

# Spring water quality, discharge, and vegetation diversity across land management regimes in UB Forest, Malang, East Java, Indonesia

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**Abstract.** Fata YA, Hidayatullah RR, Umami M, Hadiwijoyo E, Roviq M, Arviano CI, Lestari RP, Ikhsanudin M, Samudra MB, Wulandari T. 2025. Spring water quality, discharge, and vegetation diversity across land management regimes in UB Forest, Malang, East Java, Indonesia. *Biodiversitas* 26: 3610-3622. Springs in forested landscapes play a vital role in ensuring the availability of clean water and maintaining essential ecosystem services. This study explored the characteristics of springs in UB Forest, Malang, East Java, Indonesia, focusing on buffer zone conditions in secondary forest and pine plantation forest, water quality, discharge, and vegetation diversity under different land management regimes. The research was conducted across five tributary systems, where water quality was assessed through physical, chemical, and biological parameters, and vegetation diversity was evaluated using the Shannon-Wiener (H') and evenness (E) index. Spring discharge was measured using the volumetric method, with the highest discharge recorded at 0.5 m<sup>3</sup>/second. Springs in secondary natural forests showed better water quality, more stable discharge, and greater vegetation diversity compared to those in plantation or agroforestry systems. All springs are in riparian zones, within 1 to 30 meters from the nearest river, and the water quality meets drinking, raw water, and irrigation standards. The highest discharge occurred at Dampul 4 (0.5 m<sup>3</sup>/s), while other springs were below 0.2 m<sup>3</sup>/s. The buffer zones support 19 plant species, dominated by native vegetation (*Ficus gul*), with H' values ranging from 0.451 to 1.685 and E from 0.65 to 0.988. All chemical parameters comply with water quality standards (WQS-1 to WQS-4), except for chromium (Cr) and iron (Fe) levels in Petung 21-2 and Codo, which do not meet WQS-1. Positive correlations were found between vegetation diversity and NO<sub>2</sub>, Fe (moderate), and TDS (strong). These correlations indicate the potential for using vegetation diversity as an indicator of water quality. While the correlation between vegetation diversity and discharge was relatively low (R<sup>2</sup>: 20%), the findings emphasize the importance of maintaining natural vegetation and establishing protected buffer zones. The natural vegetation-based spring buffer zone protection strategy and long-term monitoring are needed for sustainable forest management efforts and water resource conservation in the tropical forest landscape.

**Keywords:** Discharge, land management, spring, vegetation diversity, water quality

## INTRODUCTION

Springs are the outlet points of water from the groundwater flow system formed from the infiltration process or long-term groundwater accumulation. There are several types of springs, including springs originating from underground aquifers or rock fracture zones, gravity springs or descending springs, and artesian springs or rising springs. Springs are important in providing clean water, maintaining hydrological balance, regulating surface flow, and supporting biodiversity in their surrounding environments. However, the existence and sustainability of springs are increasingly threatened by environmental degradation, especially in the upstream areas of the watershed, because of human activities.

Land management within catchment areas is a key factor affecting the quantity and quality of springs. Anthropogenic activities like forest clearing, land use and management within forest zones, slash-and-burn farming,

and the application of fertilizers and pesticides (Solangi et al. 2019, et al. 2024; Shah et al. 2022), and infrastructure development around springs can reduce the quantity and quality of springs (Pielech et al. 2015; Prakoso and Soedjoko 2018). These activities can reduce spring discharge, increase flow fluctuations, diminish vegetation diversity around springs, and reduce the physical, chemical, and biological quality of springs (Nugroho et al. 2019; Hani et al. 2024).

The type and management system of land around springs have different effects on hydrological functions (Shah et al. 2022; Fata et al. 2024). The complex vegetation structure in secondary natural forests is considered more effective in maintaining the water cycle through protecting against surface runoff and enhancing percolation (de Paula et al. 2015). In contrast, monoculture systems such as plantation forests tend to increase surface flow and reduce the ability of the soil to absorb water (Garcia et al. 2018). Vegetation diversity, fire prohibition,

and the protection of infiltration zones are effective in enhancing water infiltration and preserving soil moisture (Javadi et al. 2019; Fata et al. 2022; Błońska et al. 2024). Meanwhile, forests are designed as buffer zones to maintain springs as protected areas with minimal intervention (Pielech et al. 2015). The observed contamination is attributed to surface runoff associated with cliff erosion, unstable litter decomposition, or anthropogenic activities such as wood burning and agricultural waste discharge within the forest area (Boulguerager et al. 2022; Shah et al. 2022).

Buffer zones around springs are essential for sustaining hydrological and ecological functions. The physical characteristics of springs, including location, spring type, and surrounding conditions, are influenced by vegetation characteristics and land management in the buffer zone (Wibowo et al. 2024). The presence of adequate vegetation in the buffer zone can reduce external contamination, increase retention of nutrients and heavy metals (Khalil et al. 2024), and maintain the stability of water discharge and quality (Neto et al. 2020; Shah et al. 2022). In America, the determination of buffer zones is conducted strategically to protect water sources from their headwaters (Pielech et al. 2015). Meanwhile, in Indonesia, the determination of buffer zones is regulated in PP No. 43 of 2008 concerning Groundwater, the Permen PU No. 28/PRT/M/2015 concerning the Determination of River and Lake Boundary Lines.

Land management practices influence spring hydrology and ecology. Practices such as forest clearing, burning, and intensive agriculture can reduce vegetation cover and soil quality, disrupt groundwater recharge, and affect spring discharge and water quality (Neto et al. 2020; Semiun et al. 2020; Adams et al. 2021). Forest vegetation, particularly in spring buffer zones, plays a key role in maintaining water balance and supporting ecosystem services (Ferreira et al. 2019; Bhat et al. 2022). Previous studies in Indonesia have investigated spring conditions across agricultural and forested areas, such as in Bali (Wibowo et al. 2024), East Nusa Tenggara (Mamula and Semiun 2021), and East Java (Semiun et al. 2020). Research specifically addressing riparian vegetation diversity around springs in East Java (Najih et al. 2023) is still limited. Comprehensive studies integrating spring ecosystem characteristics with sustainable land management in tropical Indonesian forests remain limited.

Special Purpose Forest Area of Education and Training (*Kawasan Hutan dengan Tujuan Khusus*, KHDTK) of Universitas Brawijaya in Malang, East Java, Indonesia, better known as UB Forest, is an educational forest with diverse land use and management, including secondary natural forest in protected areas, pine and mahogany plantations established as monoculture or agroforestry, and settlements. The diversity of land use and management makes UB Forest an ideal natural laboratory to study the relationship between ecological and hydrological functions of springs. Therefore, spring exploration activities in UB Forest are important to assess the condition of the buffer zone, the water quality, spring discharge, and the impact of vegetation and land management on the sustainability of

water resources. The results of this study provide a robust scientific foundation for sustainable forest management, especially in the UB Forest, in determining buffer zones, managing water utilization, and conservation.

## MATERIALS AND METHODS

### Study area

This research was conducted in the UB Forest in Malang District, East Java, Indonesia. The area of UB Forest, according to the Decree of the Minister of Environment and Forestry of the Republic of Indonesia Number 676/MenLHK-Setjen/2015, is 544.74 Ha as an education and training forest. The State-Owned Forestry Company previously managed this forest area, which had both production forest and protected forest status. Data on spring locations, historical land use, and local management practices were collected through interviews with local communities and forest farmer groups in the UB Forest area. The land cover in UB Forest is presented in Figure 1.

