



Sustainability analysis of spring water utilization as a community-based clean water supply system in rural areas

Evi Cahyanila Kurnia Widjoyo¹, Aulia Rizky Zildzan¹, Olifadia Eka Andiny Aulia¹, Aditya Rayyis Haqqani¹, Fitranto Adi Nugroho¹, Trida Ridho Fariz^{1,*}, Abdul Jabbar¹, Putri Alifa Kholil¹, Amnan Haris¹

¹ Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

*Correspondence: trida.ridho.fariz@mail.unnes.ac.id

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ABSTRACT

Background: This study aims to assess the sustainability of utilizing spring water as a clean water supply system (WSS) in Truko Hamlet, Surokonto Kulon Village, Kendal Regency. Parikesit Spring serves as the primary source of clean water for the village community and plays a crucial role in meeting daily needs. By integrating a community-based approach through the Community-Based Water Supply and Sanitation Program/*Penyediaan Air Minum dan Sanitasi Berbasis Masyarakat* (PAMSIMAS), water resource management is carried out independently and sustainably. **Method:** The research method follows a sustainability framework for WSS, encompassing social, financial, institutional, environmental, and technical aspects. Data collection involved laboratory water quality analysis and in-depth interviews with eight key respondents, including PAMSIMAS managers and community users. Environmental services provided by the spring were also identified. **Findings:** The findings indicate that the WSS in this village is able to meet the community's clean water needs in terms of quantity, quality, and continuity, despite challenges such as sedimentation during heavy rains and limited availability of backup pumps. High community participation in water management and the sustainability of PAMSIMAS services are key points supporting the achievement of Sustainable Development Goal (SDG) 6, "Clean Water and Sanitation for All." **Conclusion:** For further sustainability, recommendations include improving water quality, strengthening the organizational structure, and enhancing technical facilities. **Novelty/ originality of this article:** The novelty of this study lies in evaluating the sustainability of a community-based spring water supply system (PAMSIMAS) in Truko Hamlet, integrating social, technical, environmental, and institutional aspects to support SDG 6.

KEYWORDS: community-based water management; spring water; PAMSIMAS; rural water supply sustainability; ecosystem service.

1. Introduction

Water is a fundamental necessity for all human societies. Beyond its biological function of sustaining life, it underpins health, economic productivity, cultural practices, and ecological stability (Amalia et al., 2024; Karr, 1993). Yet, despite its ubiquity on Earth, access to water that is both safe and reliable remains one of the most pressing development challenges of the 21st century. The World Health Organization (WHO) and UNICEF Joint Monitoring Programme reported that in 2017, an estimated 785 million people, or about 11% of the global population, still lacked access to basic water services, defined as improved

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water sources with collection time less than 30 minutes for a round trip (Daniel et al., 2021a). The majority of this population resides in rural areas, where infrastructure gaps, environmental challenges, and institutional limitations converge to create persistent inequalities between rural and urban communities (World Health Organization, 2019).

The consequences of inadequate water access extend far beyond thirst or household inconvenience. Lack of clean water has been directly linked to the prevalence of waterborne diseases such as diarrhea, cholera, and dysentery, which disproportionately affect rural populations with limited sanitation facilities (Liu et al., 2024). Moreover, the uneven distribution of safe water services undermines progress toward achieving Sustainable Development Goal (SDG) 6.1: to “achieve universal and equitable access to safe and affordable drinking water for all” by 2030 (Arora & Mishra, 2022). While substantial progress has been made in extending basic services, global trends of population growth, climate change, and groundwater depletion suggest that water scarcity is accelerating, particularly in regions where livelihoods depend heavily on natural hydrological systems (Shunglu et al., 2022).

Indonesia is one of the countries facing water challenges. Despite its abundant water resources, including rivers, lakes, and springs, Indonesia still faces significant challenges in ensuring equitable access to clean water, particularly in rural areas. According to the 2017 WHO/UNICEF JMP report, 95% of urban households in Indonesia had access to at least basic water services, compared to only 82% in rural areas (Daniel et al., 2021a). The disparity not only highlights infrastructural gaps but also the socio-economic divide between urban centers and peripheral rural communities. While urban water service coverage increased modestly by 5% between 2000 and 2017, rural access grew more substantially by 16%, indicating the impacts of targeted interventions. Nonetheless, many rural households remain dependent on vulnerable sources such as unprotected springs and shallow wells, which are easily contaminated and subject to seasonal fluctuations (Fatimah & Maulani, 2019; Fariz et al., 2025). In response to these disparities, the Government of Indonesia, with support from the World Bank, launched the Community-Based Drinking Water Supply and Sanitation Program (PAMSIMAS) in 2007. This program represents one of the largest rural water supply initiatives in Southeast Asia, aiming to increase coverage in underserved villages by mobilizing communities to manage their own water systems. By 2018, PAMSIMAS had benefited an estimated 17.2 million people across the country (Daniel et al., 2021b). At the operational level, village water management committees known as drinking water and sanitation supply system management group play a central role in planning, constructing, and maintaining local water supply infrastructure (Kurniatin & Maksum, 2022). The program’s strength lies in its participatory approach, emphasizing local ownership and accountability, but its long-term sustainability remains contingent on multiple interlinked factors, ranging from financing to environmental conservation.

