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The importance of riparian vegetation in maintaining spring water quality in Yeh Penet Watershed, Bali, Indonesia

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Abstract. *Wibowo FAC, Pramudya AD, Muttaqin T, Pangestu MNA. 2024. The importance of riparian vegetation in maintaining spring water quality in Yeh Penet watershed, Bali, Indonesia. Biodiversitas 25: 2051-2062.* Water quality changes along with population growth and human activities. Riparian ecosystems play an important role in maintaining water quality since riparian vegetation have a complex root system which acts as a filter of toxic substances to not enter the spring water. This research analyzes the relationship between riparian vegetation and water quality at five springs in the bamboo rehabilitation area of the Environment Bamboo Foundation (YBLL) in the Yeh Penet Watershed, Bali, Indonesia. At each spring, vegetation analysis was carried out to determine the diversity and composition of riparian vegetation, as well as water quality assessment based on bio-physiochemical parameters. The result of vegetation analysis found that spring 1 was dominated by *Equisetum hyemale*, spring 2 by *Diplazium esculentum*, spring 3 by *Digitaria longiflora* and springs 4 and 5 by *Musa paradisiaca*. The analysis of bio-physicochemical parameters showed that the water from the five springs was suitable for consumption, but it needs to be heated to a temperature of ±100°C before consuming it due to the presence of coli bacteria. Riparian vegetation diversity had a strong relationship with water quality parameters especially Biochemical Oxygen Demand (BOD) values, Ammonia (NH3), and total coliform. Our findings confirm the importance of riparian vegetation in maintaining water quality in water springs within a watershed.

Keywords: Riparian vegetation, water quality, Yeh Penet Watershed

INTRODUCTION

The Yeh Penet Watershed (DAS Yeh Penet) is an ecologically important area in Bali Island, Indonesia with various ecosystem functions (Mudiasa et al. 2017). The Yeh Penet watershed provides water source for the surrounding community. Data from the Central Statistics Agency 2020 showed that the population of Tabanan District was 448,000, where the majority depend on the springs within the Yeh Penet Watershed as a drinking water supply system. Vegetation in Yeh Penet Watershed supports the availability of drinking water for the community especially during the dry season. A study by Cao et al. (2024) found that there is decrease in water availability in the dry season (32.61%) compared to the rainy season (64.21%).

Even though it plays a crucial role, the Yeh Penet watershed faces environmental challenges, especially the decline in water quality due to pollution and changes in land use from forests into agricultural and ecotourism areas. Disturbances to the watershed are generally observed in the upstream area through the increase in agricultural land and residential areas, resulting in erosion and sedimentation. These have an impact on decreasing land productivity and increasing the frequency of water-related disasters (Pambudi 2019). Water, as a key element for the survival of humans and other living creatures, is a critical global issue, especially if water sources are polluted. Changes in water quality, along with human population growth and accompanying activities, pose risks to the sustainability of water sources and human health (Addisie 2022). Water pollution, characterized by a decrease in quality, makes water no longer suitable to use.

The determination of water quality standards can be inferred from water's chemical, physical, and biological parameters (Syeed et al. 2023). Water quality status from physical parameters includes odor, color and temperature, while those from chemical aspects include pH, mineral content, nitrate, nitrite, iron and sulfate, and from biological properties include organic substances such as bacteria *Escherichia coli* and total coliform (Sarda and Sadgir 2015). Drinking water must meet continuity, quantity and quality aspects including how much pollutant load the water receives. In meeting water needs, many communities still use water spring and ground water because they are still considered relatively clean, the pollution level is relatively low, and the temperature is relatively low.

Water quality in spring and ground water depends on the soil's mineral layer through which it passes (Arthana 2011). One ecosystem type that plays an important role in maintaining the quantity and quality of ground water and water spring is riparian ecosystem (Latella et al. 2020). Riparian ecosystem is a transitional ecosystem between aquatic and terrestrial realms (Manne et al. 2022). This ecosystem is composed by vegetation with a complex root system so they can serve as a filter for toxic substances to not enter the spring water. Ramadhanti et al. (2020) stated that riparian vegetation acts as a barrier or binder for soil (mud), nutrients, and chemicals carried by water from the left and right banks of the river through its root system so that they are not carried into the river body. So, riparian vegetation is important in improving water quality because the vegetation can filter polluted substances (Dunea et al. 2021). Beside that, the ecological function of riparian vegetation is to support ecosystem stability because it plays a role in the carbon, oxygen, nitrogen, and water cycles (Hoppenreijs et al. 2022).

Vegetation analysis in riparian ecosystem is very useful to determine the coverage, diversity, composition, structure and dominance of vegetation community (Dufour et al. 2019; Zhu et al. 2021). Such analysis can be related to water quality of the river especially the level of pollution since riparian vegetation is in direct contact with river water bodies; if there is no riparian vegetation around the river body, waste and heavy metals can easily enter the river (Kauffman et al. 2022). This research aims to comprehensively investigate the relationship between riparian vegetation and the quality of water springs around the Yeh Penet Watershed, Bali using biophysicochemical parameters. We expected the results of this study can be an ecosystem conservation decision for sustainable use of available water quality that supports the diversity of riparian vegetation.

MATERIALS AND METHODS

Study area and period

The research was carried out in the Yeh Penet Watershed area, Baturiti Sub-district, Tabanan District (Figure 1) from 12 September to 12 October 2023. The research site was located at bamboo rehabilitation area (8.454075°S and 115.190491°E) of the Environmental Bamboo Foundation (*Yayasan Bambu Lingkungan Lestari*/YBLL). Based on River Management Agency (*Balai Wilayah Sungai/*BWS) Bali-Penida, the Yeh Penet River has a length of 53.58 km with a watershed area of 228.49 km^2 located at the coordinates of 8.454075°S and 115.190491°E. Land use management in the studied area includes agriculture in the form of vegetable farm and coffee plantation, agroforestry and forestry.

Data collection procedure

Water sampling

Water samples were taken at five spring points along the Yeh Penet Watershed. The location of the spring water collection was determined using the purposive sampling method, a technique that directly determines the sampling object that meet the research objectives. Water samples from the springs were taken directly and placed into 1.5-liter bottles for further analysis as listed in Table 1. When taking water samples, the BOD5 (Biochemical Oxygen Demand) which was measured for 5 days at 20°C and pH were measured in the field. Water samples taken using bottles were then put into a cold box for analysis at the laboratory of Perum Jasa Tirta, Malang, East Java.