### Research design

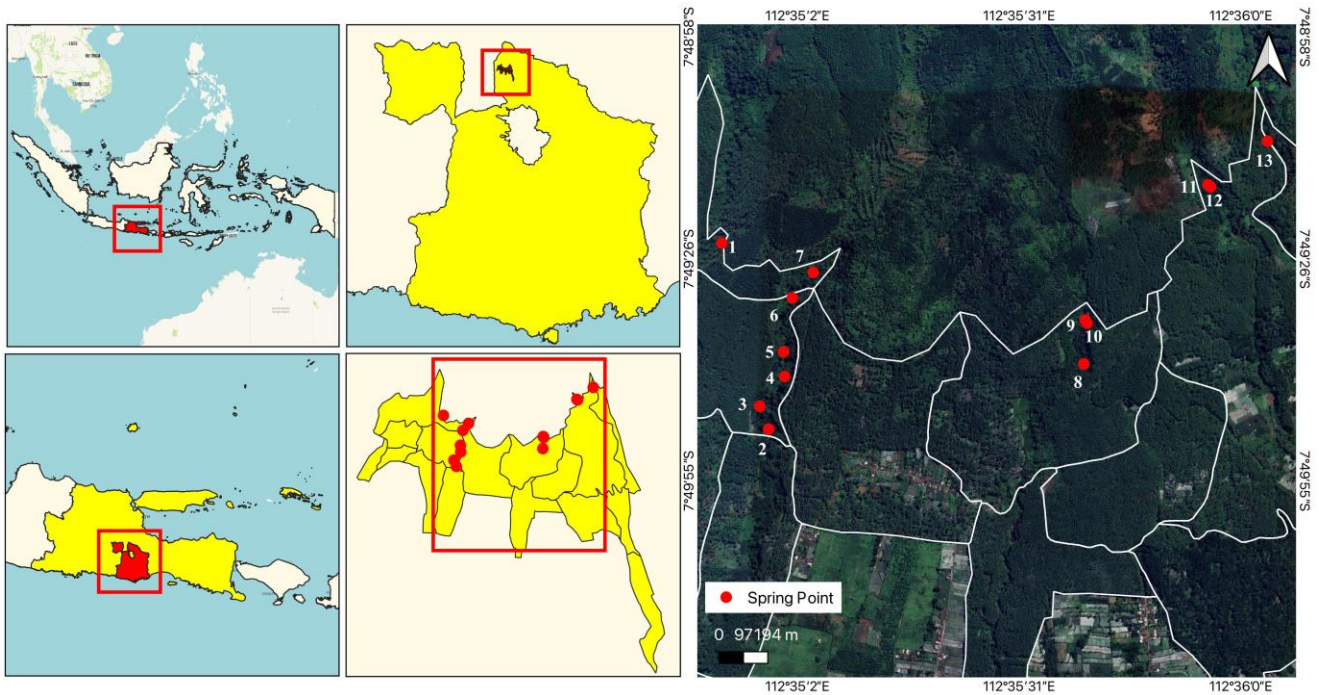
This research was initiated by exploring springs within the UB Forest area, guided by information from interviews with local communities, forest farmers, and UB Forest staff (Nugroho et al. 2019). Following the exploration, spring discharge was measured directly in the field, and water samples were collected for subsequent laboratory analysis of water quality. Spring water samples were taken to represent the distribution of springs around the tributary area in the UB Forest area.

Vegetation diversity was assessed through vegetation surveys by establishing 20×20 m observation plots within the spring buffer zones (Figure 2), with a total of eight plots. Vegetation observations consisted of vegetation types and the number of species. Land management types were determined by analyzing the relationship between spring locations and surrounding land cover within a 50-meter buffer zone (Neto et al. 2020) (Figure 1).

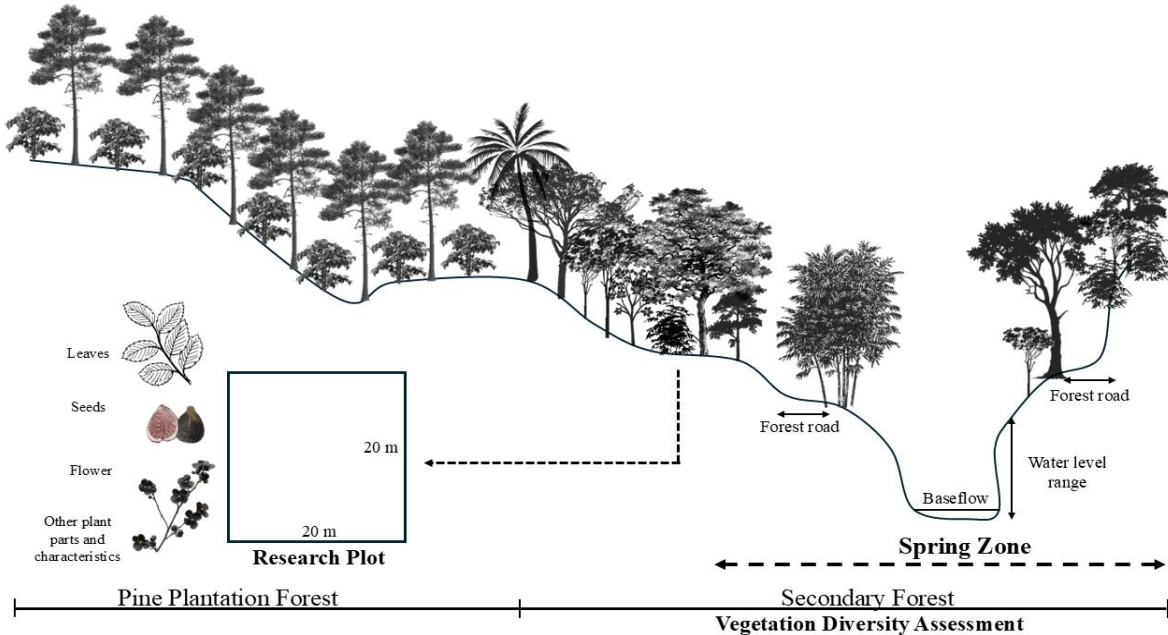
### Data collection

We conducted data collection from August 2024 to March 2025. Spring exploration, discharge measurement, and water sampling were conducted at the end of the dry season in August-September 2024, when the seasonal river remained dry, so the springs remained unaffected by river water (Hendrayana et al. 2023). The spring discharge (m<sup>3</sup>/second) was measured on-site using a volumetric collection method, repeated three times.

Water sampling for water quality testing represented the distribution of springs in tributaries within the UB Forest area. Five springs represent the five tributaries in UB Forest. The location of the spring water collection was determined using a purposive sampling method. Water samples from the spring were taken directly, placed into 1.5-liter bottles, and put into a cold box for analysis at the laboratory of Perum Jasa Tirta, Malang, East Java.



**Figure 1.** Distribution of springs and land cover in UB Forest, Malang, East Java, Indonesia. Spring name: 1. Buk Bejat; 2. Dampul 1; 3. Dampul 2; 4. Dampul 3; 5. Dampul 4; 6. Dampul 6; 7. Dampul 5; 8. CAA 1; 9. CAA 2; 10. CAA 3; 11. Petung 21-1; 12. Petung 21-2; 13. Codo



**Figure 2.** Research design for vegetation diversity assessment in UB Forest, Malang, East Java, Indonesia

Vegetation diversity was assessed by establishing a 20x20 m research plot for trees, followed by plant sampling (including leaves, flowers, fruits, or other plant parts) to support plant species identification. The scientific names of vegetation were standardized using World Flora Online (WFO) (<http://www.worldfloraonline.org/>) and Plants of the World Online (<https://powo.science.kew.org/>), while

the conservation status of vegetation species was checked against the International Union for Conservation of Nature's Red List of Threatened Species (<https://www.iucnredlist.org/>).

