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Environmental Economic Valuation of Water Utilization in Keceme Cave, Gunungkidul, Yogyakarta, Indonesia

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Abstract

The Karst Region of Gunungsewu in Gunungkidul Regency is the largest karst area in Southeast Asia, containing significant potential for groundwater resources. However, due to its unique topography and karst morphology, much of this region experiences drought during the dry season. One of the potential water sources successfully utilized by local communities is Keceme Cave in Padukuhan Temuireng II, Girisuko Village, Panggang Subdistrict. This study aims to assess the economic valuation of the environmental services provided by Keceme Cave's water and its contribution to community water resilience. The research methods include field observations, water quality tests, discharge measurements, and socioeconomic surveys of water users. The economic valuation was conducted using the cost-saving approach, comparing the costs of water from tanker trucks, water kiosks, and water sourced from Keceme Cave. The results show that water from Keceme Cave has a pH of 7.3–7.7, TDS of 331–358 ppm, EC of 644–776 µS/cm, and a temperature of 27.2°C. The average water discharge is 0.11 liters/second with a supply of 9,500 liters per day. Economically, the community has saved up to IDR 2.1 billion over six years of utilization. Beyond economic value, the use of this water source has fostered new awareness of cave conservation, shifted cultural perceptions toward caves, and strengthened community-based social networks.

Keywords: *Economic valuation, environmental services, Gunungsewu karst, community-based conservation word*

1. Introduction

Karst landscapes are ecosystems with unique, complex, and highly vulnerable characteristics. Geologically, these areas are composed of limestone that is easily dissolved by water, forming underground systems of interconnected passages, rivers, and caves. This condition causes rainwater that falls on the surface to rapidly infiltrate through cracks and fractures in the limestone, making surface water difficult to find. This phenomenon explains why the karst region of Gunungkidul is known as an area rich in groundwater but poor in surface water. Ecologically, karst plays an important role as a natural reservoir and regulator of groundwater, a supporter of cave and surface biodiversity, and a provider of essential environmental services for surrounding communities. However, the carrying capacity of this ecosystem is extremely fragile. Small disturbances such as deforestation, limestone mining, or changes in land cover can significantly affect the ability of karst to store water. Socially, communities' reliance on surface water makes karst regions highly vulnerable to water crises, especially during prolonged dry seasons.

The chronic drought phenomenon in Gunungkidul presents a paradox. On one hand, the region frequently experiences water deficits for domestic, agricultural, and livestock

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needs. On the other hand, underground river systems such as Bribin, Seropan, and Sindon store enormous volumes of water that flow year-round. This great potential has not been optimally utilized due to technological limitations, high exploration costs, and limited local knowledge. This disparity underscores the importance of innovation and collaboration between science, technology, and local wisdom in managing water resources in karst regions. One concrete example of community-based groundwater utilization is the initiative undertaken at Keceme Cave, located in Padukuhan Temuireng II, Girisuko Village, Panggang Subdistrict, Gunungkidul Regency. Since 2019, the Save Rescue Indonesia community, together with local residents, has initiated the exploration and utilization of water from Keceme Cave in response to extreme drought. This activity is not only aimed at providing clean water but is also driven by the spirit of self-reliance, social solidarity, and environmental conservation. The water extracted from the cave is used for domestic needs of nearby communities and stands as evidence that community-based approaches can serve as adaptive solutions to water crises in karst regions.

The phenomenon at Keceme Cave is particularly interesting to study because it reflects the integration of geological, ecological, social, and economic dimensions within a single natural resource management system. Geologically, the cave is part of a major underground river network in the southern Javanese karst mountains. Ecologically, using cave water in a limited and cautious manner helps maintain the balance of the hydrological system. Socially, this initiative demonstrates how community capacity can grow through collaborative practices, local knowledge, and the values of mutual cooperation. Economically, the water from the cave provides tangible environmental service values — including water cost savings, improved community productivity, and strengthened social resilience to drought. The concept of economic valuation of environmental services becomes important in this context. Through valuation, ecological and social benefits of water resources can be translated into measurable economic values, which can serve as the basis for decision-making, policy planning, and conservation-based resource management. Economic valuation does not only assess water as a commodity but also accounts for sustainability values, existence values, and option values of the resource for future generations. Thus, the economic valuation of environmental services at Keceme Cave can serve as a local model for assessing and managing the potential of karst groundwater sustainably. Through an interdisciplinary approach that integrates geological, ecological, social, and economic sciences, the study of Keceme Cave is expected to provide a comprehensive overview of how karst communities build resilience to drought. Furthermore, this research can strengthen a new paradigm in natural resource management that positions communities not only as beneficiaries but also as primary actors in conservation and environmental stewardship.