Riparian vegetation sampling

Vegetation sampling was conducted at each water spring by establishing four plots with the plot size being 20x20 m^2 (Stackhouse et al. 2023), resulting in total of 20 sample plots. Vegetation sampling was carried out at each spring point according to the direction of the spring location (north, west, south and east) (Figure 2) to tree species at four stages, namely seedlings (plot size 2x2 m), poles (plot size 5x5 m), saplings (plot size 10x10), and trees (20x20 m) and understory plants (ferns, lianas, herbs, shrubs, and grass with plot size 2x2 m). Stand density were measured as the number of trees per hectare (ha) at each plot. Vegetation found at the observation location was then identified using the google lens and plantnet applications. Species verification and validation were based on the book Diversity and Riparian Vegetation Dynamics (Dowe et al. 2015).

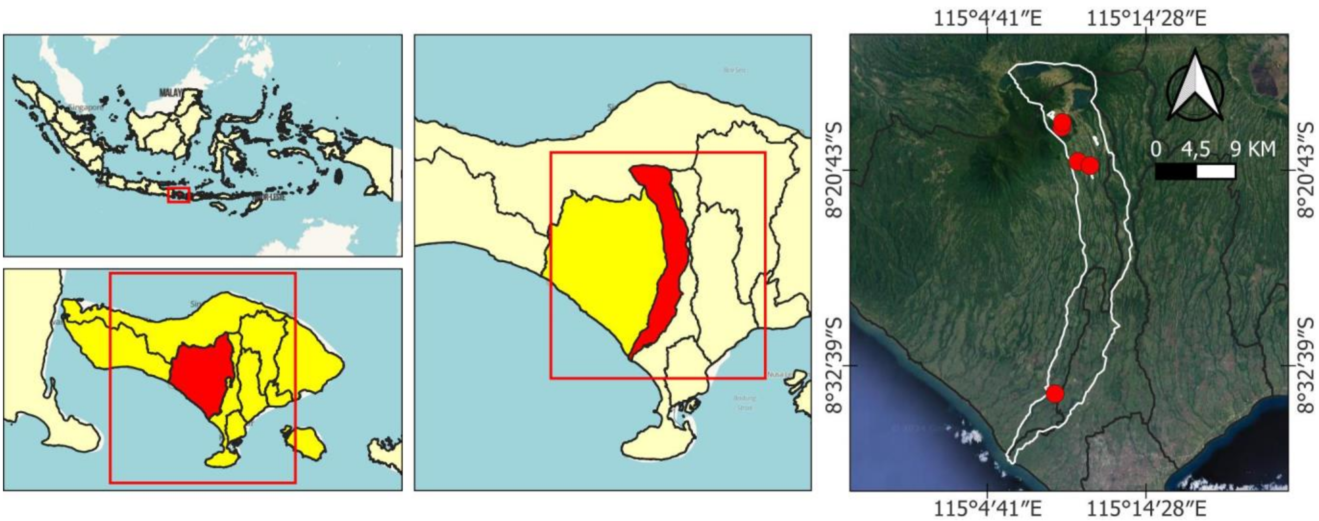

Figure 1. Map of study area in bamboo rehabilitation area of the Environmental Bamboo Foundation (*Yayasan Bambu Lingkungan Lestari/YBLL*), Yeh Penet Watershed, Baturiti Sub-district, Tabanan District, Bali, Indonesia

Data analysis

Vegetation data was then processed to calculate the Shannon-Weaver diversity index as follow (Naidu and Kumar 2016):

$$H' = -\sum_{i=1}^{n} pi \ln pi$$

where:

H' = Shannon and Weaver (1949) maximum diversity index

Pi = ni/N

Ni = number of individuals of type i found in the research plot (individuals)

N = number of individuals of all species found in the research plot (individual)

The categorry for the Shannon - Weaver diversity index value are (Song et al. 2016): H'<1 = Low diversity; H' ≤3 = Medium diversity; H' >3 = High diversity.

The data was also analysed by descriptive quantitative and descriptive qualitative. Quantitative descriptive research describes and explains things and concludes observed phenomena using numbers (Sulistyawati et al. 2022). Quantitative analysis was obtained through correlation tests using MiniTab 19 software. Qualitative descriptive research aims to describe and illustrate existing natural and human engineering phenomena, focusing more on the characteristics, quality, and interrelationships between activities (Utami et al. 2021).

RESULTS AND DISCUSSION

Riparian vegetation

Riparian vegetation varied in terms of habitus from grass, herbs, shrubs, poles, and trees and in terms of deliberately planted and growing naturally. The riparian vegetation recorded in the studied area is presented in Table 2.

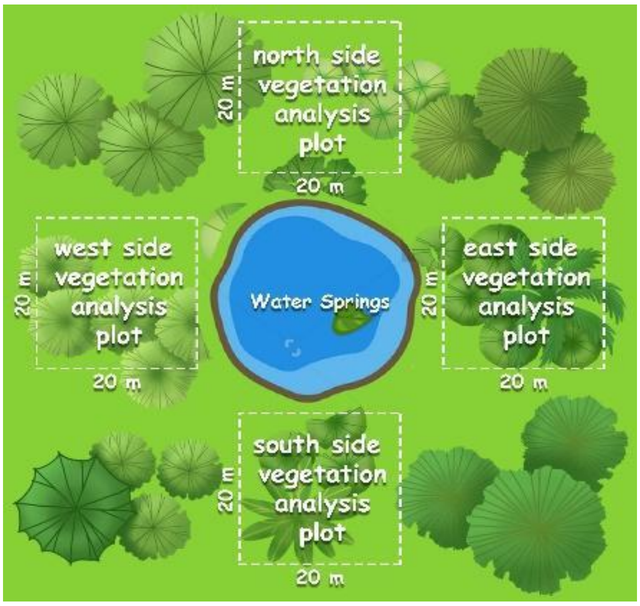

Figure 2. Diagram of vegetation sampling based on cardinal directions

Table 1. The method for water quality analysis following Arthana (2011)

