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Banyan (*Ficus*) Presence and Spring Quantity–Quality Associations in Gendol Hill, Bulukerto, Wonogiri

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Abstract

Springs are primary water sources for rural communities and are sensitive to land-cover changes in recharge areas; therefore, assessing spring quantity and quality is essential for local water security. This study examines the association between banyan (*Ficus*) presence and spring quantity and water quality in Gendol Hill, Geneng Village, Wonogiri. A quantitative descriptive design was applied during the dry season, including an inventory of all springs and spatial documentation of nearby *Ficus*. Spring quantity was measured as flow/discharge, while water quality was evaluated using physico-chemical parameters (temperature, dissolved oxygen/DO, electrical conductivity/EC, salinity) and microbiological testing for *Escherichia coli*. All springs were perennial and showed variability in spring quantity (Meinzer classes V–VII). *Ficus* occurred at most spring outlets, paired comparisons of selected nearby springs indicated higher spring quantity at sites with *Ficus* than at sites without *Ficus*, although the pattern was not uniform across locations. *E. coli* was detected in three springs, while seven were negative. DO ranged from 1.93 to 4.99 ppm and temperature from 20.70 to 27.52°C, suggesting heterogeneous outlet conditions. These findings support spring protection zoning and sanitation management, alongside conserving woody vegetation as a supporting element for spring-ecosystem stability.

Keywords: Gendol Hill, *Ficus*, Springs, Water quantity, Water quality

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Introduction

Springs are a key component of clean water provision in rural areas because they represent aquifer discharge that is sensitive to changes in recharge and land-cover conditions in recharge zones (Jain, 2023). Therefore, the sustainability of clean water availability cannot be separated from the agenda of water resource security (Pantha *et al.*, 2022). In rural and steep-slope settings, springs often function as the main water source because they can provide a relatively stable supply compared with surface runoff, which is strongly season-dependent (Pandit *et al.*, 2024). Spring resilience is determined by two interrelated dimensions: quantity and quality (Locke, 2024; Shi *et al.*, 2024; Yan *et al.*, 2022). At the spring scale, water-quality assessment commonly integrates physico-chemical and microbiological indicators into a water quality index (Afonso *et al.*, 2025; Uddin *et al.*, 2021) to clarify health implications and conservation priorities (Mooney *et al.*, 2024). Time-series evidence shows that spring discharge can exhibit declining trends linked to changes in recharge and increasing drought events, reinforcing the urgency of evidence-based management for spring systems (Casati *et al.*, 2024).

One case of spring scarcity has occurred in the Gendol Hill area, located in Geneng Village, Bulukerto District, Wonogiri Regency. In the 1960s, a forest fire occurred in Geneng Village, eliminating vegetation in the area. The loss of vegetation reduced recharge capacity, caused springs to nearly dry up, eliminated wildlife habitat, and triggered prolonged drought. In the absence of adequate

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recharge areas, rainfall became surface runoff that transported materials along its flow paths. Recent reviews report that post-fire conditions can increase runoff and peak flows and alter soil properties in ways that reduce infiltration and increase erosion (Rey *et al.*, 2023). The resulting consequences include disrupted groundwater replenishment, altered baseflow, and degraded water quality through increased nutrients and other contaminants in surface flows (Moazeni & Cerdà, 2024; Rodríguez-Jiménez *et al.*, 2024).

In the 1990s, banyan trees *(Ficus)* and several other tree species were planted. Post-disturbance vegetation recovery can improve hydrological functioning, but effects vary across biophysical settings and spatial scales (Bruijnzeel *et al.*, 2025; Wang *et al.*, 2024). Hydrological modeling evidence indicates that vegetation restoration can reduce surface runoff and increase baseflow contributions, including lower wet-season peaks and greater flow during non-flood periods (Chang *et al.*, 2024). Vegetation influences water quantity by modifying soil structure and hydraulic properties (Lin *et al.*, 2025). Reviews further emphasize that plant roots can alter porosity and flow pathways through root penetration, root exudates, root water uptake, and root decay, which collectively influence infiltration, saturated hydraulic conductivity, and soil water retention, key components that ultimately determine the persistence of spring discharge (Nurrohmah *et al.*, 2025; Shi *et al.*, 2021; Xiao *et al.*, 2024).