2. Methods

a. Research Location and Period
   The research was conducted at Keceme Kidul Cave, Padukuhan Temuireng II, Girisuko Village, Panggang Subdistrict, Gunungkidul (coordinates 8°01'29.8"S, 110°26'45.1"E). Fieldwork was carried out periodically from 2019 to 2024.
b. Type and Approach of Research
   This study is descriptive-quantitative with an eco-social approach. Data were collected through hydrological measurements, laboratory tests, field observations, and socioeconomic household surveys.

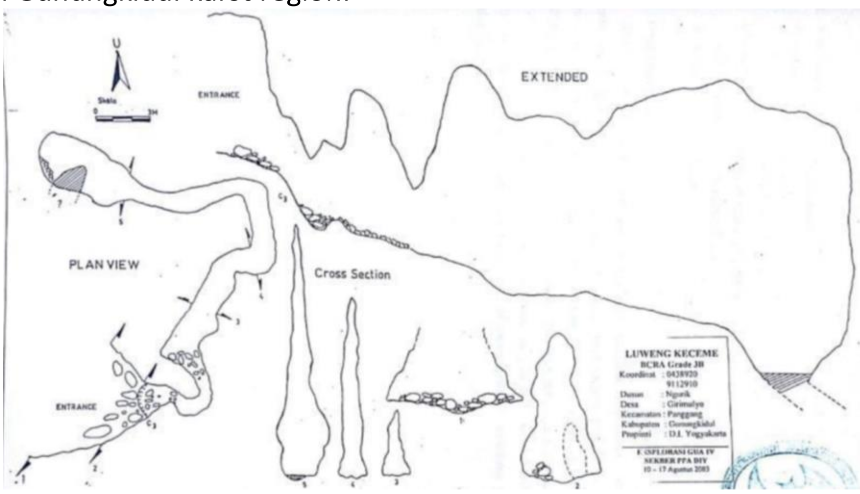
c. Data Collection Techniques
   1. Direct observation: measuring discharge, depth, and water quality.
   2. Water quality testing: including pH, TDS, EC, temperature, and salinity.
   3. Interviews and questionnaires: conducted with 89 household heads who use the water.
   4. Secondary data: hydrology literature, geomorphological data, and reports from Save Rescue Indonesia.

d. Data Analysis
   1. Hydrological analysis: discharge was calculated using the volumetric method and flow comparison.
   2. Economic valuation analysis:
      VE=(Ctanker−Ccave)×NHH×12×T where CCC is the monthly cost, NHH is the number of households, and TTT is the duration in years.
   3. Social analysis: using qualitative interpretation to understand changes in behavior and local wisdom.

3. Results

a. Characteristics of the Cave and Surrounding Environment

Keceme Cave is one of the distinctive geomorphological features of karst landscapes, formed through the collapse of the roof of an underground river passage, commonly referred to as a *karst window*. This phenomenon occurs when the upper section of an underground river channel experiences intensive dissolution and weathering, eventually collapsing and creating a direct connection between the surface and the groundwater system. This natural structure functions as an active sinkhole, serving as an entry point for surface water into the underground hydrological system. Thus, Keceme Cave plays an important role in regulating the micro-hydrological cycle of the southern Gunungkidul karst region.



Picture 1. Map of Keceme Cave, Girisekar, Panggang, Gunungkidul, Yogyakarta

Morphologically, the cave has a main passage approximately 20 meters long with an inclination of 15°–25°, leading toward deeper underground water channels. The passage displays bedded limestone walls with characteristic solution features such as vadose channels, scallops, and dripstones. The presence of smooth walls with areas showing active water flow indicates that Keceme Cave remains part of a living underground river system (*active conduit system*). This suggests that the cave is not only a geomorphological unit but also a functional component of the subterranean drainage system in the Gunungsewu karst.