Water quality parameters	Unit	Analysis method	Tools used
Physico-chemical			
pH	pH	Measurement	PH meter
BOD5	mg/L	Measurement	DO Meters
COD	mg/L	Titration	Burette
Sulfide	mg/L	Color comparison with standard	Spectrophotometer
Sulfate	mg/L	Color comparison with standard	Spectrophotometer
Nitrate	mg/L	Color comparison with standard	Spectrophotometer
Nitrite	mg/L	Color comparison with standard	Spectrophotometer
Ammonia	mg/L	Color comparison with standard	Spectrophotometer
Oil	mg/L	Titration	Burette
Calcium (Ca)	mg/L	Titration	Burette
Magnesium (Mg)	mg/L	Titration	Burette
Nickel (Ni)	mg/L	Titration	Burette
Iron (Fe)	mg/L	Titration	Burette
Manganese (Mn)	mg/L	Titration	Burette
Copper (Cu)	mg/L	Radiance of color	Spectrophotometer (AAS)
Lead (Pb)	mg/L	Radiance of color	Spectrophotometer (AAS)
Zinc (Zn)	mg/L	Radiance of color	Spectrophotometer (AAS)
Chrome (Cr)	mg/L	Radiance of color	Spectrophotometer (AAS)
Cadmium (Cd)	mg/L	Radiance of color	Spectrophotometer (AAS)
Mercury (Hg)	mg/L	Radiance of color	Spectrophotometer (AAS)
Bacteriology			
Escherichia coli	MPN/100 mL	Most Probable Number (MPN)	Agar media in a test tube
Total coliforms	MPN/100 mL	Most Probable Number (MPN)	Agar media in a test tube

Table 2. List of species from five springs in Yeh Penet Watershed, Baturiti Sub-District, Tabanan District, Bali, Indonesia

Species	**Family**	**Habitat**	**S1**	**S2**	**S3**	**S4**	**S5**
Agathis dammara (Lamb.) Rich. & A. Rich.	Araucariaceae	Lowland forest		●		●	●
Ageratina riparia Regel.	Asteraceae	Grasslands and plateaus	●		●	●	
Ageratum conzyoides L.	Asteraceae	Lowland forest	●	●	●	●	●
Alocsia scabriuscula N. E. Br.	Araceae	Lowland forest	●	●	●	●	●
Alternanthera dentata R.E.Fr.	Asteraceae	Lowland forest	●	●			●
Amaranthus spinosus L	Amaranthaceae	Lowland to highland forests	●			●	
Asystasia gangetica (L.) T. Anders	Acanthaceae	Lowland to highland forests		●			●
Axonophus compressus (Sw.) P. Beauv.	Amaranthaceae	Lowland forest	●	●			●
Bambusa vulgaris Schrad. ex J. C. Wendl.	Poaceae	Lowland to highland forests	●	●	●	●	●
Calliandra calot Meissn.	Poaceae	Lowland to highland forests	●	●	●	●	●
Centrosema pubescens (Schltdl.) R.J. Williams.	Fabaceae	Lowland forest		●			●
Cissus javana L.	Vitaceae	Lowland to highland forests		●		●	●
Clidemia hirta (L.) D. Don.	Fabaceae	Lowland forest	●	●	●	●	
Coffea canephora Pierre.	Melastomataceae	Lowland to highland forests	●		●	●	
Colocasia esculenta (L.) Schot.	Araceae	Tropical forest	●	●	●	●	
Cyperus kyllingiella Endl.	Cyperaceae	Grasslands and lowlands		●			
Cyperus odoratus L.	Cyperaceae	Tropical forests and surrounding waters		●	●	●	
Cyperus rotundus L.	Cyperaceae	Tropical forests and surrounding waters		●	●	●	●
Digitaria didactyla Wild.	Poaceae	Lowland to highland tropical forests	●	●	●	●	●
Digitaria insularis (L.) Mez	Poaceae	Lowland to highland forests	●	●	●	●	●
Digitaria longiflora (Retz.) Pers.	Poaceae	Lowland to highland forests	●	●	●	●	●
Digitaria violances Links.	Poaceae	Lowland to highland forests	●	●	●	●	●
Diplazium esculentum (Retz.) Pers.	Athyriaceae	Lowland to highland tropical forests	●	●	●	●	●
Durio zibethinus L.	Malvaceae	Lowland to highland forests	●	●	●	●	●
Eclipta prostrata L.	Asteraceae	Tropical forests and surrounding waters	●	●	●		●
Emilia sonchifolia (L.) DC. ex Wight.	Asteraceae	Grasslands and plateaus	●	●	●		●
Equisetum hyemale L.	Equisetaceae	Tropical forests and surrounding waters	●	●	●		●
Eucalyptus urophylla S.T. Blake	Myrtaceae	Lowland to highland forests		●			●
Eupatorium odoratum L.	Asteraceae	Lowland to highland forests	●	●	●		
Gigantochloa apus (Schult.f.) Kurz	Poaceae	Lowland to highland forests	●	●	●		
Heterogonium pinnatum H.	Tectariaceae	Lowland to highland tropical forests		●			
Ichnanthus vicinus Merr.	Poaceae	Grasslands and plateaus	●	●	●		●
Leucaena leucocephala (Lam.) de Wit.	Fabaceae	Lowland to highland forests		●	●		●
Mangifera indica L.	Anacardiaceae	Lowland to highland forests			●		
Melissa officinalis L.	Anacardiaceae	Lowland to highland tropical forests	●	●			●
Mikania micrantha Kunth.	Lamiaceae	Grasslands and plateaus	●	●			●
Mimosa pudica L.	Fabaceae	Lowland to highland tropical forests		●		●	●
Musa paradisiaca L.	Musaceae	Lowland to highland forests		●	●	●	●
Ochroma grandiflorum Rowlee	Malvaceae	Lowland to highland forests			●	●	●
Paspalum conjugatum Berg.	Asteraceae	Grasslands and plateaus	●	●	●	●	●
Pennisetum purpureum Schaum.	Poaceae	Lowland to highland forests	●	●	●	●	●
Persea americana Mill.	Lauraceae	Lowland to highland forests		●	●	●	●
Phyllanthus niruri L.	Phyllanthaceae	Lowland to highland tropical forests		●		●	●
Physalis angulata L.	Poaceae	Lowland to highland forests	●	●		●	●
Pinus merkusii Jungh et de Vriese.	Poaceae	Lowland to highland forests	●	●	●		
Psidium guajava L.	Pinaceae	Lowland to highland forests	●	●		●	●
Senna siamea Lam.	Myrtaceae	Lowland forest	●	●		●	●
Smilax glauca Walter.	Smilacaceae	Lowland to highland tropical forests		●	●	●	●
Swietenia mahagoni (L) Jacq.	Meliaceae	Lowland to highland forests		●		●	●
Teramnus labialis (L. f.) Spreng.	Fabaceae	Lowland to highland forests	●	●	●	●	●
Urtica sp	Fabaceae	Lowland to highland tropical forests	●	●			●
Xanthosoma sagittifolium (L.) Schott.	Urticaceae	Tropical forests and swamps	●	●	●		●

