springs in Paranggupito Sub-district meet community needs, but there are differences in discharge during the dry season. Efforts to address drought during the dry season include providing rainwater harvesting systems and planting crops adaptive to dry conditions (Wijayanti and Noviani 2020). A simple rainwater harvesting example involves collecting the rainwater into a well fed from the roof via gutters, then filtering it using containers filled with gravel or charcoal before it reaches the well or tank (Bajec and Krajc 2023). Water sources can be managed in karst areas by increasing vegetation density to extend the delay time for water and pollutants entering the soil layer (Riyanto et al. 2020). Karst ecosystems can naturally provide high-quality drinking water that can be utilized through springs such as wells. However, a good understanding of the characteristics of karst aquifers is crucial for efficiently protecting and sustainably utilizing water (Golob et al. 2019).

In conclusion, it was found that in the three coastal karst villages of Paranggupito Sub-district, Wonogiri District, the majority of water sources are significantly affected by the seasons. According to the interview results, 46% of the community manages water sources communally, while 54% are managed individually or through private wells. The water sourced from SPAM managed communally is clear; however, some have salinity levels similar to hard water. In this area, regulations or applicable rules have not yet been implemented. As a result, the management and sustainability of water resources are at risk. In terms of sustainability, the management of water resources can meet daily water needs for the next few years. Still, it does not guarantee the sustainability and quality of water, especially for drinking. However, there is hope in the form of the CSR program plans, which, if realized, could significantly improve the situation. Additionally, research on managing water sources in karst areas is needed.

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