The sustainability of community-based water supply systems is often framed through the FIETS (Financial, Institutional, Environmental, Technical, and Social) framework (Swastomo & Iskandar, 2020). Each aspect represents both an enabler and a vulnerability point. Financial sustainability ensures that water tariffs or contributions cover operational and maintenance costs; institutional sustainability depends on capable and transparent village committees; environmental sustainability requires protection of raw water sources against degradation; technical sustainability involves reliable infrastructure; and social sustainability hinges on community participation and equitable access (Krisdhianto & Sembiring, 2016; Andriyanto et al., 2023). Studies consistently show that weaknesses in any of these dimensions can compromise long-term access (Djono, 2011).

In rural Indonesia, springs are among the most critical raw water sources. They provide gravity-fed, relatively low-cost, and renewable supplies suitable for community-scale systems (Wadu et al., 2020). Increasingly, springs are recognized not just as water sources but as hydroecological keystones, functioning as unique groundwater-dependent ecosystems (GDEs) that provide critical ecosystem services (Stevens et al., 2021; Cantonati et al., 2020). However, the sustainability of spring utilization is increasingly threatened by land-use change, deforestation, sedimentation, and variability in rainfall intensity (Okafor

et al., 2024). Heavy rains, for example, can increase turbidity and sediment loads, complicating water treatment and raising costs for communities with limited resources. In Truko Hamlet, Surokonto Kulon Village, Pageruyung District, Kendal Regency, Central Java, springs such as Parikesit serve as the lifeline of agricultural and domestic activities. Yet, sustaining these resources in the face of environmental pressures and institutional limitations remains a daunting challenge.

PAMSIMAS has been implemented in several villages in Kendal Regency, including Truko, where community-driven management of the Parikesit spring has provided an essential safety net for clean water supply. The program has improved access, strengthened local participation, and fostered conservation awareness. Nevertheless, challenges remain acute. As studies show, many PAMSIMAS systems falter after initial project support ends, largely due to weak institutional capacity, inadequate financing, or insufficient environmental stewardship (Kurniatin & Maksum, 2022; Andriyanto et al., 2023). This raises important questions about the long-term resilience of spring-based community water supply systems, especially in regions where agriculture, population growth, and ecological stress converge.

Previous studies on community-based rural water supply in Indonesia have largely focused on system functionality, financial mechanisms, or institutional governance (Wandari et al., 2023; Putri et al., 2023; Nugroho et al., 2024). Few have integrated all sustainability dimensions holistically, particularly in spring-based systems where ecological services play an equally critical role. Moreover, while system dynamics approaches have been applied to water and sanitation projects in other contexts, their application in Indonesian rural water systems remains limited (Daniel et al., 2021b). Given that water, sanitation, and hygiene (WASH) systems are inherently complex and dynamic, integrative approaches are needed to understand sustainability pathways (Valcourt et al., 2020). The urgency of this research aligns closely with Indonesia's National Medium-Term Development Plan (2020–2024), which sets a target of 100% appropriate drinking water and 15% safely managed drinking water services by 2024. Despite these ambitious goals, many rural areas remain underserved, with disparities persisting even within provinces (National Development Planning Agency, 2020). Achieving universal access requires not only expansion of infrastructure but also robust strategies to safeguard the sustainability of existing systems, particularly those dependent on springs. As (Kurniatin & Maksum, 2022) emphasize, villages that have already received PAMSIMAS assistance must be supported in managing and maintaining their systems, while those without access require alternative governance pathways to secure water services.

This study therefore seeks to evaluate the sustainability of spring water utilization as a community-based clean water supply system in Truko Hamlet, Kendal Regency, with a particular focus on the integration of technical, environmental, financial, institutional, and social dimensions. By analyzing the interdependence of these aspects, the research addresses a critical gap in existing literature, which has rarely considered spring-based systems within a holistic sustainability framework. Unlike prior studies that emphasize non-spring sources or urban contexts (Wandari et al., 2023; Putri et al., 2023; Lomi et al., 2021), this work highlights the ecological services of springs and the role of community participation in ensuring their conservation. Ultimately, the study aims to contribute to both academic discourse and practical policy by demonstrating how community-driven initiatives can be sustained in the long run. Its findings are directly relevant to the global SDG 6.1 agenda, which remains unmet in many rural regions worldwide, as well as to national efforts to strengthen rural water governance in Indonesia. By situating the Truko case within the broader debates on rural water sustainability, this research underscores the dual challenge of ensuring immediate water security while safeguarding environmental and institutional resilience for future generations.

2. Methods

The study was conducted in Truko Hamlet, Surokonto Kulon Village, Kendal Regency, Central Java. Surokonto Kulon Village is geographically positioned at 110°08'46" East Longitude and 7°09'6.15" South Latitude. The village lies within a moderate plain area, with an average elevation of approximately 600 meters above sea level. Administratively, Surokonto Kulon Village is bordered as follows: to the north by Pagergunung Village, to the east by Surokonto Wetan Village, to the south by Bangunsari Village, and to the west by Kebongembong Village (Figure 1). This setting provides a unique context for examining the sustainability of community-based water supply systems in rural upland environments.