Ground checks were performed following a spatial analysis of the land cover around the spring site to verify land use and management, and pollution sources in the

vicinity. The management level was evaluated based on factors such as the intensity of input use (e.g., fertilizers, pesticides), the condition of infrastructure around the site, land maintenance practices, plant productivity, and long-term land use and management. Erosion levels were assessed by examining signs of soil loss, vegetation cover, water flow, and suspended particles or sediment sustainability.

The tools used in this study include a Global Positioning System (GPS) Garmin 64s, a walkie-talkie, a stopwatch, a calculator, a gadget, a measuring funnel, a sample bottle, a cooling box, a label, a sample plastic, a ruler, a phi band, an Hagameter, a tally sheet, and stationery. The materials used included UB Forest land cover maps and alcohol to preserve the integrity of plant samples during the identification process.

### Data analysis

Coordinate points are marked on the area map to create a UB Forest Springs distribution map (Figure 1). Summersari Resort, Sumberwangi Resort, and Buntoro Resort categorize spring discharge as measured at the end of the dry season.

The water quality observed included physical, chemical, and biological parameters. The physical parameters observed were pH, temperature (°C), Total Dissolved Solids (TDS) (mg/L), turbidity (NTU), color (TCU), and odor, with analysis methods based on SNI 6989.11.2019, SNI 06-6989.23.2005, SM APHA 23rd Ed., 2540 C.2017, SNI 06-6989.80.2011, and SNI 06-6860.2002, respectively. The chemical parameters observed were Nitrate (NO<sub>3</sub>), nitrite (NO<sub>2</sub>), Chromium Valence 6, dissolved Manganese (Mn), and dissolved Iron (Fe) in units (mg/L) with analysis methods based on Q1/LKA/65 (Spectrophotometry) and SM APHA 23rd Ed. 2017. The biological parameters observed were Total coliform and *Escherichia coli* in units (CFU/100 mL) with an analysis method based on SM APHA 24th Ed 2023.

Water quality data is then analyzed to compare with water quality standards based on the Indonesian Minister of Health Regulation No. 02/2023 for sanitation hygiene purposes, Indonesian Government Regulation No. 82/2001 concerning Water Quality Management and Water Pollution Control (Hani et al. 2024), National Environment Commission (NEC) 2018, and FAO for irrigation. Water quality data information is then analyzed using the Geographical Information System (GIS) using Inverse Distance Weighted (IDW) interpolation spatial analysis to create a map of each water quality indicator (Khouni et al. 2021). Interpolation using IDW is based on the principle of a collection of sample points used to predict unmeasured points between the sample points. The general equation used for IDW is shown in equation:

$$\hat{Z}(x_0) = \frac{\sum_{i=1}^n z(x_i) \cdot d_{ij}^{-p}}{\sum_{i=1}^n d_{ij}^{-p}}$$

Where, Z is the interpolated value of a grid node, Z<sub>i</sub> is the neighboring data points, and d<sub>ij</sub> is the distance between the grid node and the data points.

Vegetation was analyzed based on species composition, Shannon-Wiener diversity index (H'), and species evenness index (E). The type and number of species represent the total species identified from vegetation surveys conducted using 20×20 m observation plots within the spring buffer zones (Figure 2). Eight plots were selected through purposive sampling to represent the distribution of springs across five sub-watersheds in the UB Forest. The diversity index was calculated based on equation as follows:

$$H' = -\sum_{i=1}^n \left(\frac{n_i}{N_t}\right) \ln \left(\frac{n_i}{N_t}\right)$$

Where, H' is the Shannon-Wiener diversity index, n is the number of species, n<sub>i</sub> is the number of individuals, and N<sub>t</sub> is the total number of individuals of the entire species. The H' value <2.0 indicates low species diversity, 2<H'>3 indicates moderate diversity, and the H' value >3.0 indicates high species diversity.

The species evenness index is calculated by the formula as shown in equation:

$$E = \frac{H'}{\ln S}$$

Where, E is the species evenness index, H' is the Shannon-Wiener diversity index, and S is the number of species found. The E value <0.3 indicates low species evenness, 0.3<E>0.6 indicates moderate species evenness, and E>0.6 indicates high species evenness.

A field inspection was then conducted to identify the types of land cover, land use, land management practices, and potential sources of pollution around the spring. Risk factors around spring are based on the modification from the WHO (2022) about Sanitary Inspection Form. The relationship between the Shannon-Wiener vegetation diversity index (H') and water quality parameters was analyzed using Pearson Correlation and associated P-values (Wibowo et al. 2024), while the relationship between H' and spring discharge was assessed through regression analysis.

## RESULTS AND DISCUSSION

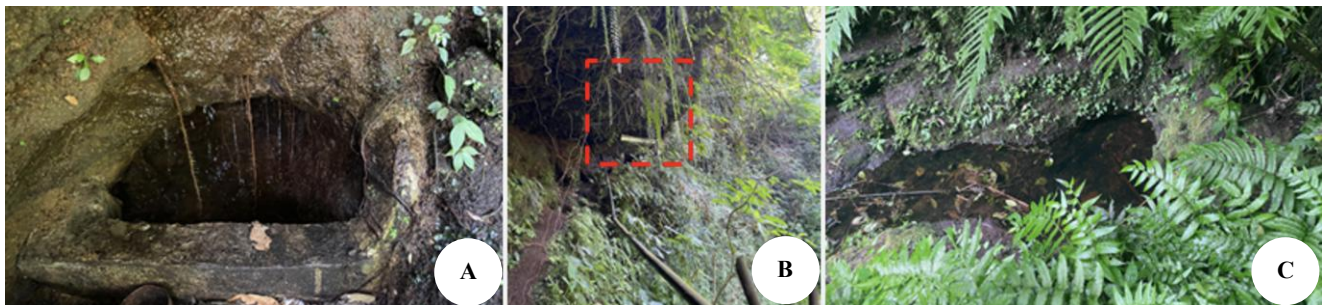
### Characteristics of spring

The springs in UB Forest are classified into three types: small cave springs, artesian springs, and fracture springs. Cave springs refer to groundwater sources not connected to surface water, emerging directly from the ground. In UB Forest, the cave openings where these springs flow are less than 2 meters wide and are typically found at the base of cliffs or slopes with gradients exceeding 45°. Fracture springs originate from cracks, fissures, or joints within rock formations, formed through tectonic activity, weathering, or other geological processes. Meanwhile, artesian springs occur when water confined between impermeable layers is pressurized and naturally flows to the surface (Stevens et al. 2021; Keegan-Treloar et al. 2022). The types of springs in UB Forest are presented in Figure 3 and Table 1.

