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Water Quality Dynamics of Sumber Suko Spring in East Java, Indonesia: Towards Sustainable Management

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ABSTRACT

Springs are vital freshwater sources for rural communities, yet they are increasingly threatened by nutrient enrichment, microbial contamination, and declining ecological integrity. This study assessed the water quality of Sumber Suko Spring in East Java, Indonesia, through an integrated ecological approach combining physicochemical, microbiological, biological, and hydrological parameters across wet and dry seasons. Physicochemical results showed stable temperature (24.1–26.7 °C), near-neutral pH (6.4–6.9), and adequate dissolved oxygen (6.2–7.4 mg/L). However, nitrate concentrations were elevated (39.37–48.16 mg/L), exceeding natural background levels and indicating agricultural leaching, while phosphate values ranged between 0.12–0.21 mg/L. Microbial analysis revealed high total coliform counts (24 CFU/100mL), far above WHO standards, although E. coli was not detected. Plankton analysis identified 10 genera, with Microcystis aeruginosa dominating, particularly in the dry season, signaling risks of eutrophication. Shannon-Wiener diversity indices (H') ranged from 1.25 to 1.67, with evenness values between 0.43 and 0.56, reflecting low-to-moderate community stability. Hydrological measurements showed seasonal discharge fluctuations from 14.6 L/s in the wet season to 7.8 L/s in the dry season, strongly correlated with rainfall. Overall, the integration of nutrient enrichment, coliform contamination, and cyanobacterial dominance indicates that Sumber Suko Spring is under ecological stress and does not meet drinking water standards without treatment. The findings highlight the urgent need for source protection, disinfection, and continuous

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monitoring within a water safety plan framework. This study provides evidence-based insights to support local policy alignment with WHO guidelines and emphasizes the importance of community participation in sustaining spring ecosystems for long-term water security.

Keywords: Spring Water Quality; Nitrate Contamination; Coliform Bacteria; *Microcystis aeruginosa*; Eutrophication; Hydrological Variability; Sustainable Water Management

1. Introduction

Freshwater resources are under increasing stress worldwide due to climate variability, population growth, and land-use change. Springs, as one of the most important sources of freshwater in rural areas, provide vital ecosystem services such as drinking water supply, irrigation, and habitat support[1]. However, their ecological integrity is increasingly threatened by nutrient enrichment, microbial contamination, and declining discharge[2]. Poor management of spring systems may result in eutrophication, waterborne diseases, and reduced availability of safe water[3–5]. Understanding spring water quality is therefore crucial for sustainable freshwater governance and public health.

Indonesia, despite being endowed with abundant freshwater resources, is currently categorized as a country with medium-to-high water stress, with stress levels reaching 20–40%. Rapid urbanization and agricultural intensification contribute significantly to declining water quality across the country[6,7]. In many rural communities, dependence on natural springs has intensified, while conservation measures remain limited. In East Java Province, water scarcity is evident, with decreasing access to clean water reported in recent years[8]. This condition highlights the urgent need for localized studies assessing the quality and sustainability of community-based spring systems.

The Sumber Suko Spring, located in Bocek Village, Karangploso District, Malang Regency, is the primary water source for both domestic use and agricultural irrigation. Over the past decade, the spring has experienced a decline in discharge, particularly during dry seasons, accompanied by reports of water quality degradation. Local communities depend heavily on the spring, yet management practices are largely traditional and lack systematic monitoring. Land-use change, such as the conversion of forests and farmlands into residential and industrial areas, has exacerbated pressure on groundwater recharge zones[9,10]. These factors raise concerns regarding the long-term sustainability of Sumber Suko as a reliable freshwater source. Sumber Suko Spring is characterized by relatively stable discharge throughout the year, but seasonal fluctuations are still observed. During the wet season, rainfall contributes to increased recharge and slightly higher flow, while in the dry season, the discharge remains steady due to the aquifer's buffering capacity. This hydrological peculiarity is important, as the stable flow helps ensure continuous water availability but may also influence the dilution or accumulation of pollutants over time. Understanding these flow dynamics provides essential context for interpreting water quality variations in the spring.