Springs are sensitive to climate variability and landscape change (Casati *et al.*, 2024; Havyarimana *et al.*, 2026), yet site-based evidence on species-specific restoration interventions that link both discharge recovery and water-quality outcomes remains limited. For the genus *Ficus*, empirical evidence indicates that old-growth banyan trees can correlate with increased groundwater storage and water-holding capacity, supported by higher soil organic matter, aggregation, and porosity, hydrologically relevant attributes for stabilizing groundwater levels and mitigating flooding in green spaces (Barros *et al.*, 2024). This study addresses a key evidence gap by examining, at a site-specific scale, the extent to which *Ficus* planting is associated with the recovery of spring quantity (discharge) and spring water quality in a landscape that has experienced major disturbance, using measurable comparisons with surrounding reference conditions within the recharge system. The study aims to investigate the association between *Ficus* presence and spring quantity and water quality in Gendol Hill. This is motivated by observed increases in spring discharge following *Ficus* planting, whereby springs that had the potential to dry up resumed discharging water at the ground surface. Accordingly, this study contributes to strengthening local groundwater-based water governance in developing regions, where more contextual studies are needed to bridge knowledge gaps and support policy application.

Methods

This study employed a quantitative descriptive design using a geographic–environmental (geoecological) approach. The analyses were intended to describe and examine the spatial association between *Ficus* presence and spring quantity and water quality. As this study was designed as a site-specific descriptive ecological assessment involving the complete inventory of springs in the study area (n = 10). Quantitative descriptive analysis was used to summarize spring discharge, water-quality parameters, and *Ficus* characteristics, while spatial analysis was applied to examine their distribution patterns and ecological associations within the hydrogeomorphological setting of the study area. The research was conducted at Gendol Hill, which is administratively located in Geneng Village, Bulukerto District, Wonogiri Regency, Central Java, Indonesia. Astronomically, the site is located at 07°37’15.2’’ S and 110°18’28.7’’ E, at an elevation of approximately 428 m above sea level. Geomorphologically, the study area represents denudational landforms as an advanced stage of volcanic landforms shaped by erosion and mass-movement processes. The general land cover consists of secondary forest with grasses, bamboo, pine, and banyan *(Ficus)* vegetation on hilly terrain.