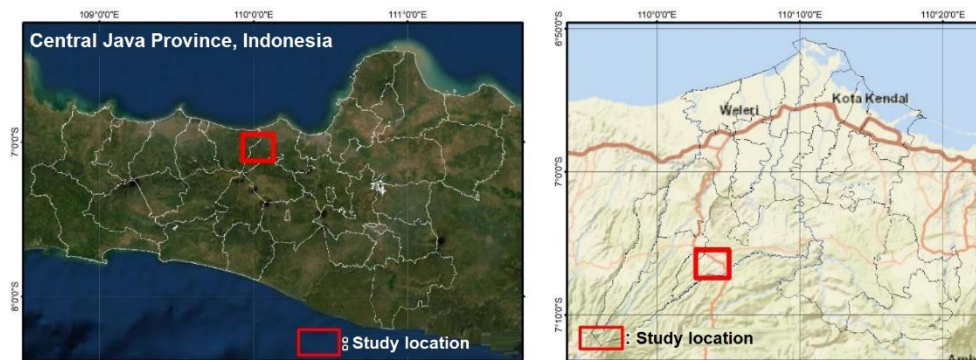


Fig. 1. Study location

A water supply system is considered sustainable when it effectively integrates multiple interrelated aspects: social, financial, institutional, environmental, and technical (Mukherjee & van Wijk, 2003; Wandari et al., 2023). These five dimensions serve as the primary indicators for assessing sustainability in this study, as illustrated in Figure 2. To comprehensively evaluate these indicators, this research employs a mixed-methods approach, combining both qualitative and quantitative data collection and analysis techniques.

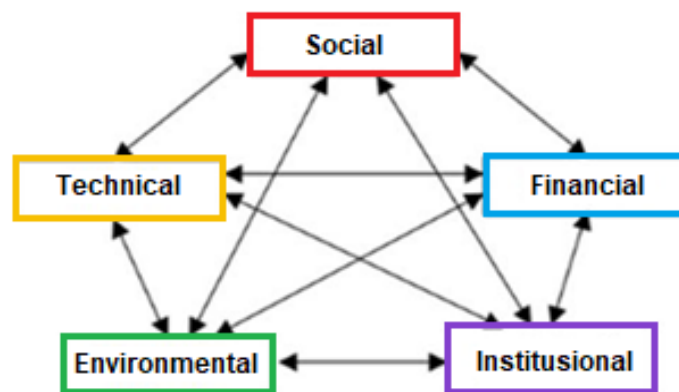


Fig. 2. Key aspects of sustainable clean water infrastructure (Wandari et al., 2023; Mukherjee & van Wijk, 2003)

2.1 Qualitative data collection

Social data were collected using qualitative methods, specifically through in-depth interviews and direct observation. Primary data were gathered via semi-structured interviews with local community members, utilizing a purposive snowball sampling technique. Interviewees included residents of Surokonto Kulon Village, PAMSIMAS (Community-Based Water Supply and Sanitation Program) management personnel, and individuals directly utilizing the Parikesit Spring. A total of eight respondents were purposively selected to represent the diverse groups involved in clean water management.

However, to strengthen the sampling validity, this study should clearly describe the criteria used in selecting respondents, such as their level of involvement, years of experience in water-related activities, or specific knowledge about the spring water system. Additionally, a clearer explanation of the snowball sampling process and how initial subjects were identified would enhance the transparency and replicability of the research. The profile of the respondents is summarized in Table 1.

Table 1. Respondent profiles

Respondent	Age	Gender
Village Head	45	Male
PAMSIMAS Chairperson	58	Male
Pump Technician I	58	Male
Pump Technician II	43	Male
Resident I	64	Male
Resident II	50	Female
Resident III	59	Male
Resident IV	51	Male

2.2 Quantitative data collection

Quantitative data were obtained through laboratory analysis of water quality parameters. Water samples were collected using a random sampling technique from two distinct locations. The samples were then analyzed at the Environmental Laboratory of Universitas Negeri Semarang. Physical parameters assessed included odor, turbidity, taste, and color, while the chemical parameter measured was pH (acidity level). The results were compared with the national standards set forth in Government Regulation No. 82 of 2001 concerning Water Quality Management and Water Pollution Control.

2.3 Data analysis

Data analysis was conducted using both descriptive quantitative and qualitative approaches. Qualitative analysis focused on interpreting interview and observation data to understand social, institutional, and management dynamics. Quantitative analysis involved statistical and comparative evaluation of water quality parameters to assess environmental and technical sustainability. This dual analytical approach allowed for a holistic assessment of the sustainability of the community-based water supply system in Surokonto Kulon Village.