Water quality assessment provides a scientific basis for identifying ecological stressors and developing management strategies. Parameters such as nitrate concentration, total coliform levels, and plankton composition are commonly used as indicators of pollution and ecological balance. Elevated nitrate and phosphate levels often reflect agricultural runoff, while coliform contamination signals risks of fecal pollution. Biological indicators, including the presence of cyanobacteria like *Microcystis aeruginosa*, further reveal risks of eutrophication and harmful algal blooms[11]. Monitoring these indicators over seasonal cycles is essential for detecting trends and developing preventive measures.

Previous studies on spring systems in tropical regions have often focused narrowly on hydrological or socio-economic aspects[12–14], overlooking the integration of ecological indicators[15]. Research has shown that community springs worldwide are vulnerable to nutrient enrichment and microbial pollution, particularly in areas experiencing land-use change. However, comprehensive studies that simultaneously examine physicochemical, biological, and hydrological parameters in Indonesian springs remain limited. In

addition, few studies have linked water quality findings with implications for sustainable community-based management. Addressing this gap is critical for ensuring both water security and ecological sustainability.

This study aims to evaluate the water quality of Sumber Suko Spring through an integrated ecological approach, examining physicochemical, biological, and hydrological parameters. By assessing seasonal variations, the study seeks to provide a comprehensive picture of the current water quality status and risks of degradation. The findings are expected to inform local stakeholders and policymakers in designing adaptive strategies for spring conservation. Furthermore, this research contributes to the broader discourse on freshwater sustainability by linking empirical water quality data to the Sustainable Development Goals (SDG 6: Clean Water and Sanitation). Ultimately, the study highlights the importance of continuous monitoring and community participation in maintaining spring water quality.

2. Methods

2.1. Study Area

The study was carried out at Sumber Suko Spring, located in Bocek Village, Karangploso District, Malang Regency, East Java, Indonesia (7°53′ S, 112°36′ E) (**Figure 1**). The spring is situated at an elevation of approximately 520 meters above sea level and supplies freshwater for domestic use, agricultural irrigation, and small-scale industries. The catchment area surrounding the spring is characterized by mixed land use, including residential settlements, rice fields, horticultural crops, poultry farms, and light industries. These land-use practices create potential risks for water contamination, particularly from agricultural runoff, domestic wastewater, and livestock effluents. The study was conducted between April 2024 and January 2025 to capture the contrast between wet and dry seasonal conditions that strongly influence spring water quality.