**Table 1.** Characteristics of spring in UB Forest, Malang, East Java, Indonesia

Spring name	Spring type	Land use 1	Land use 2	Distance from river (m)	Distance from forest road (m)	Litter thickness (cm)	Land management level	Erosion level	Uphill barrier	Spring box	Wood burning
Dampul 1	Small cave spring	Mixed forest	Pine - coffee	f	b	b	M	L	A	A	NA
Dampul 2	Small cave spring	Mixed forest	Pine - coffee	h	b	a	M	L	A	NA	NA
Dampul 3	Small cave spring	Mixed forest	Coffee	c	b	a	M	M	A	A	NA
Dampul 4	Small cave spring	Bamboo	Mixed forest	f	b	a	M	M	A	A	NA
Dampul 5	Small cave spring	Mixed forest	Coffee	e	b	a	L	L	A	A	A
Dampul 6	Fracture spring	Mixed forest	Pine	a	c	a	L	L	A	A	NA
CAA 1	Artesian spring	Mixed forest	Pine - coffee	e	b	a	L	L	A	A	NA
CAA 2	Small cave spring	Mixed forest	Shrubs and Bushes	d	c	a	L	L	A	A	NA
CAA 3	Small cave spring	Mixed forest	Shrubs and Bushes	d	b	a	L	L	A	A	A
Buk Bejat	Fracture spring	Mixed forest	Pine - coffee	g	b	a	M	L	A	NA	A
Codo	Artesian spring	Mixed forest	Pine - coffee	a	c	b	M	L	A	A	A
Petung 21 1	Artesian spring	Mixed forest	Shrubs and Bushes	b	b	a	M	M	A	A	NA
Petung 21 2	Artesian spring	Mixed forest	Shrubs and Bushes	c	b	a	M	M	A	NA	NA

Note: CAA: Curah Ayam Alas, A: Available, NA: Not Available, L: Low, M: Medium. Distance Level: a: 0 m, b: 1-5 m, c: 6-10 m, d: 11-15 m, e: 16-20 m, f: 21-25 m, g: 26-30 m, h: 30 m. Litter Thickness: a: 1-10 cm, b: 11-20



**Figure 3.** Spring type in UB Forest, Malang, East Java, Indonesia. A. Small spring cave of Dampul 4, B. Fracture spring of Buk Bejat, C. Artesian spring of Petung 21-2

Spatial analysis (Figure 1) indicates that secondary natural forest dominates the land cover within a 50 m radius of 10 spring locations. Three springs, Buk Bejat (26% pine cover), CAA 1 (14% pine cover), and Codo (39% pine cover), are situated within pine plantation zones. Field assessments confirm that mixed forest represents the predominant land use at 12 spring sites, while bamboo stands characterize one site. Other land use types identified within the 50 m buffer include monocultures of pine and coffee, pine-coffee agroforestry systems, shrublands, and bushlands.

The springs in UB Forest are located near a seasonal river that flows only during the rainy season, with two springs (Dampul 6 and Codo) situated directly within the riverbed, and the remainder positioned less than 30 m from

the riverbank. The distance to the nearest forest road ranges between 1-10 m (Table 1). The proximity of the springs to forest roads corresponds with their active utilization by surrounding communities to support UB Forest operations.

### Spring discharge

The springs in UB Forest are distributed across three management units such as Sumberwangi Resort (9 springs), Summersari Resort (1 spring), and Buntoro Resort (3 springs). Spring discharge measurements collected during the dry season are presented in Figure 4.

The highest spring discharge was recorded at Dampul 4, reaching 0.5 m<sup>3</sup>/s, while the remaining springs exhibited discharges below 0.2 m<sup>3</sup>/s. Three springs, such as Dampul 6, Petung 21-1, and Petung 21-2, were dry during the

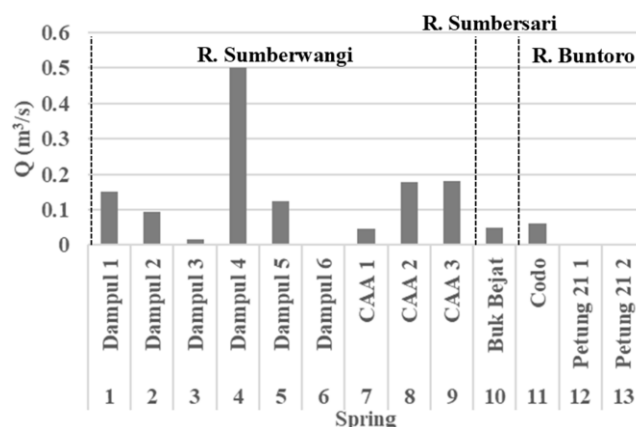
measurement period (Figure 4). Most springs have been used by local communities, as evidenced by the installation of piping systems for agricultural irrigation and raw water supply, except for Dampul 6, which has remained unused following coverage by a landslide. Dampul 4, with the highest discharge, is specifically utilized by UB Forest as a raw water source for the Sumberwangi Resort office.

**Spring water quality**

Five spring locations in Buk Bejat, Dampul 4, CAA 2, Codo, and Petung 21-2 were selected to represent the major tributary flows traversing UB Forest (Figure 1), and water samples were collected from these sites. Water quality was assessed based on four regulatory standards: Regulation of the Ministry of Health of the Republic of Indonesia (Permenkes RI) No. 02/2023, Government Regulation (PP RI) No. 82/2001, National Environment Commission (NEC) 2018, and Food and Agriculture Organization (FAO) standards for irrigation. The applicable water quality thresholds are summarized in Table 2, and the spatial distribution of water quality results is illustrated in Figure 5.

Figure 5 presents the spatial distribution of various physical, chemical, and biological parameters of springs within the UB Forest area and its surroundings. Each parameter is represented by a contour map with color

gradations, where darker shades (red, purple, dark brown) typically correspond to higher concentrations or values. In comparison, lighter shades (light green, light yellow) indicate lower values. The interpretation of these color variations depends on the specific parameter being depicted.



**Figure 4.** Spring discharge in Resort Sumberwangi, Sumberari, and Buntoro in UB Forest, Malang, East Java, Indonesia

**Table 2.** Water quality standard

Parameter	Unit	Water Quality Standard (WQS)										
		WQS-1	WQS-2				WQS-3			WQS-4		
		Permenkes RI No.02/2023	PP RI No.82/2001				NEC 2018			FAO for irrigation		
			I	II	III	IV	A	B	C	None	Slight to Moderate	Severe
<b>Microbiology</b>												
<i>E. Coli</i>	CFU/100 ml	0	-	-	-	-	-	-	-	-	-	-
Tot. Coliform	CFU/100 ml (WQS-1) or ind/ml (WQS-2) or MPN/100 ml (WQS-3)	0	1000	5000	10000	10000	50	5000	10000	-	-	-
<b>Physics</b>												
Color	TCU (WQS-1 and 2) or Hz (WQS-3)	10	50	100	-	-	5	50	-	-	-	-
Turbidity	NTU	<3	5	-	-	-	-	-	-	-	-	-
TDS	mg/L	<300	1000	1000	1000	2000	-	-	-	<450	450-2000	>2000
Temperature	C	30	Deviation 3		Dev. 5	-	-	-	-	-	-	-
Smell	-	No Smell	-	-	-	-	-	-	-	-	-	-
<b>Chemistry</b>												
pH	-	6.5-8.5	6-9	6-9	6-9	5-9	6.5 - 8.5	6-9	6-9	-	6.5 - 8.4	-
NO <sub>3</sub>	mg/L	20	10	10	20	20	10	50	-	<5	5-30	>30
NO <sub>2</sub>	mg/L	3	0.06	0.06	0.06	(-)	-	-	-	-	-	-
Cr	mg/L	0.01	0.05	0.05	0.05	1	0.05	0.05	-	-	-	-
Fe	mg/L	0.2	0.3	(-)	(-)	(-)	0.1	0.5	-	-	-	-
Mn	mg/L	0.1	0.1	(-)	(-)	(-)	-	-	-	-	-	-

Note: Permenkes: Peraturan Menteri Kesehatan (Minister of Health Regulation), RI: Republik Indonesia, NEC: National Environment Commission, FAO: The Food and Agriculture Organization, TDS: Total Dissolved Solids, CFU: Colony-Forming Unit, MPN: Most Probable Number, -: not required. Water quality standard classification of PP RI No.82/2001: I: Allocation of raw water and drinking water, II: Allocation of water recreation facilities, freshwater fish cultivation, livestock, and irrigation, III: Allocation of freshwater fish cultivation, livestock, and irrigation, IV: Allocation of irrigation. Water quality standard classification of NEC 2018. A: Very good (Drinking water source without conventional treatment, but after disinfection), B: Good (Drinking water source with conventional treatment), C: Moderate (Irrigation, industrial cooling, etc.)