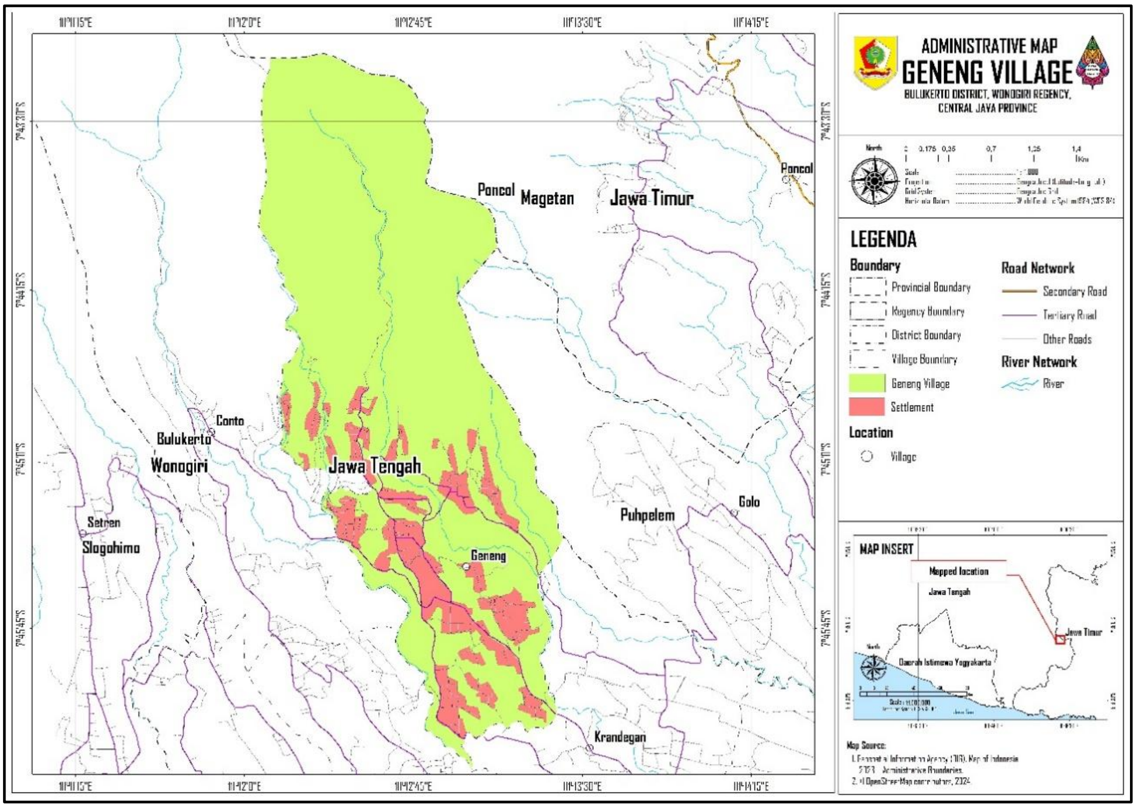

Figure 1. Map of Study Area

Field data collection was carried out during the dry season, as this period represents minimum-flow conditions and is therefore more sensitive for assessing spring-quantity resilience and potential water-quality risks. Data were collected through field surveys and mapping to inventory all relevant springs and *Ficus* trees, record their coordinates, and produce distribution maps as a basis for spatial analysis. Spring quantity was measured by determining discharge at each spring using a standardized procedure to ensure comparability across sites. Spring water quality was assessed by in situ measurements and/or water sampling at each spring for physico-chemical parameters (salinity, temperature, dissolved oxygen/DO, and electrical conductivity/EC) using a multiparameter instrument, and for biological parameters (*E. coli*) through laboratory testing, following consistent sampling procedures to minimize bias. Geological and geomorphological context data were obtained from field observations and interpretation of relevant maps and references to support the hydrological interpretation of the study area.

Data analysis applied a mixed approach at the interpretation stage, with primary emphasis on quantitative and spatial analyses. Quantitative analysis was used to describe the distribution of springs and *Ficus*, spring types, discharge values, and water-quality parameters, as well as to compare these characteristics among springs and assess the association between *Ficus* variables and spring quantity and quality. Spatial analysis was used to depict distribution patterns of springs, *Ficus*, and water-use locations, and to support interpretation of spring–*Ficus* linkages within the geomorphological and land-use context.

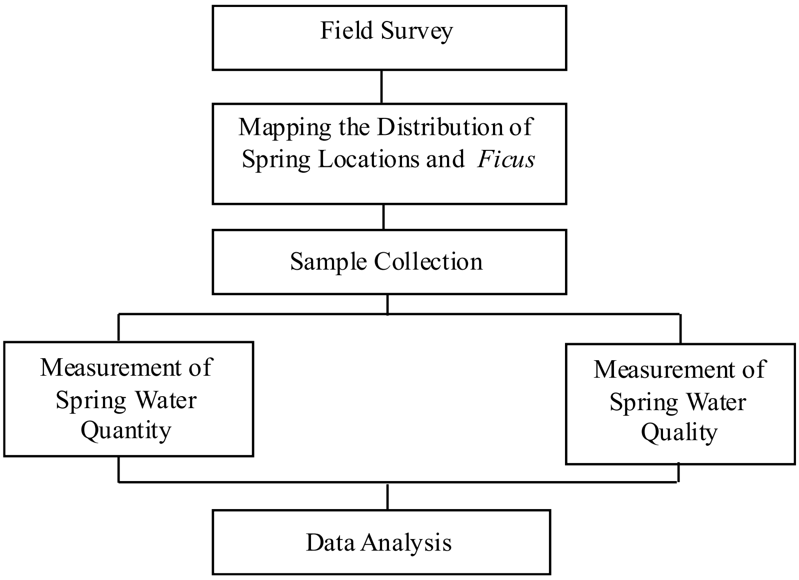

Figure 2. Research Workflow

Results and Discussion

Ecological Conditions of Springs and Banyan *(Ficus)* in Gendol Hill

The ecological conditions of springs in Gendol Hill, Geneng Village, are primarily shaped by geological controls, particularly the structure of the Sidoramping Lava Formation, which consists of porphyritic andesite and Quaternary volcanic materials. Volcanic andesite generally has low primary porosity; however, groundwater flow can occur effectively through secondary porosity in the form of fractures, joints, and weak zones developed within flow-structured lava bodies and along lineaments (syncline–anticline zones), as is characteristic of the Bulukerto area. This configuration promotes focused subsurface flow pathways, causing springs to emerge as discharge zones at specific topographic positions, especially where the groundwater table is intersected by the land surface.