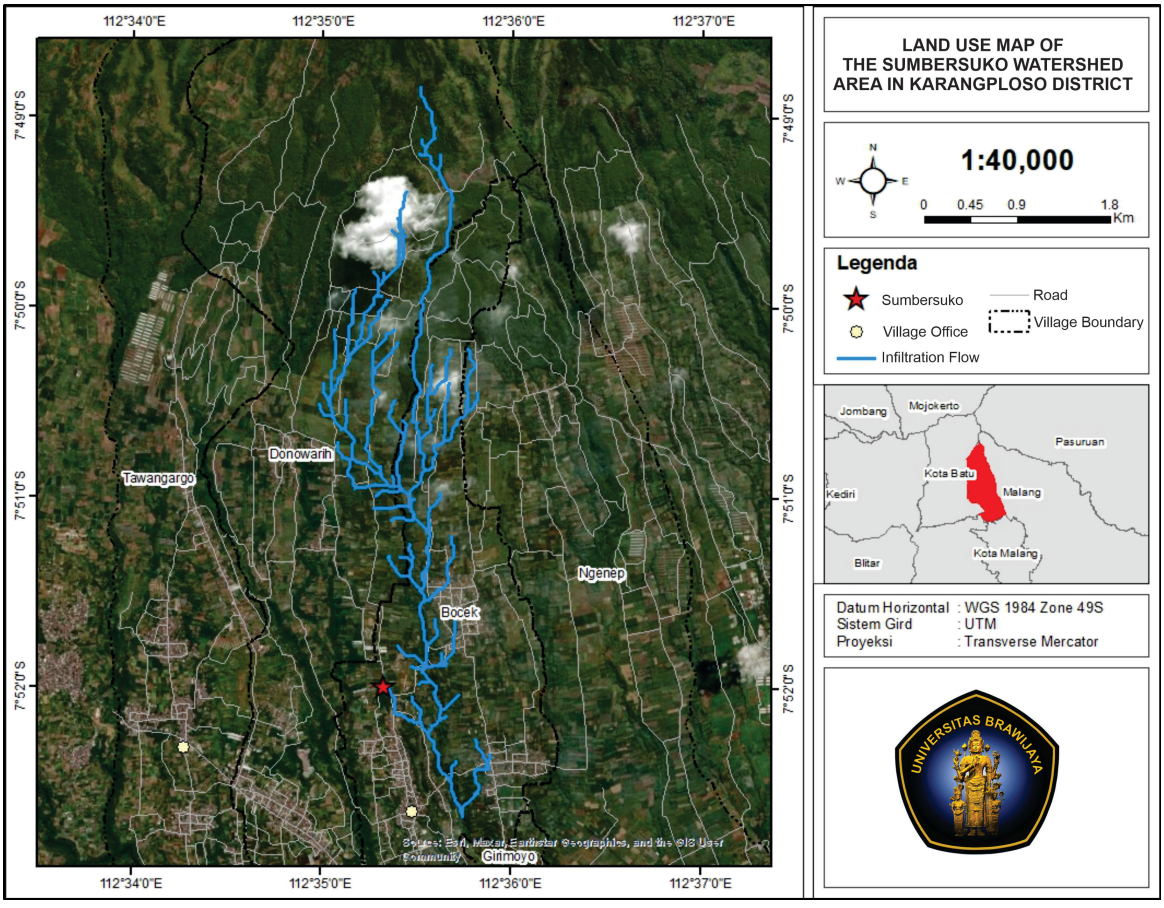


Figure 1. *Cont.*

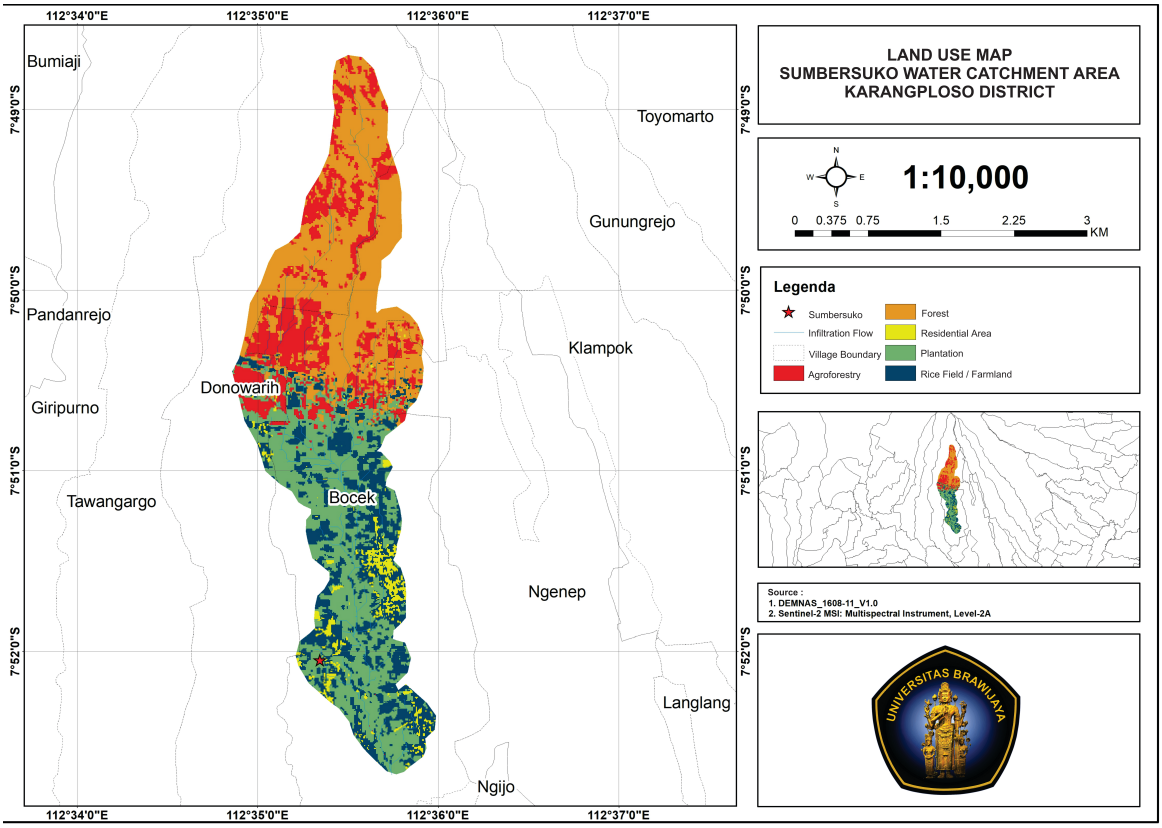


Figure 1. Research Site and Land Use.