3. Results and Discussion

3.1 Sustainability of water management and provision

Surokonto Kulon Village covers an area of 3.40 km², divided into 15 Neighborhood Unit and 7 Community Association. As of 2023, the village is home to 2,093 residents. The research focus area, Truko Hamlet, is part of this village and consists of 5 Neighborhood Unit and 2 Community Association. The majority of residents in Truko Hamlet work as farmers and are highly dependent on the PAMSIMAS water supply system, as there is no centralized piped water utility in the area. Water Resource Utilization in Truko Hamlet began in the early 2000s with the installation of a hydraulic ram pump. In 2011, a transmission pipe was installed, marking a significant step in water management. The system has since evolved, and currently, PAMSIMAS provides clean water access to the entire hamlet. The number of household connections has steadily increased, reaching 150. This growth reflects both the reliability and acceptance of the system among residents.

Community members are required to pay a water tariff set through mutual agreement between PAMSIMAS management and the community. The current tariff is IDR 2,000 per cubic meter, with an additional subscription fee of IDR 5,000. These funds are used for

system maintenance, electricity for pumps, and management fees. Payment collection has proceeded smoothly, with the village head actively compensating for any late payments to ensure operational continuity. This collaborative financial model has proven effective in maintaining service sustainability. The quantity and quality of water from the Parikesit Spring have remained sufficient and protected. Laboratory tests conducted at the Environmental Laboratory of Universitas Negeri Semarang analyzed two samples: one from the Parikesit Spring source and one from a household tap connected to the system. The results are summarized in Table 2.

Table 2. Results of chemical and physical water quality tests

Sample	pH	Odor	Turbidity	Color
1	5.2	None	None	None
2	5.8	None	None	None

Water quality standards refer to Government Regulation No. 82 of 2001 on Water Quality Management and Water Pollution Control, specifically Class 2 water standards. Both samples meet the required standards for pH, odor, turbidity, and color. The water demand in Truko Hamlet ranges from 20 to 115 m³ per household per month. Table 3 details the allocation of PAMSIMAS connections by Neighborhood Unit/Community Association.

Table 3. Allocation of households utilizing PAMSIMAS by Neighborhood Unit/Community Association

Neighborhood Unit/Community Association	Households using PAMSIMAS
01/04	47
02/04	40
01/05	57
02/05	26
03/05	38
Total	208

PAMSIMAS management is entirely community-driven and voluntary. Operations began in 2011 with a single transmission pipe from the Parikesit Spring. By 2018, an additional transmission pipe was installed, enhancing distribution capacity and raw water intake. Communication among PAMSIMAS managers and volunteers is facilitated through a WhatsApp group, while socialization and problem-solving occur through community meetings. In the organizational structure, PAMSIMAS management is led by a protector, then under the protector there is a chairman, then under him there is a secretary, treasurer and technician.

The sustainability of the water supply system in Truko Hamlet is underpinned by strong community participation, transparent financial management, and effective institutional arrangements. The PAMSIMAS model demonstrates how local ownership and collaborative decision-making can ensure reliable access to clean water, even in the absence of formal utility services. Regular water quality monitoring and infrastructure upgrades have further strengthened the system's resilience. The success of PAMSIMAS in Surokonto Kulon Village highlights the importance of integrating social, financial, institutional, environmental, and technical aspects, reflecting the multidimensional framework for sustainable water management. This approach not only meets immediate water needs but also fosters long-term stewardship of local water resources, aligning with broader goals of rural development and environmental sustainability.

3.2 Current condition of the water production unit

The current condition of the water production unit in Truko Hamlet reflects both strengths and challenges within the broader framework of community-based water supply management. In assessing its sustainability, the FIETS framework provides a holistic view,

capturing the multifaceted dimensions of rural water service delivery (Daniel et al., 2021a). Each aspect is interconnected, meaning that weaknesses in one dimension may affect the overall sustainability of the system.



Fig. 3. Water production unit condition

The water production unit has been operating for more than a decade, with relatively stable performance. Two pumps currently sustain operations, one of which was added in 2014 to accommodate the rising number of households served. Since the system’s inception, the pumps have been replaced five times, with the most recent replacement in March 2024, indicating that technical maintenance and renewal are periodically conducted. Both pumps are functional at present, but the absence of a backup pump poses a potential risk for future emergencies. In water supply systems, redundancy is crucial to ensure uninterrupted service, especially during unexpected breakdowns (Daniel et al., 2021b). The pipeline network, made of buried PVC-AW pipes with transmission sizes between 1.5–2 inches and distribution sizes of 1–3 inches, is in good condition, showing only occasional leakages that are quickly repaired by the community. The relatively short length of the main pipeline (350 meters from spring to reservoir) reduces vulnerability to large-scale damage.

Table 4. Sustainability aspects of water management and supply

Sustainability aspect	Description
Social	High community participation in management and maintenance, including mutual cooperation (“ <i>gotong royong</i> ”) for repair and upkeep. Access to clean water is available 24 hours.
Financial	Operational and maintenance costs are covered by user fees. There is a strong willingness to pay among residents; a monthly tariff of IDR 2,000 per cubic meter plus a subscription fee of IDR 5,000 is collected. Collected funds are used for facility maintenance, electricity bills, and management incentives. The billing system is transparent and well-run.
Environmental	Water quantity is sufficient for daily needs. Water quality is monitored, but pH levels do not fully meet the standards set by Government Regulation No. 82 of 2001 concerning Water Quality Management and Pollution Control.
Institutional	The PAMSIMAS management body in Truko Hamlet remains active, with established rules and norms. However, only the chairperson and village head are actively involved in management, and the organizational structure is not optimal. The management body has been in place since 2011, with no changes in leadership.
Technical	The water production unit is in good condition, with two functioning pumps. However, a backup pump and long-term maintenance plans are needed for operational sustainability. The pipeline network, made of buried PVC-AW pipes (transmission: 1.5–2 inches; distribution: 1–3 inches), is robust and rarely damaged. Any leaks are promptly repaired to minimize service disruption.