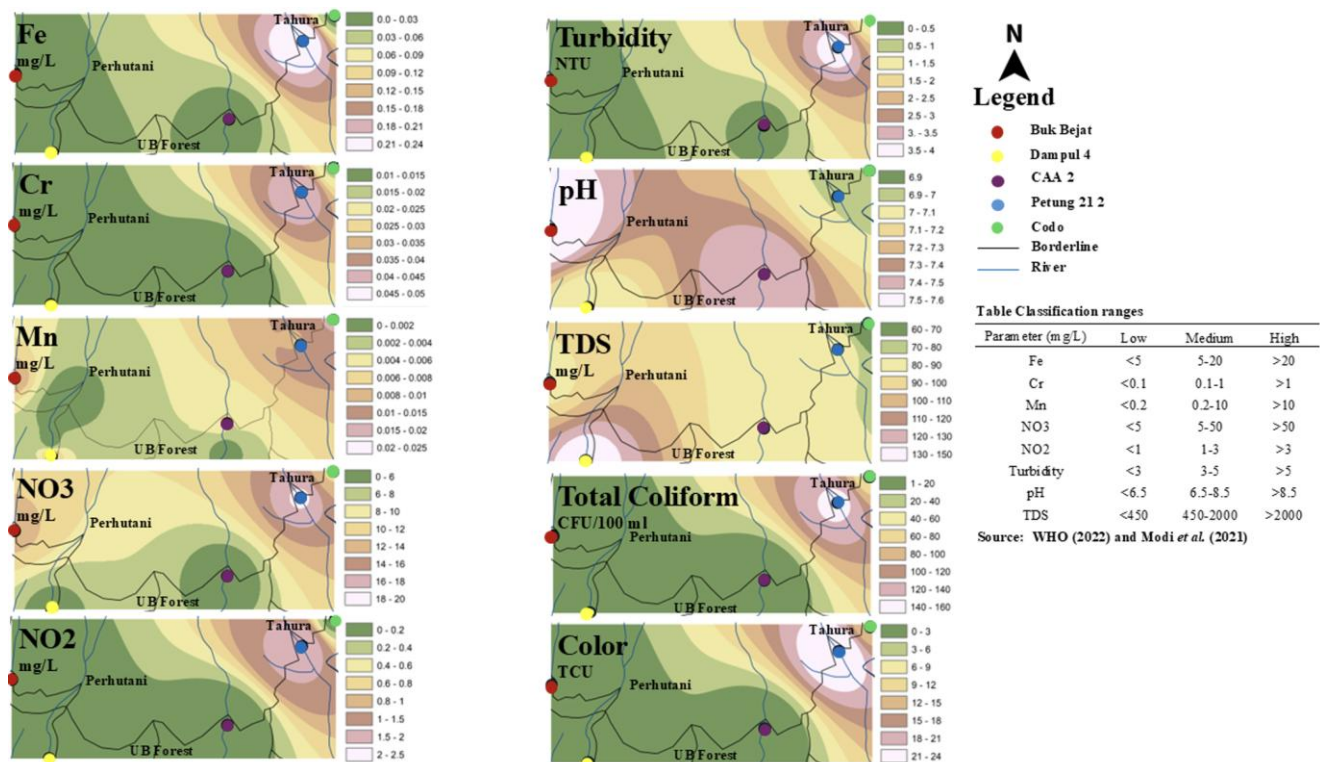


Figure 5. Spatial distribution of water quality in UB Forest, Malang, East Java, Indonesia

The overall water quality analysis indicated a spring temperature of 26°C, with no detectable odor, and *E. coli* levels below 1 CFU. Both temperature and odor met the Water Quality Standard (WQS)-1 and WQS-2 criteria. Although *E. coli* was present, its concentration was minimal (Table 2).

Microbiological analysis revealed *E. coli* levels below 1, with the highest spatial distribution of total coliform found in Petung 21-2 and Codo. *Escherichia coli* and total coliform concentrations did not meet the criteria of WQS-1 but were within WQS-2, class 1. The total coliform distribution map indicates that Buk Bejat, Dampul 4, and CAA 2 fall under WQS-3, class A, while Petung 21-2 and Codo are classified under WQS-3, class B. Based on microbiological parameters, these results suggest that the water in UB Forest is suitable for raw and drinking water following conventional treatment (Ameen 2019). The elevated total coliform levels indicate potential biological contamination due to human, livestock, or wildlife activity, particularly in springs lacking proper spring boxes.

Based on physical parameters such as temperature and Total Dissolved Solids (TDS), water quality in UB Forest meets WQS-1 and WQS-2 standards. Color parameters align with WQS-1 and WQS-2, except for Petung 21-2 and Codo, which do not meet WQS-1. Turbidity levels in Petung 21-2 do not meet WQS-1 but are within class 2 under WQS-2 (Table 2). Overall, UB Forest water quality complies with the standards, except for color and turbidity parameters, which fall short of WQS-1. Turbidity, TDS, and color variations suggest potential physical disturbances, such as soil erosion, material weathering, or dissolved

minerals from organic matter (e.g., humus or phenolic compounds) from decaying leaves or cliff erosion at the spring sites. pH levels ranged from 6.9 to 7.6, indicating neutral conditions and meeting WQS-1 to WQS-4.

All chemical parameters comply with water quality standards, except for chromium (Cr) and iron (Fe) levels in Petung 21-2 and Codo, which do not meet WQS-1. Cr may result from mineral weathering, industrial activities, or pesticide use. At the same time, Fe can cause brown deposits, metallic tastes, and biofilm formation in piping systems, originating from the weathering of rocks or clay-rich soils (Merk et al. 2020; Arota et al. 2022). Water sources with elevated Cr and Fe concentrations should be monitored regularly to ensure compliance with WQS thresholds (Alfalahi and Aldhamin 2025). Low levels of manganese, nitrate, and nitrite suggest minimal agricultural activity and an effective nitrification process in the soil. Overall, based on general chemical parameters, the water quality in UB Forest springs is suitable for drinking, raw water, and irrigation use. However, it does not meet hygiene and sanitation standards for the two affected water sources.

### Spring's vegetation diversity

Vegetation samples were collected from a 20×20 m plot within the 50 m buffer zone around the springs, and the results are presented in Figure 6. Table 3 lists the species names, families, vegetation counts, and IUCN status for each species. Figure 6 shows the results of the Shannon-Wiener diversity index ( $H'$ ) and evenness ( $E$ ) calculations. Table 4 presents the relationship between vegetation diversity and water quality.