2.2. Sampling Design

Water sampling was conducted during two distinct hydrological periods: the wet season in April 2024, when rainfall was relatively high (486.4 mm), and the dry season in January 2025, when rainfall decreased significantly (36.9 mm). To represent the variability of the spring system, three sampling sites were selected: the main source outlet where water emerges naturally, the distribution channel where water is directed for domestic consumption, and the downstream irrigation point where water flows into agricultural land. At each sampling site, three replicate samples of one liter each were collected at a depth of approximately 20 cm below the surface using sterile polyethylene bottles. The samples were preserved in iceboxes at 4 °C and transported to the Environmental Laboratory of Universitas Brawijaya within six hours to ensure accurate and uncontaminated measurements. Three sampling points were deliberately selected to represent different potential sources of contamination. The source outlet was chosen to reflect the original spring water quality, the distribution channel represented water conditions after contact with domestic use and transportation systems, and the irrigation point captured the influence of agricultural runoff. Together, these sites were intended to cover the main pollution pathways that may affect the spring.

2.3. Physicochemical Analysis

Physicochemical parameters were measured both in situ and in the laboratory following the APHA (2017) Standard Methods for the Examination of Water and Wastewater. Field measurements included water temperature using a mercury thermometer, pH using a portable digital meter (Hanna HI 98103), dissolved oxygen (DO) with a YSI Pro20 meter, electrical conductivity with a Hanna HI 9033 device, and turbidity with a Hach 2100Q turbidimeter[16]. Laboratory analyses were conducted for nutrient and organic load parameters, including nitrate using the cadmium reduction method and phosphate using the ascorbic acid method, both analyzed with a Shimadzu UV-1800 spectrophotometer. Additional parameters included total suspended solids (TSS) measured by gravimetric filtration, biochemical oxygen demand (BOD_5) determined after five days of incubation at 20 °C, and chemical oxygen demand (COD) analyzed through the dichromate

reflux method. These measurements allowed for a comprehensive evaluation of the chemical status of the spring water in relation to environmental standards.

2.4. Biological Analysis

The biological quality of the spring was evaluated through microbial contamination and plankton community structure. Total coliform counts were assessed using the Most Probable Number (MPN) method with Lauryl Tryptose Broth as the presumptive medium and Brilliant Green Bile Broth for confirmatory testing. Results were expressed as MPN per 100 mL of water and compared to international and national water quality standards. Phytoplankton and zooplankton samples were collected using a plankton net with a mesh size of 25 µm, preserved in 4% formalin, and observed under an Olympus CX23 compound microscope at 400× magnification. Identification was conducted to the genus level using standard taxonomic references. The Shannon-Wiener diversity index (H') and Evenness index (E) were calculated to determine ecological balance and community stability. Special attention was given to the occurrence of *Microcystis aeruginosa*, a cyanobacterium known to indicate eutrophication processes [17,18]. Benthic macroinvertebrates were also sampled using an Ekman grab, sieved with a 500 µm mesh, and preserved in 70% ethanol for laboratory identification, providing additional indicators of ecological integrity.

2.5. Hydrological Measurement

Spring discharge was monitored monthly over a twelve-month period, from April 2024 to March 2025, to observe seasonal variability. Measurements were conducted using the volumetric method, where water was directed into a calibrated 10-liter container, and the filling time was recorded. The discharge was then calculated by dividing the water volume by time, expressed in liters per second (L/s). To complement discharge data, rainfall information was obtained from the Karangploso Meteorological Station and correlated with discharge fluctuations to identify the relationship between precipitation and spring water availability. This hydrological monitoring was essential for understanding how seasonal changes influence both water quantity and quality.