Note: S: water spring

At spring 1, there were 34 species of riparian vegetation found with *Equisetum hyemale* L. (Horsetail fern) dominated the vegetation with 144 individuals or 10%. The *Equisetaceae* family prefers humid places close to water sources with an optimum pH of 6-8 (Boeing et al. 2021). *E. hyemale* has a high silicate content in its stems, so it easily binds particles absorbed by the roots (Pasaribu et al. 2021). *E. hyemale* can reduce levels of the heavy metal lead, set aside BOD levels of 90.34% and COD levels efficiency of 89.67% (Al Kholif et al. 2019). *E. hyemale* is able to remove TSS (Total Suspended Solid), Phosphate, and LAS (Linear Alkylbenzene Sulfonate) up to 100% and shows the best performance in laundry wastewater (Wahyudianto et al. 2019).

There were 47 plant species at the spring 2 with *Diplazium esculentum* (Retz.) Pers. (vegetable fern) had the highest density with 170 individuals or 7%. *D. esculentum* is an important wild plant species often consumed by local communities in Indonesia. Traditionally, *D. esculentum* is used to treat diseases such as diabetes, asthma, rheumatism, dysentery, measles, high blood pressure, oligospermia, fractures, swollen glands, and skin-related diseases (Semwal et al. 2021). Apart from ferns, bamboo vegetation was also found at this spring. Bamboo vegetation has significant environmental benefits; its roots can help prevent soil erosion and maintain soil stability. Additionally, its roots can dissolve heavy metals and efficiently draw water closer to the surface due to its strong absorption ability (Li and He 2019). This part of the root also filters water due to exposure to waste through the root fibers (Emamverdian et al. 2020).

At spring 3, there were 33 plant species with *Digitaria longiflora* (Retz.) Pers. (Tekik grass) dominated the vegetation with 340 individuals or 8%. *D. longiflora* is a species of the Poaceae family. This family has various ecological benefits, including mitigation of soil run-off, retaining dust grains brought from other places, and reducing the impact of rainwater on the soil surface (Arisandi et al. 2019).

There were 34 species of riparian vegetation found at the spring 4 with *Musa paradisiaca L.* (banana) had the highest number of individuals with 160 or 7%. Kusumawardani et al. (2021) state that banana stems can be used as filter media because they contain cellulose and have high hygroscopic ability. The high cellulose content in banana stems can make it an absorbent medium. Hygroscopic materials, which have the ability to absorb and release water vapor, play an important role in regulating humidity levels (Zhang et al. 2021).

At the spring 5, there were 40 plant species with *Diplazium esculentum* (Retz.) Pers. (vegetable ferns) dominated with 170 individuals or 7%. Arini and Kinho (2012) stated that the vegetation that grows around springs functions as a ground cover, which plays a very important role in preventing heavy raindrops from falling directly on the ground surface so that it will prevent humus from being carried away by water, regulate water management, and help forest litter weathering process.

Good ground cover vegetation, such as thick grass or dense vegetation, can eliminate the impacts of topography on erosion which might trigger landslides. Plants that densely cover the soil surface slow down runoff and inhibit the transport of soil particles. Besides that, plant roots also bind soil grains while maintaining the soil's pores beneath them, so rainwater infiltration runs smoothly (Adhitya 2017). Riparian vegetation functions as a protector of soil and water and maintains the health of rivers by providing mechanical support to the soil through the root system (Dosskey 2010) and has the potential for carbon storage (Dybala 2019).

The diversity of vegetation in the watershed, both trees and ground cover plants, can be used as an indicator in determining the quality of watershed especially their role to prevent landslides and erosion (Rambey et al. 2021). The potential of vegetation to support water and soil conservation in watersheds can be realized by implementing vegetative models as a watershed conservation strategy. Since river water is disturbed daily by various inorganic and organic pollutants, spring water quality can be moderated biologically through phytoremediation mechanisms. This is also explained by Ansari et al. (2020) that phytoremediation using aquatic plants are the most capable of reducing water pollution among the various methods developed.

Spring 5 had the highest diversity index (H') with 3.478, composed by 40 species and total individuals of 1,527 (Figure 3). The spring 2 ranked second with diversity index of 3.467, composed by 1,523 individuals of 47 species, followed by spring 4 with diversity index of 3.350, 34 species and 1,478 individuals. The spring 3 had the diversity index of 3.224 with 2,251 individuals and 33 species, while spring 1 was the lowest with diversity index of 3.114, composed by 34 species and an individual density of 0.938. According to the Shannon-Winner diversity index value category, springs 1 to spring 5 are classified as high diversity class, where the H'>3.

A high H′ value indicates that vegetation community has relatively balanced composition in term of number of species and individuals. Shannon Weaver's diversity index values typically range from 1.5 to 3.5 and rarely exceed 4.5 (Adam 2015). The denser the riparian vegetation at a spring point, the better its role in soil and water conservation. River bank vegetation has functions, including reducing soil erosion, serving as a barrier to reduce sediment entering the river, and acting as shade from sunlight so that the water temperature does not change for the survival of river biota (Seele-Dilbat et al. 2022). Efforts to maintain riparian vegetation can be made by maintaining its existence and seeking the diversity of the plant species that make up it so it can function optimally (Kauffman 2022).

Water quality

Physicochemical properties

The results of water quality analysis of the physicochemical properties are presented in Table 2. The results show that springs 1, 2, 4, and 5 had a water pH that meets quality standards for drinking water, namely 7, 7.23, 6.59, and 6.67. Meanwhile, spring 3 is classified as acidic because its pH is 6.1, which is below 6.5, so it needs treatment to be used as drinking water. Addisie (2022) states a pH value ranging from 6.5 to 7.35 is the recommended degree of water acidity.