Another technical measure to maintain functionality involves shutting down the pumps during heavy rainfall to prevent sediment intrusion, which could clog pipes and reduce water quality. This preventive practice demonstrates a level of local technical knowledge

and adaptive management. However, long-term sustainability still requires a preventive maintenance plan, periodic water quality checks, and the establishment of a clear spare-part supply chain, as emphasized in previous WASH studies (Daniel et al., 2021b). The social foundation of the Truko Hamlet water system is particularly strong. Community members are actively engaged in maintaining and repairing the system, often through “*gotong royong*” (mutual cooperation). Such participation is not only practical but also strengthens social cohesion, an important factor in the sustainability of rural WASH programs (Daniel et al., 2021b). The cultural practice of *nyadran*, held annually during the Javanese month of Suro, functions both as a ritual of gratitude and a collective maintenance effort, ensuring that channels are cleaned and water continues to flow smoothly. These practices reinforce a sense of ownership among the villagers, which has been shown in other studies to be a crucial determinant of long-term sustainability (Hamer et al., 2020; Daniel et al., 2021b).

Social resilience is also visible in the community’s responsiveness during crises. When pumps fail or leaks occur, the local technicians and community quickly organize repairs, preventing prolonged service disruption. Such rapid mobilization suggests that local knowledge and social norms are well aligned with the goals of sustaining clean water provision. The financial system underpinning the Truko Hamlet water production unit is robust and transparent. Residents pay a monthly tariff of IDR 2,000 per cubic meter, supplemented by a subscription fee of IDR 5,000. These funds are earmarked for electricity bills, facility maintenance, and incentives for management personnel. Importantly, there is a high willingness to pay among residents, reflecting their recognition of water as a valuable service. This aligns with findings from other rural WASH studies, where sufficient and reliable financial contributions were critical for operational sustainability (Daniel et al., 2021b).

Nevertheless, while the current financial flows are adequate for day-to-day operations, questions remain about long-term capital replacement. Pumps, for instance, have been replaced five times since the system’s establishment, implying a replacement cycle of roughly two to three years. Without an established sinking fund for large-scale investments, the system may face financial stress in the future, particularly if sudden and costly breakdowns occur. Establishing such long-term savings mechanisms is an area for improvement. Institutionally, the system is managed under the framework of PAMSIMAS (Community-Based Water Supply and Sanitation Program). Rules and norms are formally in place, yet the actual management is concentrated in the hands of the chairperson and the village head. This concentration of responsibility indicates limited organizational depth and weak succession planning. A more inclusive structure with active participation from multiple members could enhance institutional resilience and reduce dependency on a few individuals.

The lack of leadership rotation since 2011 suggests institutional inertia. While stability can be beneficial, it may also hinder innovation and adaptation to changing circumstances. Studies from East Sumba, for example, highlight that active and diverse water boards are more effective in ensuring continuity, particularly when leadership transitions are smooth and participatory (Daniel et al., 2021b). Building institutional capacity at the village level, through training and broadening participation, would thus be a key recommendation. Parikesit Spring, the main water source, provides sufficient quantity for daily household needs, with 24-hour access maintained under normal conditions. However, water quality assessments revealed that pH levels do not fully meet the standards stipulated in Government Regulation No. 82 of 2001 on Water Quality Management and Pollution Control. While other physical parameters (odor, turbidity, taste, color) remain within acceptable ranges, the substandard pH could pose long-term health risks if not addressed.

Environmental sustainability also faces challenges during extreme weather events. Heavy rainfall increases sediment loads, necessitating pump shutdowns to protect the system. While this practice is effective in the short term, it underscores the vulnerability of the source to natural fluctuations. Climate variability, including shifts in rainfall intensity, may further exacerbate these issues, as documented in other rural Indonesian contexts (Daniel et al., 2021a). To mitigate risks, regular monitoring, watershed protection, and

small-scale filtration measures could be considered. Taken together, the five FIETS dimensions reveal a mixed picture. Social and financial aspects are strong, supported by cultural practices and a willingness to pay. Technical conditions are stable but lack redundancy, institutional arrangements are functional yet narrow, and environmental sustainability is partly challenged by water quality issues and seasonal sedimentation. This mirrors findings in other rural WASH studies, where sustainability often hinges on balancing strong community engagement with technical and institutional robustness (Daniel et al., 2021b). The interplay between dimensions is evident: strong community participation ensures rapid technical repairs; transparent financial flows foster trust; yet institutional limitations risk over-reliance on a few individuals. Environmental vulnerabilities, while manageable now, could worsen under climate variability unless anticipatory measures are adopted.