The environment surrounding Keceme Cave is dominated by conical limestone hills, a typical feature of tropical karst landscapes. These hills are composed of Middle to Late Miocene Wonosari Formation limestone that has undergone prolonged and intensive dissolution. This morphology forms a rolling landscape with inter-hill depressions (*dolines*) that temporarily accumulate rainwater before it infiltrates into the ground. Surface water flow patterns are generally of the *disappearing stream* type, in which water flows into ponors or swallow caves such as Keceme.

The vegetation surrounding the cave consists of typical dry karst flora, dominated by teak (*Tectona grandis*) on sloped rocky terrain, coconut (*Cocos nucifera*) in open valleys, and banana (*Musa* sp.) near seasonal water channels. This vegetation serves important ecological functions: reducing erosion, slowing runoff, and enhancing water infiltration. The plant types also reflect adaptation to shallow soils and limited water availability—a hallmark of dry tropical karst ecosystems. In terms of land use, areas around Keceme Cave are utilized for dryland farming (*tegalan*), with major crops including maize, cassava, and peanuts. This farming system depends heavily on seasonal rainfall, making it highly vulnerable to drought. In this context, Keceme Cave holds strategic value, not only ecologically as part of the karst drainage system but also socially by providing an alternative water source for the community, especially during extended dry seasons.

Given these geomorphological, hydrological, and vegetative characteristics, Keceme Cave can be categorized as a multifunctional active karst ecosystem—playing roles in geological processes, maintaining ecological balance, and supporting local socio-economic resilience through water provision and other environmental services.

b. Water Quality and Quantity

Physical water quality tests indicate that Keceme Cave water shows excellent and stable characteristics throughout the observation period. The pH level ranges from 7.3–7.7, indicating neutral to slightly alkaline conditions, typical of groundwater in limestone karst regions where $CaCO_3$ dissolution is dominant. This pH range is suitable for domestic use, agriculture, and conservation, as it does not cause corrosive effects on pipes or metal equipment and supports natural microbial activity in the aquifer.

Total Dissolved Solids (TDS) values of 331–358 ppm reflect relatively low dissolved solids, indicating high purity and minimal anthropogenic contamination. According to Government Regulation No. 82/2001 on Water Quality Management and Pollution Control, these TDS values are well below the limit of 500 mg/L for Class B water, which includes domestic and agricultural uses. Thus, Keceme water can be classified as clean water suitable for consumption after simple treatment such as filtration and mild disinfection.

The Electrical Conductivity (EC) value of 644–776 µS/cm suggests moderate ionic conductivity, reflecting natural mineral content such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) from limestone dissolution. This conductivity pattern indicates that the water originates from a confined karst aquifer with slow movement, allowing mineral dissolution without excessive ion accumulation.

The average water temperature of 27.2°C indicates thermal stability, typical of groundwater insulated from surface temperature fluctuations. This stability is important for maintaining the cave's micro-ecosystem and confirms that the water originates from deep infiltration that has undergone natural filtration through karst layers. The salinity of 0‰ confirms the absence of seawater intrusion, despite the cave's proximity to the southern Gunungkidul coastal karst.

Quantitatively, the average discharge of 0.11 liters per second represents relatively stable flow for a seasonal karst water source. With a supply capacity of approximately 9,500 liters per day or 285,000 liters per month, Keceme Cave has significant potential as an alternative household water source. Assuming average rural water needs of 60 liters per capita per day, the cave's supply can sustainably serve around 150–160 people.

Picture 2 & 3, the installation of the water lifting pump and the pump system installed in Keceme Cave, Girisekar, Panggang, Gunungkidul, Yogyakarta

These physical and quantitative characteristics indicate that Keceme Cave has high ecological and social carrying capacity as a community-based water source. Sustainability of the cave's water resources depends not only on hydrological characteristics but also on the community's capacity to maintain water quality and quantity, especially amid threats from land degradation and reduced infiltration due to land-use changes.

c. Biodiversity Aspects

Keceme Cave functions not only as a crucial water source for the community but also as a habitat for a subterranean ecosystem with high ecological value. The cave contains various troglophilic and troglobitic fauna adapted to low-light and high-humidity environments. Identified species include bats (order *Microchiroptera*), barn owls (*Tyto alba*), Toad (*Polypedates leucomistax*), frogs (*Bufo melanostictus*), whip spider (*Amblypygi*) and freshwater shrimp (*Crustacea*). These organisms represent interconnected ecological chains within the underground karst system, particularly in energy and nutrient cycles.