**Table 3.** Species name, family, number of species, and IUCN status in research area

Species name	Family	Number of species					IUCN
		Buk Bejat	Dampul	CAA	Codo	Petung 21	
<i>Trevesia sundaica</i> Miq.	Araliaceae	7					LC
<i>Dimocarpus longan</i> Lour.	Sapindaceae	2					DD
<i>Ficus fistulosa</i> Reinw. ex Blume	Moraceae	3				3	LC
<i>Alstonia scholaris</i> (L.) R.Br.	Apocynaceae		2				LC
<i>Artocarpus</i> sp.	Moraceae		1				LC to CR
<i>Ficus benjamina</i> L.	Moraceae		8				LC
<i>Heptapleurum</i> sp.	Araliaceae		1				VU
<i>Litsea</i> sp.	Lauraceae		1		1		LC to CR
<i>Coffea arabica</i> L.	Rubiaceae		1				EN
<i>Pometia pinnata</i> J.R.Forst. & G.Forst.	Sapindaceae		8				LC
<i>Ficus gul</i> K.Schum. & Lauterb.	Moraceae			15			LC
<i>Brugmansia suaveolens</i> (Humb. & Bonpl. ex Willd.) Bercht. & J.Presl	Solanaceae			11			EW
<i>Dysoxylum</i> sp.	Meliaceae			10			DD
<i>Cinchona pubescens</i> Vahl	Rubiaceae			9		4	LC
<i>Uvaria rufa</i> (Dunal) Blume	Annonaceae			14			NA
<i>Grewia</i> sp.	Malvaceae				5	6	CR
<i>Schima wallichii</i> (DC.) Korth.	Theaceae					3	LC
<i>Hibiscus macrophyllus</i> Roxb. ex Hornem.	Malvaceae					1	LC
<i>Cyrtostachys renda</i> Blume	Arecaceae					5	LC
Total		12	22	59	6	22	

Note: IUCN abbreviation code: Least Concern (LC), Data Deficient (DD), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), Not Assessed (NA)

Figure 6 illustrates 19 vegetation types in the spring buffer zone, which is characterized by secondary natural forest within the protected area (Figure 1). The highest vegetation diversity is observed at Dampul Spring, with 7 species, while the lowest is at Codo Spring (2 species). The number of species at Buk Bejat, Dampul, Curah Ayam Alas, Codo, and Petung 21 Springs are 12, 22, 59, 6, and 22, respectively (Table 3). Curah Ayam Alas exhibits the highest vegetation count, with an average of over 10 species per category. The most common species include *F. gul*, *U. rufa*, and *C. pubescens*. According to the IUCN Red List, *B. suaveolens* is listed as Extinct in the Wild (EW), and three species, *Artocarpus* sp., *Litsea* sp., and *Grewia* sp., are classified as Critically Endangered (CR). Five vegetation entries remain identified only at the genus level, warranting further species-level identification in future studies.

The highest vegetation diversity index (H') was recorded at Petung 21, followed by CAA and Dampul, while the lowest H' value was observed at Codo, indicating low species diversity (Figure 7). Vegetation evenness (E) was highest at CAA, suggesting a relatively uniform species distribution, with similarly high E values at Petung 21 and Buk Bejat. Conversely, Codo exhibited the lowest evenness, reflecting the dominance of a few species and an uneven distribution. Overall, these findings align with the study by Prakoso and Soedjoko (2018), which reported low H' values (<2) in spring environments.

The diversity (H') and evenness (E) values of vegetation, as illustrated in Figure 7, are not just numbers. They are powerful indicators that reflect the ecological condition of the spring buffer zones in UB Forest. Sites like Petung 21, CAA, and Dampul, which exhibit higher H' and E values compared to other sites, are not just healthier buffer zones. They are oases of life characterized by greater

species diversity and uniform species distribution. These conditions are not just good for the plants; they are suitable for the entire ecosystem. They promote water infiltration, stabilize spring discharge, filter pollutants, and provide complex habitats for flora and fauna. In contrast, locations such as Codo, with low H' and E values, suggest suboptimal buffer zone conditions, due to species dominance, intensive human activities, or a sparse understory (Błońska et al. 2024). The variations in diversity and evenness indices among sites reflect differences in surrounding land cover and management practices, such as secondary natural forests, agroforestry systems, or monoculture plantation forests. Therefore, vegetation diversity and evenness serve as important indicators for assessing the effectiveness of buffer zones in maintaining the hydrological and ecological functions of springs.

Table 4 indicates that NO<sub>2</sub> and Fe show moderate positive correlations (r>0.4), while TDS exhibits a strong correlation (r>0.6) with vegetation diversity. The correlations of NO<sub>2</sub> and Fe may reflect the influence of organic matter decomposition and mineral weathering, which elevate their concentrations in spring water. The strong correlation of TDS suggests that increased vegetation diversity could enhance mineral and nutrient leaching into water via root activity, soil processes, and microbial interactions. These results align with Wibowo et al. (2024), who found that relationships between vegetation diversity (H') and water quality parameters are not always significant, with most P-values exceeding 0.05. Additionally, the relationship between H' and spring discharge yielded an R<sup>2</sup> of 20%, suggesting a weak explanatory power (Figure 8). The limited sample size and heterogeneous spring characteristics (Table 1) may contribute to the absence of statistically significant correlations.

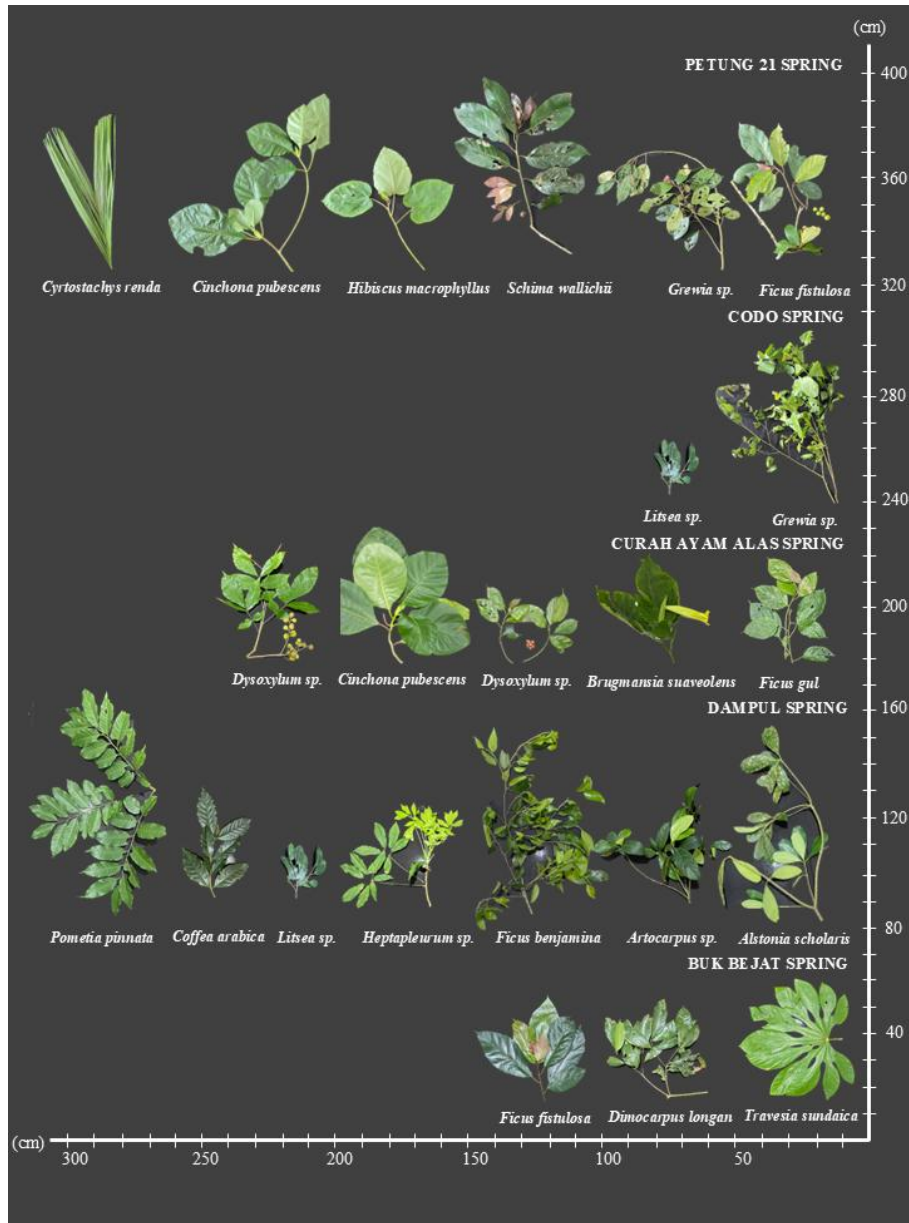
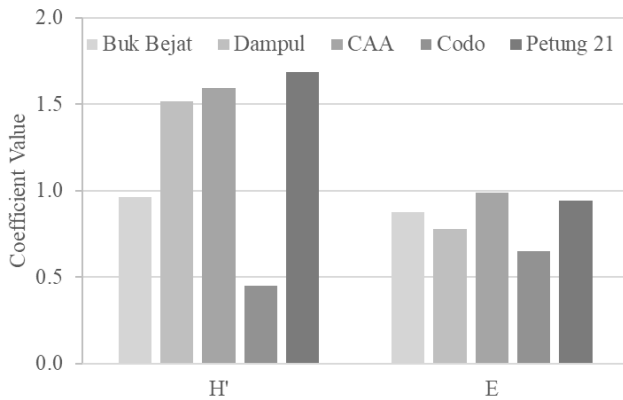