Table 2. Physiochemical parameters of water quality at each spring in Yeh Penet Watershed, Baturiti Sub-District, Tabanan District, Bali, Indonesia

Parameter	Unit	Water spring					Standard quality	Analysis methods/tools
		1	2	3	4	5		
pH	pH	7	7.2	6.1	6.6	6.7	6.5-8.5	AMTAST EC900 water test meter
Conductivity	µS/cm	143.5	78.8	434.4	306.2	414.4	-	AMTAST EC900 water test meter
Salinity	ppt	0.0516	0.036	0.21	0.15	0.2	-	AMTAST EC900 water test meter
Resistivity	ohm-m	6.96	12.78	2.294	3.234	2.48	-	AMTAST EC900 water test meter
TDS	ppm	98.16	50.72	293.8	206.4	279.6	<1000	AMTAST EC900 water test meter
DO early	mg/L	7.316	6.29	6.312	6.35	5.80	1-6	AMTAST EC900 water test meter
DO end	mg/L	5.708	5.892	5.644	5.97	5.66	1-6	AMTAST EC900 water test meter
BOD	mg/L	1.608	0.4	0.668	0.38	0.138	<3	AMTAST EC900 water test meter
COD (Spectro)	mg/L	22	24.44	23.04	18.86	17.88	<25	SNI 6989.2.2019
Sulfide	mg/L	<0.0015	<0.0131	<0.0015	0.0136	<0.0015	0.05-0.1	APHA 4500-S2-D2017
Sulfate	mg/L	<0.2172	1.594	51.7	1.006	17.46	250	SNI 6989.2.2019
Nitrate (NO3-)	mg/L	0.3871	0.9895	26.17	5.265	6.06	20	QI/LKA/65/ (UV Screening Spectrophotometer)
Nitrite (No2-)	mg/L	0.0106	0.0136	0.0175	0.0229	0.0425	3	APHA.4500-NO2 B-2017
Ammonia (NH3)	mg/L	0.3093	0.3449	0.3515	0.3836	0.0425	1.5	APHA.4500-NH3 F-2017
Oil/Fat	mg/L	<0.9935	<0.9935	<0.9935	<0.9935	<0.9935	1	APHA.3120B ed 23-2017
Calcium (Ca)	mg/L	16.34	4.298	39.32	28.75	29.85	-	APHA.3120B ed 23-2017
Magnesium (Mg)	mg/L	4.852	1.529	15.2	11.75	14.08	-	APHA.3120B ed 23-2017
Nickel (Ni) Soluble	mg/L	<0.0302	<0.0302	<0.0302	<0.0302	<0.0302	0.07	APHA.3120B ed 23-2017
Iron (Fe) Soluble	mg/L	<0.0208	<0.0208	<0.0208	<0.0208	<0.0208	0.2	APHA.3120B ed 23-2017
Manganese (Mn) Soluble	mg/L	<0.0104	<0.0104	<0.0104	<0.0104	<0.0104	0.1	APHA.3120B ed 23-2017
Copper (Cu) Soluble	mg/L	<0.0157	<0.0157	<0.0157	<0.0157	<0.0157	2	APHA.3120B ed 23-2017
Lead (Pb) Soluble	mg/L	0.0121	<0.0014	0.0057	0.0174	0.0226	0.1	APHA.3120B ed 23-2017
Zinc (Zn) Soluble	mg/L	<0.0057	<0.0057	<0.0057	<0.0057	<0.0057	3	APHA.3120B ed 23-2017
Chrome (Cr) Soluble	mg/L	<0.0105	<0.0105	<0.0105	<0.0105	<0.0105	0.05	APHA.3120B ed 23-2017
Cadmium (Cd) Soluble	mg/L	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015	0.003	APHA.3120B ed 23-2017
Mercury (Hg) Soluble	mg/L	<0.0003x10-1	<0.0003x10-1	<0.0003x10-1	<0.0003x10-1	<0.0003x10-1	0.001	QL/LKA/116

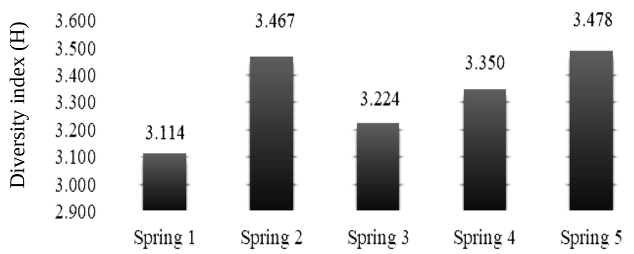

Figure 3. Shannon-Weaver diversity index (H') of riparian vegetation at each spring in Yeh Penet Watershed, Baturiti Sub-district, Tabanan District, Bali

Based on the Indonesian Minister of Health Regulation Number 32 of 2017, drinking water quality standards have a pH ranging from 6.5 to 8.5. This is also supported by the Department of Biotechnology, HST Company, Cairo research, that the pH of drinking water should be between 6 and 8.5; if the water is acidic, then a low pH treatment process is needed (Rahmanian et al. 2015).

The pH value can be lower due to the high organic material content (Roy et al. 2021). The pH value of water can decrease due to the process of respiration and decomposition of organic substances. A study by Büker et al. (2021) showed that the use of sodium bicarbonate (NaHCO3), calcium hydroxide (Ca(OH)2), or calcium carbonate (CaCO3) can change the alkalinity and pH of water, apart from using the above materials. Mudiasa et al. (2017) stated that tahar lime is useful for raising water pH. Changes in pH in water greatly affect the organisms that live in it. Water with a pH of less than 7 is acidic, while water with more than 7 is alkaline. Acidic soil will result in the dissolution and excessive availability of heavy metals in the soil.

Based on the results obtained, springs 1 and 2 had relatively low conductivity, while springs 3, 4, and 5 had higher conductivity. The amount of movement of dissolved ions influences the conductivity value. The greater the number of ions in a solution, the higher the conductivity value (Rozsa and Galli 2021). Apart from the movement of ions in water, the conductivity value of water is influenced by temperature differences (Mathur 2015); if the conductivity exceeds the specified limit, it could damage the kidneys because minerals that are not used by the body will precipitate and produce kidney stones. The conductivity values at the five spring points are within the quality standards set by the Republic of Indonesia Minister of Health Regulation No. 32 of 2017, namely 500 µS/cm, so the water is categorized as suitable for consumption.