3.3 Ecosystem services of the spring water source

Springs are increasingly recognized as hydroecological keystones, functioning both as unique groundwater-dependent ecosystems (GDEs) and as critical providers of ecosystem services to surrounding communities (Stevens et al., 2021; Cantonati et al., 2020). The Parikesit spring in Truko Hamlet, Surokonto Kulon Village, Central Java, exemplifies the multiple layers of benefits that natural springs deliver. Situated geomorphologically within the structural fold hills of the Kuningan–Kendal anticline, composed primarily of calcareous claystone and gampingan materials, this spring typifies the intimate link between structural geology and groundwater discharge described in early hydrogeological works (Bryan, 1919; Fetter, 2001). At the local scale, its emergence represents not only a hydrological phenomenon but also a cultural and ecological nucleus of community life.

Following the framework of the Millennium Ecosystem Assessment (2005), the ecosystem services of the Parikesit spring can be discussed across four interrelated dimensions: provisioning, regulating, cultural, and supporting services. Each service category is shaped both by the physical–geomorphological context of the spring and by the sociocultural practices of the Surokonto Kulon community.

3.3.1 Provisioning services

Provisioning services represent the most direct and tangible contributions of the spring to human well-being. The Parikesit spring is the primary water source for household consumption, agriculture, and small-scale economic activities in Surokonto Kulon. In villages where municipal piped water systems remain incomplete, springs function as decentralized yet reliable water providers. This is in line with Palmer & Richardson (2009), that healthy freshwater ecosystems support global food and water security by controlling mineral flows and providing clean water for household and agricultural purposes.

For Surokonto Kulon, spring-fed irrigation sustains rice paddies, ensuring both household subsistence and market-oriented production (Widjoyo et al., 2024). This role positions the spring within a larger discussion of cultural landscapes as provisioning systems. Maldonado et al. (2019), in their study of Andalusian protected areas, emphasize that agricultural landscapes linked to natural water sources (e.g., olive groves, dehesa systems) are undervalued contributors to provisioning services despite their centrality to food systems. In a similar way, the Parikesit spring sustains local agriculture while simultaneously preserving traditional knowledge of water allocation practices, such as rotational irrigation (*tandur*). The consistent yield of the spring also demonstrates the regulating influence of the anticline structure, which directs subsurface flows to points of emergence (Naghbi & Dashtpaserdi, 2017). Such geologic controls ensure reliable discharge even during dry seasons, securing livelihoods where rainfall variability would otherwise endanger crop cycles. The socio-economic resilience of the community is, therefore, directly tied to the geomorphological setting of the spring.

3.3.2 Regulating services

Beyond direct supply, the Parikesit spring provides essential regulating services that maintain ecological and social stability. Springs function as natural filters: as groundwater percolates through stratified claystone and limestone, pollutants are reduced through adsorption and microbial degradation, yielding water of high clarity and low contaminant load (Scarsbrook et al., 2007; Stevens et al., 2021). This filtration service underpins community health, reducing dependence on artificial purification systems. Hydrologically, the spring regulates flow regimes by buffering extremes between rainy and dry seasons. A study by Stevens et al. (2021) suggests that springs often mediate the local hydrological cycle, acting as "pressure valves" that stabilize groundwater levels. In Surokonto Kulon, this regulation mitigates flood risks during monsoon periods and sustains baseflow during drought. Without such natural regulation, the village would face both greater flood hazard and seasonal water insecurity.

Vegetation surrounding the spring further enhances regulating services. Root systems stabilize soil, reducing erosion that would otherwise clog channels and degrade water quality. Comparable findings have been reported in helocrene and rheocrene systems, where vegetation and hydrology interactions control both sediment dynamics and downstream water quality (Springer & Stevens, 2009). Preserving riparian vegetation is thus critical not only for biodiversity but also for maintaining the regulating capacity of the spring system.

3.3.3 Cultural services

Perhaps the most distinctive dimension of the Parikesit spring lies in its cultural ecosystem services. Water sources in Java are deeply entwined with cosmological and social narratives, often regarded as sacred entities or living ancestors. The annual Nyadran ritual, held during the Javanese month of Suro, illustrates this cultural embeddedness. During the ceremony, villagers collectively clean water channels, pray for abundance, and reaffirm their bond with nature. Such practices align with Maldonado et al. (2019), who stress that cultural landscapes intertwine biodiversity values with heritage and identity.

The spring also operates as a social hub. Daily water collection fosters informal interactions, reinforcing community cohesion. In anthropological terms, the spring represents a social commons, a shared resource that structures collective practices of care, reciprocity, and identity. Wheeler & Proctor's (2003) recognition of spring mires as GDEs with distinctive cultural values resonates here: ecological uniqueness is inseparable from sociocultural significance. This dual role as both material and symbolic resource reflects the category of "biocultural services," where ecological and cultural dimensions co-produce meanings and values (Cocks & Wiersum, 2014). In Surokonto Kulon, safeguarding the spring is not only a matter of environmental stewardship but also a moral obligation tied to ancestral respect and local wisdom.