Figure 6. Plant species growing in the buffer zone area

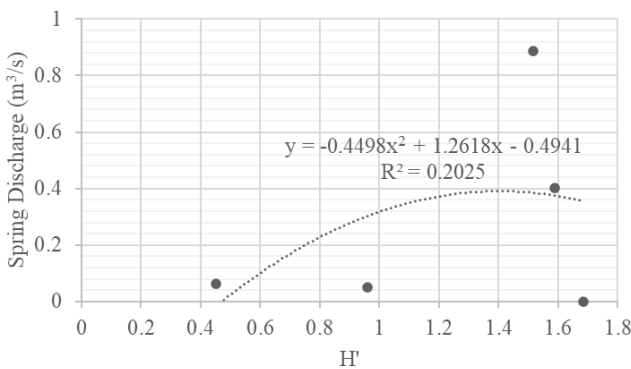
Table 4. Pearson Correlation between vegetation diversity and water quality parameters

Water quality parameters	Sample number (N)	Spring name					Correlation	P-value
		Codo	Petung 21	Dampul	CAA	Buk Bejat		
<i>E. Coli</i>	5	0.5	0.5	0.5	0.5	0.5	*	*
Tot. Coliform	5	70	144	0.5	0.5	0.5	0.067	0.915
Color	5	12.600	24.730	0.339	0.300	0.300	0.051	0.935
Turbidity	5	1.220	3.920	0.160	0.250	0.220	0.252	0.682
TDS	5	60	100	149.6	94.8	95.2	0.667	0.219
Temperature	5	26	26	26	26	26	*	*
Smell	5	1	1	1	1	1	*	*
pH	5	6.9	7	7	7.5	7.6	0.126	0.840
NO <sub>3</sub>	5	11.470	18.490	5.103	3.933	12.760	-0.131	0.834
NO <sub>2</sub>	5	0.132	1.811	0.007	0.001	0.001	0.422	0.480
Cr	5	0.019	0.044	0.005	0.005	0.005	0.178	0.775
Fe	5	0.021	0.241	0.021	0.021	0.021	0.474	0.419
Mn	5	0.016	0.022	0.010	0.010	0.010	0.021	0.973

Note: \*: No correlation



**Figure 7.** Diversity index and evenness index at each spring location in UB Forest, Malang, East Java, Indonesia



**Figure 8.** Relationship between H' and spring discharge

Spring discharge is affected by topography, soil infiltration capacity, and vegetation cover (Fata et al. 2025a, b). Springs located within densely forested zones, such as CAA and Dampul, showed higher discharge and H', likely due to enhanced infiltration and reduced surface runoff facilitated by forest litter and root systems (Prakoso and Soedjoko 2018). In contrast, springs like Buk Bejat and Codo, situated in disturbed areas, exhibited lower discharge and H' due to compacted soil and reduced water retention. Vegetation diversity is determined by soil moisture, microclimatic conditions, and levels of anthropogenic disturbance (Wibowo et al. 2024). Springs within buffer zones supported higher species richness and more complex understory structures compared to springs in degraded or open landscapes. These findings are consistent with studies in other tropical regions of Indonesia, such as Bali (Wibowo et al. 2024), Yogyakarta (Prakoso and Soedjoko 2018), and East Nusa Tenggara (Mamula and Semiun 2021), emphasizing the ecological importance of forest integrity in sustaining spring ecosystem functions. The results underscore the need for integrated conservation strategies that maintain natural vegetation cover in spring recharge areas. Sustainable land management practices can help preserve hydrological stability, protect water quality, and support local biodiversity (Pielech et al. 2015; Wibowo et al. 2024).

**Land management in the spring buffer zone**

The spring buffer area was delineated using a 50 m radius, following the findings of Neto et al. (2020), who reported that this distance provides a high capacity for nutrient retention and thus reduces spring contamination risk. Figure 1 shows buffer zones that were identified at 13 spring locations. Among these, three springs, Buk Bejat (26%), CAA 1 (14%), and Codo (39%), are partially located within pine plantation areas (*Pinus merkusii*), whereas the remaining ten springs are entirely situated within a secondary natural forest.

All springs in the UB Forest are located along riparian zones, with distances to the nearest river ranging from 1 to 30 meters. Most springs are situated within 16-25 meters of the river. Springs positioned within or near the river channel are more susceptible to the influence of river flow dynamics and potential contamination from anthropogenic activities or surface runoff. Notably, the Petung 21 and Codo Springs are close to the river. These sites exhibit greater vulnerability to riverine ecosystem disturbances, as reflected by several water quality parameters that fall outside the recommended standards (Table 2). Additionally, the proximity of springs to forest roads that are often less than 10 meters away indicates the accessibility of these water sources for community use, primarily for collecting clean water. In addition, the characteristics of spring locations in the UB Forest are further illustrated by the observed litter thickness, which ranged from 1 to 15 cm. Dampul 1 and Codo Springs exhibited the greatest litter accumulation, consistent with the high H' and E values observed at the Dampul sites. Greater litter thickness indicates a well-developed protective layer over the soil surface, contributing to enhanced soil moisture retention and serving as a buffer that supports the microflora and microfauna ecosystems surrounding the spring.