Springs 1 and 2 had low salinity, so both springs are considered drinkable. Water with very low salinity is classified as freshwater or has a small salt content. According to (Li et al. 2019), fresh water is water with a salt content below 0.5 ppt (%). While springs 3, 4, and 5 have higher salinity levels, water with a salinity content of 0.15-0.21 ppt (%) is classified as brackish water. These values are still tolerable, but corrective steps are needed to reduce the salt levels. The resistivity value describes how well the material (water) inhibits the flow of electricity; the higher the resistivity value, the lower the material's electrical conductivity. Springs 1, 2, 3, 4, and 5 had relatively low resistivity. Hence, it can be concluded that the five springs are suitable for consumption because their value is less than the standard that have been set. Water is an insulator that can conduct electricity. Water can be a conductor if pure water lacks free electrons. The resistivity value is low if the rock easily flows with electric current. In contrast, the resistivity value is high if the rock is difficult for electric current to flow. Rocks can be considered an electrical medium, such as an electrically conducting wire, so they have resistivity. Underground water resistivity value <40 ohm-m (Chang et al. 2022).

Springs 1 and 2 had a low Total Dissolved Solids (TDS), while springs 3, 4, and 5 had higher TDS. TDS refers to the total amount of dissolved substances in water, including minerals, salts, metals, and other chemicals. According to WHO, high TDS can make the water taste salty or bitter (Emad et al. 2023). The standard for healthy drinking water suitable for consumption must have a TDS level below 1000 ppm. Water containing a TDS concentration below 1000 ppm can be used as drinking water, while water with a high TDS value needs to be distilled or boiled first. Reverse osmosis is a method where water is distilled to separate the water from the substances contained in it (Marszałek and Żyłła 2021).

Dissolved Oxygen (DO) refers to the amount of dissolved oxygen in water. Dissolved oxygen is important for aquatic organisms for respiration and survival. Higher DO values indicate better oxygen availability in the water. Changes in DO values can be caused by various factors, including organism activity, water temperature, and other environmental influences (Chapra et al. 2021). The greater the DO value, the better, and the better the water quality. Vice versa, a low DO value indicates that water quality is experiencing a high level of pollution (Uddin et al. 2021). The permitted Dissolved Oxygen (DO) value requirement is a minimum of 4 mg/L. Based on the Indonesian National Standards (SNI), all studied springs can be consumed because it has a Dissoved Oxygen (DO) value higher than the specified minimum limit. The DO value is in the class A category with a value of 6 based on water quality standards (Tanjung et al. 2024).

Biochemical Oxygen Demand (BOD) refers to the amount of oxygen needed by microorganisms in biochemical processes to decompose organic matter contained in water. A high BOD value indicates a higher organic material content for the decomposition process, which can cause a decrease in water quality. Springs 2, 3, 4, and 5 had BOD values of 0.4, 0.6, 0.38, and 0.138 mg/L. This value is relatively low compared to the spring 1. The lower the BOD value, the better the water quality or cleaner. Li and Liu (2019) said that pristine rivers have BOD below 1 mg/L. Rivers with pollution have BOD values ranging from 2 to 8 mg/L. Based on this information, spring 1 needs treatment by prohibiting the dumping of livestock waste or other waste at the spring location.

Chemical Oxygen Demand (COD) refers to the amount of oxygen needed to oxidize chemicals in water. A high COD value indicates the presence of more organic matter and oxidized chemicals in the water. Springs 1, 2, and 3 had high COD values, while springs 4 and 5 had low COD values. The COD concentration in unpolluted water ranges from + 20 mg/L (Hamdi et al. 2022), and water bodies that receive waste usually have COD values ranging between 200 mg/L. Several factors that influence high and low COD values are dissolved oxygen and other organic substances. The solubility of oxygen in water depends on temperature, oxygen pressure in the atmosphere, and the salt content dissolved in the water. The higher COD level indicates that these dangerous substances are in unreasonable amounts; if consumed directly without going through the processing stages (boiling or distilling), it can cause health problems (Li et al. 2018).

Sulfide refers to the concentration of sulfur compounds dissolved in water, which is a dangerous, foul-smelling contaminant found in well water, reclaimed water, waste streams, wastewater, and pond water; it is often produced by bacterial anaerobic sulfate reduction (Tzvi and Paz 2019). The study revealed a sign (<) that the sulfide value in the water is below the detection limit, indicating that all springs showed very low sulfide concentrations. Hydrogen sulfide concentrations exceeding 6 mg/L can be removed by injecting oxidizing chemicals such as household bleach or potassium permanganate (Rubright et al. 2017). The standard for sulfides detected in drinking water is 0.05 mg/L (Xiao and Yu 2021; Deng et al. 2022).

Sulfate ($SO4^{-2}$) is an inorganic ion commonly found in water and increased sulfate concentrations in drinking water can give an unpleasant taste and impact water quality and health. The permissible limit concentration of sulfate (250 mg/L) is set by WHO (Radfard et al. 2019). Based on the results, all springs can be used as drinking water because the sulfate value is below the specified standards. Regarding nitrate, spring 3 was more than 20 mg/L compared to the other springs which were below 20 mg/L. The permitted quality standard for nitrate content is 20 mg/L (Ward et al. 2018).

Spring 3 had a nitrate concentration exceeding the quality standards, while the other springs met the quality standards permitted for consumption. Nitrate pollution is caused by agricultural wastewater containing nitrate compounds due to the use of nitrogen fertilizer (urea). Potential sources of contaminating nitrates are septic tanks, animal waste disposal sites, commercial fertilizers, and trash cans. Nitrite can come from the oxidation of ammonia in the nitrogen cycle. High nitrite levels in water can indicate the presence of pollution or undesirable biochemical processes. All springs have nitrite (NO2-) concentrations far below the quality standards. This shows that the water in all springs meets the specified quality standards. The drinking water standard for nitrates is 20 mg/L, while for nitrites, the drinking water standard is 3 mg/L (Schullehner et al. 2017).

Ammonia is a nitrogen compound often found in water due to the decomposition of organic materials or from human activities. High levels of ammonia in water can indicate pollution and can have a negative impact on aquatic organisms. The concentration of ammonia that can be used as drinking water is <2 mg/L (Schullehner et al. 2017). All ammonia values obtained at all spring points are below the specified quality standards. Hence, the five springs can be used as drinking water.

The presence of oil/fat in water can be an indication of pollution and can have a negative impact on aquatic ecosystems. All springs studied had oil/fat concentrations lower than the detection limit (<0.9935 mg/L). This shows no oil/fat content in the water in the five springs.