3.3.4 Supporting services

Supporting services are often overlooked, yet they form the foundation upon which other services rest. The Parikesit spring contributes to biodiversity conservation by providing habitat for aquatic invertebrates, amphibians, and riparian vegetation. Comparable to Swiss and New Zealand spring ecosystems, where species assemblages are strongly linked to hydrogeological settings (Zollhöfer et al., 2000; Scarsbrook et al., 2007; Stevens et al., 2021), the Parikesit spring fosters unique microhabitats along its channels.

The presence of natural vegetation also supports soil stability and nutrient cycling. Oxygen production, groundwater recharge, and the maintenance of local microclimate are indirect but vital supporting services. Freed et al. (2019) note that springs emerging from low-permeability rock units often harbor distinct assemblages due to prolonged water–rock interactions; this is likely true for the claystone-dominated geology of the Kuningan–Kendal

fold. Such supporting services enhance the resilience of the broader landscape. By sustaining biodiversity, stabilizing soils, and maintaining hydrological cycles, the spring creates the ecological preconditions for provisioning, regulating, and cultural services to continue over time.

Situating the Parikesit spring within global classification schemes enriches understanding of its ecological roles while also contextualizing its function as a community-based water source. Following the geomorphological framework of Springer & Stevens (2009), the spring most closely aligns with a rheocrene type, where water emerges and immediately contributes to surface flow. The anticline structure and slope position correspond to “hillslope rheocrene” subtypes described in the literature (Stevens et al., 2021). At the same time, anthropogenic interventions, such as channeling water through pipes and reservoirs for irrigation and domestic uses, reshape its character into what Stevens et al. (2021) describe as “anthropogenic springs.” This hybridity is crucial to acknowledge, as it indicates that management strategies must simultaneously protect ecological integrity while addressing community dependence on spring water.

The lack of standardized spring classification in Indonesia mirrors global challenges in spring research. As Cantonati et al. (2020) highlight, springs remain poorly mapped and inventoried worldwide, which constrains their integration into conservation planning and water policy. Establishing typological clarity for Indonesian springs would support their incorporation into national strategies on biodiversity and water resources. For Parikesit, such classification clarifies its ecological role while providing policymakers with a scientific rationale for protection. Coupling this framework with cultural traditions, such as the Nyadran ritual in Java, could facilitate hybrid management models that integrate ecological science with local wisdom.

The multifunctionality of the Parikesit spring illustrates the indivisibility of ecological and social systems. Provisioning services supply irrigation and household needs; regulating services stabilize soil and hydrological cycles; cultural services maintain identity and local traditions; and supporting services sustain biodiversity. Yet, these benefits face increasing vulnerability to pressures such as land-use change, over-extraction, and climate variability. Prolonged or excessive withdrawal can exceed the spring’s natural recharge capacity, leading to reduced flow, declining water tables, and habitat degradation. Such risks threaten not only provisioning services but also the broader ecological balance. To mitigate this, integrated strategies such as protecting recharge areas, restoring upstream vegetation through reforestation, and implementing water-saving technologies in households and agriculture are necessary. These measures strengthen both the ecological resilience of the spring system and the long-term sustainability of water supply for rural communities like Surokonto Kulon.

Lessons from European cultural landscapes, where communities are rewarded for environmentally friendly practices, suggest that spring stewardship should embrace socio-ecological reciprocity (Maldonado et al., 2019). Similar approaches in Java would require recognizing both ecological and cultural values of springs, moving beyond utilitarian views of water resources toward integrated management. This resonates with Stevens et al. (2021), who argue that a unified classification system forms the foundation for stewardship. For Parikesit, aligning geomorphological classification with local cultural practices strengthens both legitimacy and sustainability of water governance.

Despite these opportunities, this study also acknowledges several limitations. Current environmental parameters measured in Parikesit spring remain narrow, focusing only on basic physical indicators. A more comprehensive assessment should expand to include both physical and chemical parameters, as recommended by Wandari et al. (2023) and Purwadi et al. (2023), to better characterize water quality categories. Environmental parameters should also incorporate biological indicators such as coliform and *E. coli* (Nisa & Umar, 2023; Kesek et al., 2024), given their direct relevance to public health risks. Furthermore, a deeper understanding of socio-cultural dimensions is required, including the role of local wisdom practices specific to spring water management (Fariz et al., 2025), as well as the ecological condition of vegetation in the surrounding recharge area (Cahyaningrum et al.,

2023). These considerations emphasize that spring sustainability cannot be viewed solely from a hydrological perspective but must also integrate ecological and cultural dynamics.

Additionally, the sustainability of rural water supply programs is shaped by interrelated and dynamic factors that extend beyond the immediate catchment. Systems-based approaches, such as those suggested by Daniel et al. (2021b), are therefore required to capture the complex interactions among ecological processes, community practices, and governance arrangements. By applying dynamic models, practitioners and policymakers could better anticipate long-term challenges, such as climate variability, land use change, and demographic pressure, while also identifying adaptive management strategies that enhance resilience.