Bats, for example, play essential roles as insect population regulators, seed dispersers, and major contributors of organic matter through guano, which becomes the primary energy source for other cave organisms. Accumulated guano serves as a substrate for microorganisms, saprophagous insects, and freshwater shrimp. The presence of barn owls (*Tyto alba*) as apex predators indicates that Keceme Cave and its surroundings still maintain a functional trophic network.

Freshwater shrimp and frogs serve as biological indicators of water quality and microclimate stability. Both species are highly sensitive to changes in temperature, lighting, and chemical contamination. Field observations show that since water utilization began in 2019, populations of certain cave fauna have decreased noticeably. This suggests ecological stress due to microhabitat changes, such as reduced humidity, increased human activity, and disruption to daily behavior cycles.


Picture 3 & 5, picture of Whip spider (Amblypygi) and toad (Polypedates leucomistax) in Keceme Cave, Girisekar, Panggang, Gunungkidul, Yogyakarta

The decline in cave fauna populations highlights the need to balance human needs with conservation of subterranean ecosystems. Activities such as water extraction, pipe installation, and the use of artificial lighting can shift the cave microclimate, affecting fauna behavior and reproduction. Therefore, water management in Keceme Cave must apply sustainable conservation principles, including restricting human access to sensitive areas, periodic monitoring of indicator fauna, and establishing ecological protection zones.

Within community-based management, Save Rescue Indonesia has attempted to maintain this balance through low-impact utilization strategies, emphasizing preservation of natural discharge, gravity-based piping without pumps, and avoiding excavation of cave structures. This aligns with karst ecosystem-based management principles, which require that resource use must maintain ecological functions of caves as natural habitats and components of underground hydrological systems. Thus, Keceme Cave serves as a real example of how water resource management and karst biodiversity conservation can coexist, provided that governance is grounded in scientific knowledge, community ecological awareness, and adaptive conservation policies.

d. Social and Cultural Aspects

Before water utilization activities began, Keceme Cave was perceived by local residents as a sacred and mystical place—part of the Javanese spiritual landscape filled with symbolic meaning. Traditionally, caves are associated with supernatural realms, ancestral spirits, or guardian entities. This perception caused villagers to avoid caves, leaving them unused despite their natural potential. The cave became a "restricted" space within the local belief system—respected but kept distant from daily human activity.

Since 2019, however, interventions by Save Rescue Indonesia have led to significant shifts in local social perspectives. The community began viewing Keceme Cave not merely as a sacred site to be avoided but as a source of life and ecological knowledge to be protected. This transformation was conducted through participatory and culturally sensitive approaches, ensuring that changes did not provoke social resistance. Rather than eliminating spiritual elements, Save Rescue Indonesia integrated sacred values into conservation and water management practices.

Pictures 6 & 7, picture of community's mutual cooperation to build a water reservoir and present the ritual offering in front of Keceme Cave, Girisekar, Panggang, Gunungkidul, Yogyakarta

This transformation reflects a form of ecological–spiritual syncretism typical of Javanese karst communities. Rituals such as offerings, communal prayers, and cave sanctification ceremonies are no longer seen as superstition but as expressions of respect toward nature and the underground hydrological system. Offerings placed at the cave entrance, for instance, are reinterpreted as symbols of ecological awareness—acknowledging water as a vital resource whose balance must be maintained. Thus, the cave functions simultaneously as a spiritual and ecological space, with each reinforcing the other.