2.6. Data Analysis

The results of physicochemical and biological analyses were compared to the Indonesian Government Regulation No. 82/2001 on Water Quality Standards and the World Health Organization (WHO, 2017) guidelines for drinking water. Temporal differences between wet and dry seasons were statistically analyzed using paired *t*-tests at a 95% confidence interval ($p < 0.05$). Plankton community data were analyzed using PAST 4.03 software to calculate Shannon-Wiener diversity (H') and Evenness (E). Coliform levels were categorized according to WHO risk classifications ranging from low to high contamination levels. Finally, the integration of physicochemical, biological, and hydrological parameters provided a holistic assessment of the spring water quality status, enabling the identification of major ecological stressors and their implications for long-term sustainability.

3. Results

3.1. Physicochemical Characteristics

The physicochemical analysis of Sumber Suko Spring revealed seasonal variability between the wet and dry periods (**Table 1**). Water temperature ranged from 24.1 °C in the wet season to 26.7 °C in the dry season, remaining within the tolerance limits for tropical freshwater systems. The pH was slightly acidic to neutral, ranging from 6.4 to 6.9 across all sampling sites. Dissolved oxygen (DO) levels were relatively high (6.2–7.4 mg/L), indicating good aeration and favorable conditions for aquatic organisms. However, nutrient concentrations showed signs of anthropogenic influence. Nitrate (NO_3^-) levels were elevated, reaching 48.16 mg/L in the wet season and 39.7 mg/L in the dry season, exceeding natural background levels and suggesting leaching from agricultural fertilizer use. Phosphate (PO_4^{3-}) concentrations fluctuated between 0.12–0.21 mg/L, with higher values during the rainy period, likely due to surface runoff. Biochemical oxygen demand (BOD_5) values were moderate, ranging from 3.4 to 4.2 mg/L, while chemical oxygen demand (COD) ranged from 12.6 to 14.9 mg/L, both indicating organic matter enrichment. Turbidity was significantly higher in the wet season (12.4 NTU) compared to the dry season (6.7 NTU), reflecting sediment inflow from surrounding land.

Table 1. Physicochemical Parameters of Sumber Suko Spring.

Parameter	Wet Season	Dry Season
Temperature (°C)	24.1	26.7
pH	6.4	6.9
DO (mg/L)	7.4	6.2
Nitrate (mg/L)	48.16	39.7
Phosphate (mg/L)	0.21	0.12
BOD_5 (mg/L)	3.4	4.2
COD (mg/L)	12.6	14.9
Turbidity (NTU)	12.4	6.7

Notes: Physicochemical parameters of Sumber Suko Spring during wet and dry seasons. Nitrate and phosphate levels were elevated, indicating potential nutrient enrichment.

3.2. Microbiological Quality

Microbial analysis demonstrated that the spring water was subject to biological contamination. Total coliform counts reached 24 CFU/100 mL in both wet and dry seasons across sampling points (**Table 2**). Although this value appears relatively low, it exceeds the Indonesian drinking water standard of 0 CFU/100 mL (Permenkes RI No. 32/2017), which requires the complete absence of coliform bacteria in potable water. The presence of coliform indicates fecal contamination, most likely from domestic wastewater infiltration or livestock activities in the recharge area. According to WHO and national guidelines, the detection of coliform at any level classifies the spring water as unsafe for direct consumption, highlighting the need for proper treatment and continuous monitoring to prevent waterborne disease transmission.

Table 2. Total Coliform (CFU/100 mL).

Sampling Point	Wet Season	Dry Season
Source Outlet	19	21
Distribution Channel	24	24
Irrigation Point	21	22

Notes: Total coliform counts at different sampling points in Sumber Suko Spring. Values exceeded WHO thresholds, showing high microbial contamination risk.

3.3. Plankton Community Structure

A total of 10 genera of plankton were identified across both seasons, consisting of phytoplankton and zooplankton groups (**Table 3**). The phytoplankton community included *Frustulia* sp., *Ceratium* sp., *Coscinodiscus stellaris*, *Navicula* sp., and *Microcystis aeruginosa*. Among these, *Microcystis aeruginosa* was dominant, particularly during the dry season, accounting for more than 40% of the total phytoplankton abundance. This dominance is a strong indicator of eutrophic conditions and potential harmful algal blooms. The zooplankton community was represented by *Alona kurva*, *Eucyclops agilis*, *Sida* sp., and *Diaptomus minutus*. However, the abundance and diversity of zooplankton were relatively low, suggesting limited grazing pressure on phytoplankton populations. Diversity analysis showed Shannon-Wiener indices (H') ranging from 1.25 to 1.67, indicating low to moderate diversity, while Evenness values (E) ranged from 0.43 to 0.56, showing uneven species distribution.