Calcium is a mineral generally found in water and can come from rocks, soil, or other mineral sources. Calcium at a certain level will benefit health, but when the level is high and consumed by humans for a long time, it will harm health. In particular, excessive calcium will cause kidney stones and damage to muscle tissue (muscle weakness). The maximum calcium content allowed is 500 mg/L. The World Health Organization (WHO) does not set standards for calcium and magnesium levels in drinking water because they do not have detrimental health impacts. However, magnesium can cause hardness and a taste in water (Schullehner et al. 2017). So, based on this information, it can be concluded that the five springs can be used as drinking water.

Heavy metals in waters are very dangerous both directly to living organisms and indirectly to human health. This is related to heavy metals' properties, which are difficult to decompose, so they easily accumulate in the aquatic environment (Wibowo et al. 2020). Heavy metals are divided into essential and non-essential heavy metals; essential heavy metals which living organisms need their presence in certain amounts, but excessive amounts can cause toxic effects. According to (Slobodian et al. 2021), essential metals, such as iron, zinc, and copper, are required for various biological processes. However, high levels of this metal can be toxic and cause various adverse effects, including oxidative stress, cell death, and developmental abnormalities. Non-essential metals, such as lead, cadmium, and mercury, have no known biological function and are considered toxic at all concentrations. Exposure to non-essential metals can cause a variety of toxic effects, including nerve damage, reproductive problems, and cancer.

Nickel (Ni) is a silvery white metal which when combined with other metals, it can form a mixture/alloy (Genchi et al. 2020). Based on the results, all the five springs had Nickel concentration below the standard SNI for nickel (0.0302), implying that the water from the springs is allowed to drink. Fitriani and Sriartha (2018) stated that the standards for nickel levels in water quality for biota as prescribed in the Ministry of Environment Regulation KMNLH No. 51 of 2004 concerning water quality standards is 0.07 mg/L.

Iron (Fe) is a silvery white metal. The iron content in surface water is usually relatively low, rarely exceeding 1 mg/L, while the iron concentration in ground water varies from 0.01 to 25 mg/L. Iron in water can be dissolved, suspended, or combined with solid inorganic organic substances. The solubility of iron in water depends on its depth; the deeper the water penetrates the soil, the higher the solubility in the water. Low pH can form iron deposits due to the corrosion process. Table 2 shows the iron content at the five springs was below 0.0208, suggesting the water is suitable for consumption. The maximum limit for Fe levels in drinking water based on Minister of Health regulations is 0.2 mg/L (Rushdi et al. 2023). Iron content that exceeds drinking water quality standards can cause health problems, damage to the intestinal walls, and even death.

Manganese (Mn) is an essential heavy metal that builds healthy bone structure and metabolism and helps create enzymes. Manganese is corrosive if it exceeds the limit, making the body susceptible to disease (Walter et al. 2016). Laboratory results show that the value of manganese in the five springs was below 0.0104, meaning the water is suitable for consumption. The manganese (Mn) content suitable for consumption based on the Indonesian Minister of Health Number 492/Menkes/Per/IV/2010 is 0.1 Mg/L.

Copper (Cu) functions in the formation of hemoglobin, collagen, blood vessels, and the brain. Copper is also involved in forming the energy for metabolism and terosin activity. If the solubility of Cu exceeds the threshold, biomagnification of aquatic biota will occur. Copper is a heavy metal whose parameters must be measured as a standard for drinking water quality (Manne et al. 2022). The maximum copper level in drinking water is 2 mg/L (Arslan et al. 2020); indicating that the water from the five springs meets the copper (Cu) quality standards. The copper content in the five springs was below 0.0157.

Zinc (Zn) is an essential heavy metal that organisms need for growth and development, including in the formation of blood and enzymatic systems. Zinc can cause growth disorders, affect sexual maturation, and easily cause infections and diarrhea; in large amounts can cause death, especially in children (Briffa et al. 2020). The heavy metal zinc (Zn) concentration at the five springs obtained results of <0.0057. This value is categorized as safe for drinking water since the permitted standard zinc (Zn) content is 3 mg/L (Cobbina 2015).

Chromium (Cr) in water is generally low in nature, but it can increase in large amounts due to human activities such as industrial activities, household waste, and other activities that enter the waters (Prasad et al. 2021). The chromium (Cr) at five springs were <0.0105, suggesting that the water is safe when consumed by humans. According to SNI, the permitted Cr level is 0.05, while Sazakli et al. (2016) informed that chromium in drinking water ranges from <0.5 mg/L to 90 µg·l-1.

Cadmium (Cd) is a by-product of zinc (Zn) metal ore processing. This element is flexible, resistant to pressure, has a low melting point, and mixes other metals such as nickel, silver, copper, and iron (Sharma et al. 2015). Cadmium has bad effects on the environment and humans because it causes breast cancer, respiratory problems, kidney failure, and death. The standard of Cadmium (Cd) in drinking water following the Minister of Health

Regulation no. 492/Menkes/Per/IV/2010 was below 0.003. Therfore, the five springs were not polluted by Cadmium (Cd) since the value was below 0.0015; and are suitable for consumption.

Excessive mercury (Hg) in the environment can increase the amount of methylmercury microorganisms produce (Tang et al. 2020). Mercury (Hgo+) will sink to the bottom of the water or accumulate in sediment to a depth of 5-15 cm. The Indonesian National Standard (SNI) set Hg content for human consumption, namely 0.001. Based on this, the five springs are not polluted by mercury since the mercury (Hg) value obtained from the laboratory analysis results is below 0.0003x10-1.

Long-term exposure to lead (PB) can cause damage to the nervous system, internal organs, and various other health problems. Lead concentrations in the five springs were within the range generally found in drinking water sources, thus the water is drinkable. Even though lead concentrations are below the quality standard limits set by WHO and local health authorities, it is important to monitor regularly to ensure water quality is maintained.

Biological parameters

The results of water quality analysis of the biological parameters are presented in Table 3. Coliforms are a group of bacteria used to indicate the presence of potential microbial contamination of pathogenic bacteria in water. Springs 1, 2, 3, 4, and 5 had coliform concentrations of 9, 9, 13, 12, and 7 CFU/100 mL, respectively. These values exceeded the quality standard limit of 0 CFU/100 mL, suggesting that there is bacterial contamination. Water for human consumption must be free from fecal coliform bacteria in general and *E. coli* in particular (Navab-Daneshmand et al. 2018).

The presence of Coliforms indicates possible contamination of feces or other organic material. This contamination potentially causes health risks if used for consumption or other purposes. Water treatment and purification measures are required to maintain water quality, such as filtering, chlorination, or other disinfection because the Coliform concentration exceeds the quality standard limit.