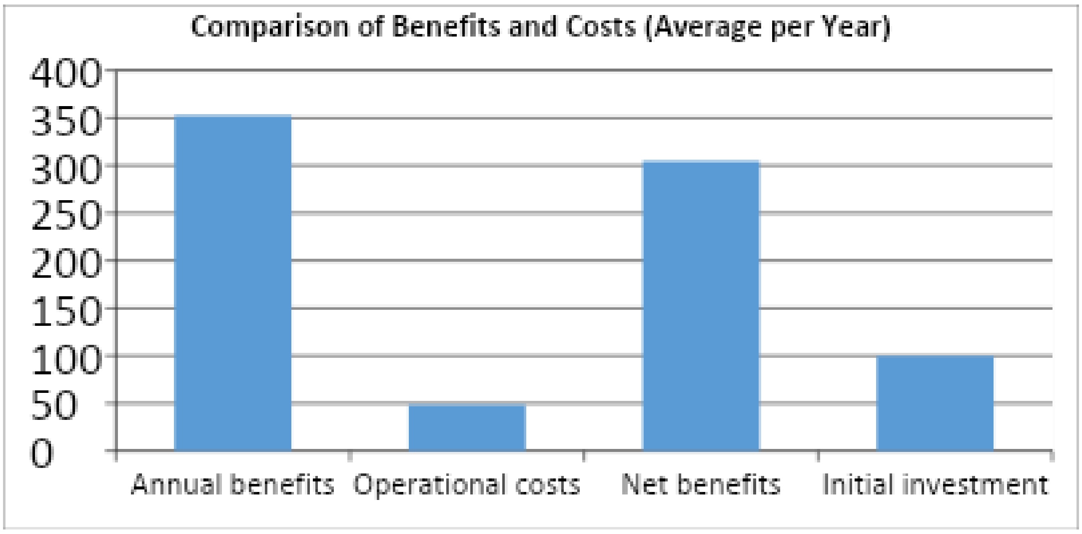
This perceptual shift highlights the sociocultural role of caves as mediating spaces between humans and nature. Rituals and spiritual practices serve as effective ecological education tools because they embed conservation values within local wisdom. In the framework of human ecology theory, the community's relationship with Keceme Cave exemplifies cultural adaptation to extreme environmental conditions, such as chronic drought in karst landscapes.

Integrating spiritual and ecological values creates strong social capital for sustainable water management. Ritual traditions function as social control against over-exploitation and strengthen collective ownership of the cave. In this context, Keceme

Cave has transformed into a living symbol of water conservation—both physically and culturally—demonstrating that cultural approaches can effectively support sustainable natural resource management in communities with strong local value systems.

e. Economic Valuation Analysis

The economic valuation aims to assess the monetary benefits of the groundwater management system in Keceme Cave, initiated by Save Rescue Indonesia since 2019. This approach demonstrates that sustainably managed natural resources offer not only ecological benefits but also measurable economic advantages. The analysis focuses on direct household cost savings using the cost-saving approach, incorporating investment, operational costs, and financial benefits over a five-year period.



Picture 8. Comparison of benefit and cost (Average per year) of water utilization in Keceme Cave

The model assumes an initial investment cost of IDR 100,000,000 used for infrastructure such as pipelines, reservoirs, and distribution systems. Operational costs are covered through community contributions of IDR 45,000 per household per month. Before the system existed, residents purchased water tankers at IDR 250,000 per 5,000 liters. With an average household need of 7,500 liters per month, pre-intervention water costs totaled IDR 375,000 per month, resulting in direct savings of IDR 330,000 per household per month.

With 89 active households, total annual economic benefits reach approximately IDR 352,440,000. Annual operational costs total IDR 48,060,000, producing net annual benefits of IDR 304,380,000. Over five years, with an 8% discount rate, the present value of benefits is IDR 1,407,190,725, while the present value of operational costs is IDR 191,889,644. After accounting for the initial investment, the Net Present Value (NPV) is IDR 1,115,301,081.

A Benefit-Cost Ratio (BCR) of 4.82 indicates that every IDR 1 invested produces economic benefits worth IDR 4.82. The Internal Rate of Return (IRR) of 304.1% far exceeds the 8% discount rate, indicating extremely high returns and a rapid payback period of less than one year (approximately four months). Thus, the Keceme Cave water system is highly feasible for expansion and replication in other karst regions.

Beyond direct financial gains, the system enhances water security and reduces drought vulnerability, a major issue in Gunungkidul's karst communities. Savings of up to

88% allow households to redirect funds to education, health, or productive activities. Meanwhile, community cooperation and shared ownership strengthen social resilience.

However, the analysis does not yet include indirect benefits such as reduced water-fetching time, improved public health due to easier clean water access, or increased economic productivity. Nor does it capture non-use values such as existence or bequest values associated with conserving cave ecosystems. Inclusion of these components in a Total Economic Value (TEV) analysis would likely yield significantly higher estimates.