Table 3. Plankton Genera Identified in Sumber Suko Spring.

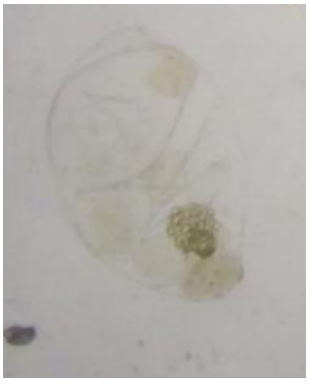
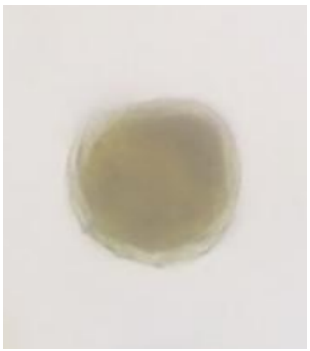
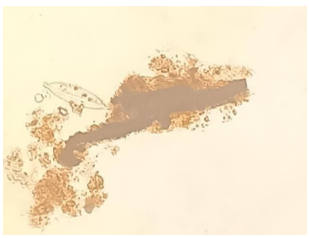
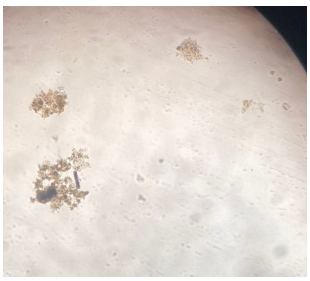
Phytoplankton		Zooplankton	
Frustulia sp.		*Alona kurva*	

Table 3. *Cont.*

Phytoplankton		Zooplankton	
Ceratium sp.		*Eucyclops agilis*	
Coscinodiscus stellaris		*Sida* sp.	
Navicula sp.		*Diaptomus minutus*	
Microcystis aeruginosa			

Notes: Plankton genera identified in Sumber Suko Spring. The dominance of Microcystis aeruginosa indicates eutrophic conditions.

3.4. Hydrological Characteristics

The discharge of Sumber Suko Spring displayed strong seasonal fluctuations. During the wet season, discharge rates reached an average of 14.6 L/s, while in the dry season they declined sharply to 7.8 L/s, reflecting reduced recharge from rainfall (**Table 4**). The reduction in discharge was particularly critical in August and September, when water availability reached its lowest level. The correlation between rainfall data and discharge confirmed that the spring is highly dependent on seasonal precipitation. Such variability not only reduces the reliability of water supply for domestic and agricultural use but also exacerbates water quality issues, as lower flows during the dry season favor nutrient accumulation and algal growth.

Table 4. Seasonal Discharge of Sumber Suko Spring.

Season	Average Discharge (L/s)	Minimum (L/s)	Maximum (L/s)
Wet	14.6	12.5	16.2
Dry	7.8	6.9	8.4

Notes: Seasonal discharge of Sumber Suko Spring. Spring discharge decreased significantly in the dry season, reflecting rainfall dependency.

3.5. Integrated Water Quality Status

The integration of physicochemical, microbiological, biological, and hydrological data indicates that Sumber Suko Spring is under significant ecological pressure. Elevated nitrate concentrations, high coliform contamination, and the dominance of *Microcystis aeruginosa* reveal nutrient enrichment and public health risks. Seasonal reductions in discharge further compound these challenges, reducing the resilience of the spring ecosystem. Although DO levels remain within acceptable ranges, the overall water quality does not meet drinking water standards without treatment. These findings highlight the urgent need for conservation and pollution control measures to prevent further degradation and to safeguard the sustainability of Sumber Suko Spring.