Another key dimension is economic valuation. The ecosystem services provided by Parikesit spring, ranging from household water security and sanitation benefits to agricultural productivity and even cultural identity, represent significant economic and social value, though these remain unmeasured. Incorporating valuation methods would strengthen the argument for conservation and sustainable use by demonstrating the tangible benefits of spring ecosystems to rural livelihoods. In addition, quantitative approaches to sustainability assessment, such as scoring and weighting frameworks employed by (Bhatta et al., 2024), would enable comparative analysis of Community-Based Clean Water Supply Systems across regions, providing policymakers with much-needed benchmarks for improvement and replication.

When evaluated through the FIETS (Financial, Institutional, Environmental, Technical, and Social) sustainability framework, the Parikesit water production unit demonstrates a commendable example of community-based management. The system benefits from active community participation, transparent financial administration, and effective technical functioning, consistent with broader findings in WASH sustainability research (Daniel et al., 2021b). However, long-term resilience demands strategic planning. This includes strengthening institutional capacity, ensuring a backup pump to reduce technical vulnerability, preparing financial reserves for future contingencies, and continuous monitoring of water quality. Embedding these improvements would ensure that the system not only fulfills present needs but also adapts to emerging future challenges.

In sum, the Parikesit spring exemplifies the intersection of ecological, cultural, and technical dimensions of rural water supply. Sustainable management requires harmonizing geomorphological understanding with socio-cultural practices, addressing risks of over-extraction, and institutionalizing adaptive governance under the FIETS framework. By linking scientific evidence with local stewardship, Parikesit offers a model for balancing conservation and development in Indonesia's rural water management systems. Importantly, such integrated approaches directly contribute to the achievement of the Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 15 (Life on Land). Strengthening community-based water governance at Parikesit not only safeguards ecological integrity but also advances inclusive development pathways, ensuring that rural populations benefit equitably from essential ecosystem services while building resilience against future uncertainties.

4. Conclusions

The case of the Parikesit spring in Truko Hamlet, Surokonto Kulon Village, demonstrates that community-based clean water supply systems can achieve a high level of sustainability when assessed through the FIETS framework. The system is socially robust, supported by active community participation, cultural practices such as *gotong royong* and *nyadran*, and a strong sense of local ownership. Financially, the willingness of households to contribute through transparent tariffs ensures operational continuity, though the absence of long-term savings for capital replacement remains a critical gap. Institutionally, PAMSIMAS provides a functional governance framework, yet limited leadership rotation and reliance on a few individuals highlight the need for capacity building and succession planning.

From an environmental perspective, the Parikesit spring continues to provide sufficient quantity and quality for daily needs, although substandard pH levels and vulnerability to sedimentation during heavy rainfall underline the importance of watershed protection, reforestation, and regular monitoring. Technically, the system benefits from reliable pumps and a sturdy pipeline network, but lacks redundancy in the form of a backup pump and preventive maintenance plans. Beyond the FIETS dimensions, the Parikesit spring embodies significant ecosystem services (provisioning, regulating, cultural, and supporting), that illustrate the inseparability of ecological and social systems. Situated within a geomorphological setting that ensures steady discharge, the spring sustains livelihoods, reinforces cultural identity, and contributes to biodiversity. However, increasing pressures from land-use change, climate variability, and potential over-extraction present real risks to its long-term resilience.

In conclusion, sustainable management of the Parikesit spring requires harmonizing ecological science with cultural practices, strengthening institutional and financial mechanisms, and adopting adaptive strategies that anticipate environmental change. Integrating classification frameworks, ecosystem service valuation, and FIETS-based assessments can provide policymakers with a comprehensive foundation for balancing conservation and rural development. As such, the Parikesit case offers a transferable model for community-based water governance in Indonesia and beyond.

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Author Contributions

All authors contributed to designing the study, collecting and analyzing data, interpreting results, and writing the manuscript. They collectively reviewed and approved the final version for publication.

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Ethical review and approval were waived for this study due to no personal data was collected in this study. The number of informants is six, and the interviews are mainly to gain insights on how food bank operates in Indonesia, no personal information is collected.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data is available upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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Biographies of Authors

Evi Cahyanila Kurnia Widjoyo, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: evicahyanila@students.unnes.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Aulia Rizky Zildzan, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: azildzan@students.unnes.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Olifadia Eka Andiny Aulia, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: olifadiaekaa@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Aditya Rayyis Haqqani, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: adityarayyis7@students.unnes.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Fitranto Adi Nugroho, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: fitrantoadin438@students.unnes.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Trida Ridho Fariz, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: trida.ridho.fariz@mail.unnes.ac.id
- ORCID: 0000-0002-3943-0089
- Web of Science ResearcherID: N/A
- Scopus Author ID: 57576594500
- Homepage: <https://scholar.google.com/citations?user=25XaPcAAAAJ&hl=id>

Abdul Jabbar, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: abduljabbar@mail.unnes.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: 58881942000
- Homepage:
<https://scholar.google.com/citations?user=EA54JRAAAAAJ&hl=id>

Putri Alifa Kholil, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: putrialifa@mail.unnes.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Amnan Haris, Environmental Science Study Program, Faculty of Science, Universitas Negeri Semarang, Semarang, Central Java 50229, Indonesia.

- Email: amnanharis@mail.unnes.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A