Thus, the Keceme Cave water management initiative functions as both a technical solution to drought and an effective community-based environmental economics model. Community involvement from exploration to infrastructure maintenance demonstrates true community-based resource management, aligning with sustainability principles that balance ecological, social, and economic dimensions.

f. Environmental Impacts and Conservation Recommendations

Human activities in Keceme Cave—such as installation of metal stairs, water pipes, and gabion walls for erosion control—have unintentionally altered the cave's physical and ecological conditions. Although these interventions aim to facilitate access and water distribution, they may cause minor impacts on the cave's natural structure, wall stability, and microhabitats of cave fauna. To balance utilization and preservation, integrated technical conservation guidelines are necessary.

1. Restricting access to sensitive areas of the cave is essential to prevent physical damage such as wall abrasion or disturbance to bat colonies. Certain zones should be designated as limited conservation areas under community supervision.
2. Water quality monitoring every six months is required to ensure that water extraction does not degrade ecosystem health. Key parameters such as pH, TDS, EC, temperature, and heavy metal content must remain within clean water standards.
3. Planting conservation vegetation around the catchment area is recommended to enhance infiltration, reduce runoff, and maintain hydrological balance. Suitable species include endemic or karst-adaptive plants such as teak, kemlandingan, and lamtoro.
4. Community education about cave ecosystems and biodiversity should be integrated into management programs. Through outreach, training, and educational tourism, residents can understand the importance of protecting caves as both water sources and high-value ecological habitats.

Implementation of these guidelines will allow sustainable utilization of Keceme Cave water without compromising ecological functions, while strengthening community roles in conservation-based resource management.

4. Discussion

The discussion in this study aims to explain the main findings obtained from the implementation process, effectiveness testing, and ongoing assessment of the AR-KARSA augmented reality educational media development. In general, the results indicate an increase in user knowledge and understanding of karst geology concepts, increased conservation interest, and high product validity based on expert assessment. These findings are outlined sequentially based on the research objectives, supplemented by tables, graphs, and relevant documentation presented in the results section. First, the results of user requirements and implementation testing indicate that 92% of users can operate AR-KARSA without technical assistance. This finding demonstrates that the application's interface design meets the principles of usability and user-centered design. This aligns with human-computer interaction (HCI) theory, which emphasizes that ease of use is a key factor in the success of technology-based learning media. The presented usage graphs support these findings, with the majority of respondents stating that the application is easy to understand and intuitive.

Furthermore, the 34% increase in understanding of karst concepts based on pre- and post-test scores indicates that AR-KARSA is effective as a conservation educational medium. This improvement is consistent with previous research suggesting that AR-based media can improve retention, visual-spatial understanding, and conceptual comprehension in science and geology materials. The pre-posttest results table in the results section supports this conclusion and shows relatively uniform improvement across all respondents. Expert validation also confirmed the product's quality, with an average feasibility score of 89%, categorized as "Very Feasible." This assessment encompassed pedagogical, technical, visual, and geological content aspects. Theoretically, these results support the concept that the success of learning media is determined not only by the technology used, but also by the integration of scientific content, instructional design, and visual quality. The accompanying validation table shows that all four experts gave consistent and positive assessments of the product.

Furthermore, several suggestions for improvements, such as increasing the resolution of 3D objects and adjusting visual contrast, confirm that the implementation of AR technology in the field is significantly influenced by environmental conditions, such as karst surface texture and light intensity. This aligns with AR theory, which states that marker detection is highly sensitive to distance, lighting, and camera stability. The presented internal test table demonstrates variations in marker detection performance at different distances and light intensities, thus providing the basis for revisions during the product refinement stage. Overall, this discussion demonstrated that AR-KARSA successfully achieved its stated activity target of producing a feasible, effective, and relevant AR-based conservation education product. The integration of observation results, data tables, implementation graphs, and field documentation provided empirical evidence that AR technology has the potential to be an innovative educational medium to support karst conservation in a sustainable digital era.

5. Conclusion

Keceme Cave is an active cave system with an average discharge of 0.11 L/second and water quality suitable for consumption. The utilization of Keceme Cave water has generated economic savings for the community amounting to IDR 2.1 billion over five years. Beyond economic value, Keceme Cave provides social benefits, including increased solidarity, conservation awareness, and cultural transformation within the community. Integrated community-based management and regional policy support are required to ensure the ecological and social functions of Keceme Cave remain sustainable.

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