4. Discussion

The findings of this study demonstrate that the water quality of Sumber Suko Spring is physically suitable but faces serious challenges in terms of chemical and biological parameters. Water temperature and pH remained relatively stable across sampling campaigns, while turbidity and total dissolved solids (TDS) were very low, which is favorable for consumption. However, nitrate concentrations were high, ranging between 39.73 and 48.16 mg/L, exceeding the local drinking water standard of 20 mg/L, though still below the World Health Organization (WHO) guideline of 50 mg/L as nitrate ion. WHO clearly emphasizes that this threshold is established to protect public health, particularly infants vulnerable to methemoglobinemia, meaning that even values below 50 mg/L should be considered a potential risk for sensitive populations [19]. Thus, although the water appears clear and stable in physical parameters, chemically, it carries significant health concerns.

The elevated nitrate concentrations are closely linked to land use in the spring recharge area. Intensive agricultural activities with heavy nitrogen fertilizer applications, household septic tanks, and livestock operations are likely contributors to the nitrogen load entering the aquifer [20,21]. Seasonal differences further highlight hydrological influences on nutrient dynamics, with nitrate levels decreasing slightly during the wet season due to dilution effects, but showing accumulation during the dry season [22]. This pattern confirms that water quality is not only determined by natural hydrological conditions but is strongly shaped by anthropogenic pressures in the watershed. Effective management must therefore prioritize upstream interventions rather than relying solely on seasonal flushing.

From a microbiological perspective, the absence of *E. coli* in both sampling campaigns suggests no fresh fecal contamination at the time of monitoring. However, the detection of total coliform counts as high as 24 CFU/100 mL in the dry season indicates vulnerability of the spring to contamination through possible infiltration pathways such as soil fractures, shallow hydraulic connections, or human activities near the spring outlet [23,24]. WHO guidelines state that *E. coli* must not be detectable in 100 mL of water intended for drinking, and although this criterion was met, the presence of total coliform remains a signal of potential intrusion and inadequate source protection [25]. This finding underscores the need for proper spring box maintenance, sanitary protection zones, and disinfection measures in line with the multiple-barrier principle for safe drinking water management.

The plankton community analysis further supports the interpretation of ecological stress in the spring ecosystem. The identification of *Microcystis aeruginosa* among phytoplankton, with higher dominance in the dry season, points to nutrient enrichment and the potential onset of eutrophication [26,27]. Although toxin measurements were not conducted, the WHO has established a provisional guideline of 1 μg/L for microcystin-LR in drinking water, making the detection of *Microcystis* an early warning signal of possible health hazards [28]. Furthermore, the decline in zooplankton diversity from three taxa in the first sampling to only two taxa in the second reflects reduced ecosystem stability. Lower zooplankton richness implies weaker top-down control on phytoplankton populations, which in turn increases

the likelihood of harmful cyanobacterial dominance. Based on both the literature and field observations, no outbreaks of Microcystis dominance have been reported in the study area. Nevertheless, the detection of Microcystis cells in water samples highlights the potential risk of bloom formation if environmental conditions become favorable, such as increased nutrient input, higher temperatures, and reduced water circulation. This finding underscores the importance of continuous monitoring, since even in the absence of current outbreaks, early detection may serve as an indicator of possible future ecological imbalances.

Hydrologically, the spring's discharge remained relatively stable, ranging from 7.8 L/s to 14.6 L/s, suggesting that water quality is determined more by pollutant loads than by fluctuations in water quantity. This stability implies that degradation is not a result of water scarcity but of persistent contamination sources [29]. Consequently, management efforts must focus on controlling inputs from the recharge zone, such as improving sanitation, regulating fertilizer and livestock waste, and establishing riparian buffer zones with vegetative cover. Without such interventions, nutrient loading and microbial risks will continue to threaten the sustainability of the spring even if discharge remains adequate. Although the spring discharge of Sumber Suko remained relatively stable across seasons, this hydrological characteristic has important long-term implications for water quality. A consistent flow rate can support dilution of pollutants during periods of moderate contamination, thereby maintaining basic ecological functions. However, stability in discharge may also result in the continuous accumulation of nutrients and microbial contaminants when external inputs persist, especially from agriculture and domestic wastewater. Over time, this condition can reduce the self-purification capacity of the spring and increase the risk of eutrophication and harmful microbial proliferation [30–32]. Therefore, hydrological stability should be viewed not only as a guarantee of water supply reliability but also as a factor influencing pollutant dynamics, requiring proactive management of land-use practices and contaminant sources in the recharge area.