E. coli (Fecal Coli) is a common group of bacteria in human and animal feces, indicating fecal contamination and potential health hazards. Springs 1, 2, 3, 4, and 5 had Fecal Coli concentrations of 35, 28, 35, 21, and 17 CFU/100 mL, respectively. These exceeded the quality standard limit of 0 CFU/100 mL, indicating potential disease-causing pathogens from human or animal feces. There is factor that have a small but significant impact on *E. coli* levels in the soil. *E. coli* concentrations are significantly higher in residential areas with domesticated animals. Handling of animal waste has long been suspected as a source of fecal contamination in developing countries (Lupindu et al. 2015; Purohit et al. 2017; Navab-Daneshmand et al. 2018). Further action is needed to overcome pollution and ensure that it meets quality standards to maintain water quality. An effective water treatment and purification process is needed to eliminate fecal coliforms and ensure the water is safe for consumption. Monitoring the amount of coliforms and *E. coli* in water is very important for public health and safety to improve water quality and accessibility (Odonkor and Mahami 2020).

Relationship between riparian vegetation and spring water quality

The Pearson Correlation test showed a strong correlation between riparian vegetation (in the form diversity index (H')) and water quality parameters. The correlation value close to 1 indicates a strong relationship between the two variables, and vice versa the value close to 0 indicates a weak relationship. A positive correlation value means the relationship is directional, whereas a negative number means the relationship is opposite. The results of correlation analsysis is presented in Tabel 4 with strong correlation is indicated by the value of >0.8.

Table 4 shows that the riparian vegetation diversity had a strong correlation with BOD, Ammonia (NH3), and Total Coliform with the correlation value between the two variables is >0.75. Riparian vegetation diversity strongly relate to Biochemical Oxygen Demand (BOD) parameters, which shows that riparian vegetation plays an important role in influencing the ability of waters to degrade organic matter. Biochemical Oxygen Demand (BOD) is a parameter used to estimate the amount of oxygen in the water to break down the organic material contained therein. The BOD value reflects how organic matter in water can be decomposed naturally (biodegradable). Therefore, by observing the BOD value, we can assess whether the water's ability to break down organic matter. If the BOD value is low, the water's ability to self-recovery (self-purification) is good. Riparian vegetation acts as a provider of oxygen for aquatic ecosystems through the process of photosynthesis. The photosynthesis process is closely related to the brightness level in the waters. The higher the brightness value, the photosynthesis process will run optimally, causing lower BOD values in the waters. If the oxygen level in the water decreases, it causes the BOD value to increase. A high BOD value indicates that the water quality is also low (Jouanneau et al. 2014).

Table 3. Biological parameters of water quality at each spring in Yeh Penet Watershed, Baturiti Sub-district, Tabanan District, Bali

Parameter	Unit	Water spring					Standard quality	Analysis methods/Tools
		1	2	3	4	5		
Total coliforms	CFU/100mL	9	9	13	12	7	0	QL/LKA/18 (double tube)
Fecal coli	CFU/100mL	35	28	35	21	17	0	QL/LKA/53 (double tube

Table 4. Results of Pearson Correlation between riparian vegetation diversity and water quality parameters in Yeh Penet Watershed, Baturiti Sub-district, Tabanan District, Bali

Water quality parameter	Sample number (N)	Correlation	95% CI for ρ	P-Value
pH	5	0.135	(-0.830, 0.919)	0.524
Conductivity	5	0.092	(-0.860, 0.901)	0.613
Salinity	5	0.110	(-0.841, 0.913)	0.555
Resistivity	5	0.117	(-0.838, 0.915)	0.547
TDS	5	0.082	(-0.863, 0.899)	0.622
BOD	5	-0.916	(-0.995, -0.174)	0.029
COD	5	-0.248	(-0.927, 0.812)	0.477
Sulfide	5	0.314	(-0.715, 0.954)	0.308
Sulfate	5	-0.125	(-0.907, 0.851)	0.584
Nitrate (NO3-)	5	-0.175	(-0.916, 0.836)	0.540
Nitrite (No2-)	5	0.358	(-0.673, 0.961)	0.260
Ammonia (NH3)	5	-0.752	(-0.982, 0.387)	0.099
Calcium (Ca)	5	-0.208	(-0.921, 0.826)	0.512
Magnesium (Mg)	5	0.115	(-0.839, 0.914)	0.549
Nickel (Ni) Soluble	5	*	(*,*)	*
Iron (Fe) Soluble	5	*	(*,*)	*
Manganese (Mn) Soluble	5	*	(*,*)	*
Copper (Cu) Soluble	5	*	(*,*)	*
Lead (Pb) Soluble	5	0.097	(-0.847, 0.910)	0.571
Zinc (Zn) Soluble	5	*	(*,*)	*
Chrome (Cr) Soluble	5	*	(*,*)	*
Cadmium (Cd) Soluble	5	*	(*,*)	*
Total Coliforms	5	-0.773	(-0.984, 0.343)	0.125
E. coli	5	-0.386	(-0.946, 0.752)	0.521

Apart from that, riparian vegetation also plays a role in filtering heavy metals and organic and inorganic waste. These results confirm that riparian vegetation significantly impacts the water quality of aquatic ecosystems, especially through its influence on BOD values (Retnaningdyah et al. 2023). The high organic matter content in water increases water's need for dissolved oxygen (BOD). Conversely, the lower the amount of organic matter in the waters, the decrease in BOD value.

In conclusion, this study found that water springs in the Yeh Penet watershed had varying vegetation diversity and composition with spring 1 was dominated by *Equisetum hyemale*, spring 2 by *Diplazium esculentum*, spring 3 by *Digitaria longiflora*, springs 4 and 5 by *Musa paradisiaca*. The water of the five springs is suitable for consumption based on most physicochemical parameters assessed. However, all springs showed contamination with feces and other organic materials and have total coliform and fecal coli concentration values that exceeded the quality standard limits. Thus, the communities are expected to heat the water to a temperature of ±100°C before consuming it. In particular, they need to maintain environmental conditions by paying attention to the location of septic tanks and waste disposal sites so that they are not located near water sources. We revealead that riparian vegetation diversity had strong relationship with Biochemical Oxygen Demand (BOD) values, Ammonia (NH3), and total coliform. Our findings confirm the importance of riparian vegetation in maintaining water quality in water springs within a watershed.

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