Most of the springs exhibited a moderate level of land management (M), reflecting a degree of human intervention related to the utilization of forest land and its protection. In contrast, five springs, including two from the Dampul group and three CAA points, were characterized by a lower level of management, as indicated by minimal signs of erosion, effective spring protection measures (e.g., the presence of spring boxes and uphill barriers), and limited burning activities by local communities. These springs also showed higher discharge rates (Figure 5), superior water quality (Table 2 and Figure 5), and greater vegetation diversity (Figure 7), highlighting the positive association between minimal disturbance and the maintenance of spring ecosystem functions. All springs in UB Forest are equipped with uphill barriers and spring boxes, which serve to regulate surface water flow, minimize the risk of contamination from upslope areas, protect water quality, maintain ecosystem stability around the springs, and control the discharge of water. Wood-burning activities were observed at several springs, leading to degraded vegetation, habitat disturbance, and poorer air quality.

The quantity and quality of spring water in UB Forest are influenced by an interplay of spring type, vegetation

structure, management practices, and land cover within the buffer zone. Based on the classification of spring types, most springs (8 out of 13) are categorized as small cave springs (Table 1), whose hydrogeological dynamics are highly dependent on surface conditions, particularly the buffer zone's capacity for rainwater infiltration. Dampul 4, which exhibited the highest discharge (0.5 m<sup>3</sup>/s), is characterized by mixed forest and bamboo dominance, thick litter accumulation, low species diversity ( $H' < 1.5$ ), and high vegetation evenness ( $E > 0.6$ ). These conditions support the ecohydrological role of the buffer zone in enhancing infiltration and sustaining stable spring discharge (Ghimire et al. 2021). Conversely, several springs such as Dampul 6 (fracture spring), Petung 21-1, and Petung 21-2 (both artesian springs) displayed very low discharge, with some drying up completely, despite artesian springs being associated with more stable water supplies from pressurized aquifers.

Although this study primarily emphasizes biophysical factors, geological conditions also play a critical role in determining the discharge and sustainability of springs in UB Forest. Geological characteristics such as rock type, degree of fracturing, and aquifer structure are fundamental in controlling groundwater storage capacity and hydraulic conductivity (Fata et al. 2021). Artesian springs, such as those at CAA 1 and Codo, require very specific geological settings, characterized by a permeable layer confined between two impermeable layers. When this structural integrity is compromised, discharge can decline significantly or cease altogether, as observed at Petung 21-1 and Petung 21-2, which have dried up despite being in forested areas. This finding highlights that favorable vegetation conditions and effective buffer zone management alone are insufficient to guarantee spring sustainability without adequate geological support. Keegan-Treloar et al. (2022) similarly emphasized that spring discharge results from a complex interplay between subsurface geological conditions and surface biophysical factors. Therefore, future research in UB Forest should incorporate detailed geological and hydrogeological analyses to understand better and manage spring dynamics.

Water quality also strongly correlates with land use and management patterns surrounding the springs. Locations such as Codo and Petung 21-2, which are situated near rivers and surrounded by pine-coffee agroforestry systems and shrublands, exhibited elevated total coliform levels, increased turbidity, and concentrations of heavy metals such as Cr and Fe that exceeded the WQS-1 threshold. In contrast, sites like CAA 2 and CAA 3, although also categorized as small cave springs and surrounded by mixed forest and shrub vegetation, displayed better and more stable water quality. These sites benefit from minimal anthropogenic disturbances and protective structures such as spring boxes and uphill barriers. Bedrock lithology conditions can also affect water quality (Brighenti et al. 2024) and vegetation species (Parzych et al. 2020).

The sustainability of springs in UB Forest requires management through an ecosystem-based approach, with conservation strategies tailored to each spring type and land use (Nugroho et al. 2019; Fata et al. 2024). Vegetation

diversification, fire prohibition, and the protection of infiltration zones effectively enhance water infiltration and preserve soil moisture (Javadi et al. 2019; Błońska et al. 2024). Previous studies have also highlighted that buffer zones with diverse vegetation can filter sediments and pollutants, thereby maintaining the stability of both water quality and discharge (Kiraga 2020). In contrast, forest phenology is also affected by the environmental conditions around spring (Adams et al. 2021). These findings are consistent with the conditions observed in UB Forest, where springs with lower management intervention and diverse vegetation, such as those in CAA and Dampul, exhibit superior water quality and discharge stability compared to springs under higher anthropogenic pressure. Given that each spring type operates under distinct hydrological dynamics, conservation strategies must be specifically adapted to preserve the sustainability of their hydrological functions (Sammoudi et al. 2023).

Based on the findings of this study, it is recommended that the management of forest areas surrounding springs prioritize the protection and restoration of ecosystems around spring sources (Wibowo et al. 2024). This can be achieved by planting species from the Moraceae family, which is known for its role as a natural riverbank vegetation family, alongside other native species, especially within the buffer zone of at least 50 meters from the spring outlet (Anggana and Susanti 2020). This recommendation aligns with national regulations in PP No. 43 of 2008 concerning Groundwater, the Permen PU No. 28/PRT/M/2015 concerning the Determination of River and Lake Boundary Lines, which suggests 200 m as a spring buffer zone. Strengthening the role of secondary natural forests as conservation zones will contribute to the stability of discharge, the maintenance of water quality, and an increase in biodiversity. Additionally, long-term monitoring of land cover changes and spring discharge dynamics is essential for a more comprehensive understanding of hydrological trends (Barbieri et al. 2023). Further research is recommended to assess the contribution of various vegetation types to ethnobotany, water filtration, retention functions, and soil quality for supporting plant growth (Fata et al. 2022; Najih et al. 2023; Mouchane et al. 2024), as well as the seasonal fluctuations in water quality and quantity (Sammoudi et al. 2023). A more detailed investigation into the water-use patterns of local communities, including *Pesanggem* and *Magersaren* as local communities, alongside the integration of socio-economic data, will provide a more holistic perspective for developing sustainable water resource protection policies (Riza et al. 2023; Hani et al. 2024) and long-term sustainability (Hoque et al. 2024).

While our findings highlight the negative impacts of land conversion on spring quality and vegetation diversity, it is important to acknowledge that not all land management practices lead to ecological degradation. Technological developments and well-managed agroforestry systems, for instance, can enhance biodiversity, enhance forest farmer economy and society, improve soil stability, and maintain water quality when applied appropriately (Riza et al. 2023; Fata et al. 2025a,

b). In our study area, however, poor land use and management practices, such as medium management level, erosion occurrence, inappropriate agroforestry activity, and limited conservation activity, have likely intensified the degradation of spring ecosystems. Although natural factors like geology and climate variability influence spring discharge, human activities exacerbate these effects (Keegan-Treloar et al. 2022; Barbieri et al. 2023; Brighenti et al. 2024). Vegetation within spring buffer zones plays a critical role in maintaining ecological health, as evidenced by higher species richness and better water quality at less disturbed sites. Therefore, future land management should focus on maintaining protected forests as buffer zones with minimal intervention or applying ecologically based practices that prioritize the preservation of natural vegetation, supported by long-term ecological monitoring to ensure the sustainability of spring ecosystems (Shah et al. 2022; Hoque et al. 2024).

In conclusion, the different land management practices in UB Forest greatly affect water quality, discharge stability, and vegetation diversity around the springs. Springs located in secondary natural forest areas show better water quality, more stable discharge rates, and higher vegetation diversity indices compared to those in monoculture or agroforestry plantation areas. These results emphasize the important role of natural vegetation cover and minimal land disturbances in maintaining the hydrological and ecological functions of springs. Therefore, protecting natural vegetation in the spring buffer zones is vital for sustainable water resource management, especially in educational forest areas like UB Forest.

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