From a policy perspective, these findings have important implications for local water governance. Indonesian regulations under Government Regulation No. 22/2021 provide a framework for water quality management, while WHO guidelines establish risk-based health protection targets. The fact that nitrate levels exceed local standards but remain below WHO guidelines creates regulatory ambiguity, which requires clear local policy decisions to avoid misinterpretation. The implementation of a comprehensive water safety plan encompassing source protection, minimal treatment through disinfection, and routine monitoring of microbiological, nutrient, and cyanotoxin parameters is therefore essential to ensure the safe use of Sumber Suko Spring as a community drinking water source.

This study provides a strong assessment of water quality risks; several limitations should be acknowledged. The temporal resolution was limited to two sampling periods, which does not capture intra-seasonal variability or extreme hydrological events. Microbial source tracking was not conducted, leaving the precise origin of contamination unresolved. Cyanotoxin measurements and quantitative phytoplankton cell counts were not performed, limiting the evaluation of potential harmful algal bloom risks. Despite these limitations, the consistent signals of high nitrate, coliform presence, and detection of *Microcystis* clearly demonstrate that Sumber Suko Spring is under ecological pressure and requires urgent, evidence-based management interventions to safeguard public health and maintain long-term sustainability.

5. Conclusions

This study revealed that Sumber Suko Spring, while physically suitable in terms of turbidity, TDS, and pH, faces significant risks from chemical and biological contamination. Nitrate concentrations consistently exceeded the local drinking water standard and approached the WHO guideline limit, highlighting nutrient enrichment in the aquifer. Although *E. coli* was absent, the detection of total coliform and the presence of *Microcystis aeruginosa* indicate vulnerabilities in microbial safety and early signs of eutrophication. The findings emphasize that water quality degradation in Sumber Suko is primarily driven by anthropogenic activities in the recharge zone, particularly agriculture, sanitation, and livestock waste. Hydrological stability of the spring discharge suggests that pollution control, rather than reliance on seasonal flushing, must be prioritized to safeguard drinking water safety. Protecting the spring requires both source-oriented interventions and minimal treatment before human consumption.

Policy implications are equally critical. The discrepancy between local and WHO nitrate thresholds highlights the need for clear regulatory alignment and the adoption of water safety plans. Such plans should integrate source protection measures, disinfection protocols, and regular monitoring of microbiological and cyanotoxin parameters to ensure compliance with health-based standards. Future research should extend monitoring across seasons, include microbial source tracking, and measure cyanotoxins such as microcystin-LR to better quantify risks. A comprehensive approach combining ecological monitoring, land-use management, and health-oriented regulation will be essential to secure the sustainability of Sumber Suko Spring as a reliable source of drinking water for local communities. The relatively small number of water samples is acknowledged as a limitation of this study. To provide context, historical water quality data from local environmental agencies and previous research were consulted to supplement and validate the findings. Incorporating these records allows for a broader interpretation of seasonal and long-term trends in Sumber Suko Spring. Although the presence of Microcystis aeruginosa was confirmed in the spring, this study did not include toxin analysis, such as for microcystins. This is recognized as a limitation, as toxin data are essential to assess the actual health risks posed by cyanobacterial blooms. Future research should therefore incorporate toxin monitoring and molecular analysis to better understand the ecological and public health implications.

Author Contributions

Z.H. and M. contributed equally as co-first authors. Z.H. was responsible for field sampling, laboratory analysis, and data interpretation. M. supervised the research design, coordinated data analysis, and critically revised the manuscript. S. provided expertise on environmental and agricultural aspects, assisting in the contextualization of land-use impacts on water quality. F.P. contributed to the statistical analysis and economic interpretation of findings. All authors read and approved the final version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (Ethics Committee) of Universitas Brawijaya (protocol code 255/UN10/KERIS/09/2025 and date of approval: September 2025).

Informed Consent Statement

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

Data Availability Statement

The datasets generated and analyzed during this study are available from the corresponding author on reasonable request. Due to local agreements, some restrictions may apply.

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Conflicts of Interest

The authors declare no conflict of interest.

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