Bulukerto has steep topography (15–40%) with volcanic hill relief and river drainage patterns that range from parallel to sub-radial, indicating slope systems that remain active under erosion and mass-movement processes. Such slope conditions typically position springs at slope breaks, footslopes, or valley heads, locations where topographic incision most likely intersects the groundwater table. The spring distribution map (Figure 3) and the Ficus distribution map (Figure 4) show that many Ficus samples occur in the same zones as springs, particularly within forested areas and along forest–open land boundaries. Ecologically, this pattern can be interpreted as co-existence in environments with higher soil moisture availability. Steep slopes also imply that when vegetation cover declines, surface runoff and erosion can increase, potentially reducing effective infiltration and accelerating degradation of recharge zones. Therefore, maintaining vegetation on slopes is not only a biodiversity issue but also a prerequisite for stabilizing recharge systems that sustain springs. On the maps, spring points appear predominantly within a green land-cover matrix, supporting the interpretation that forests and woody vegetation function as hydrological buffers that enhance infiltration, reduce runoff, and maintain groundwater discharge.

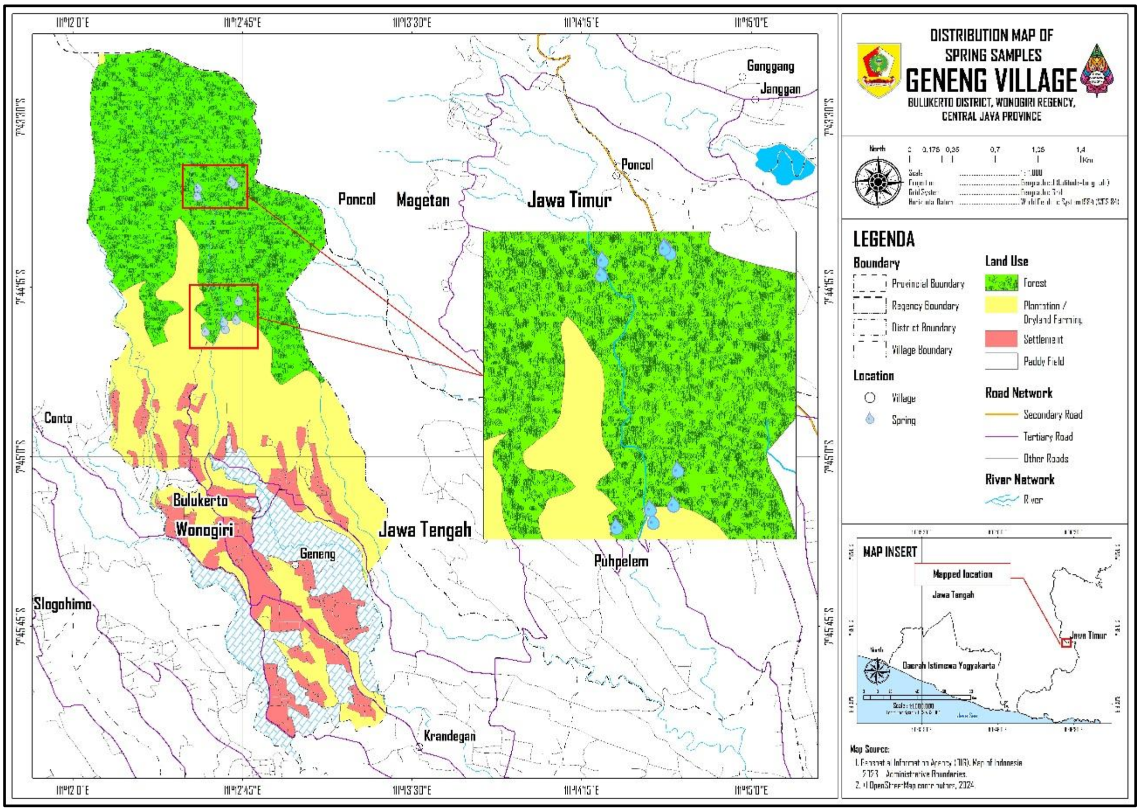

Figure 3. Distribution Map of Springs in Gendol Hill

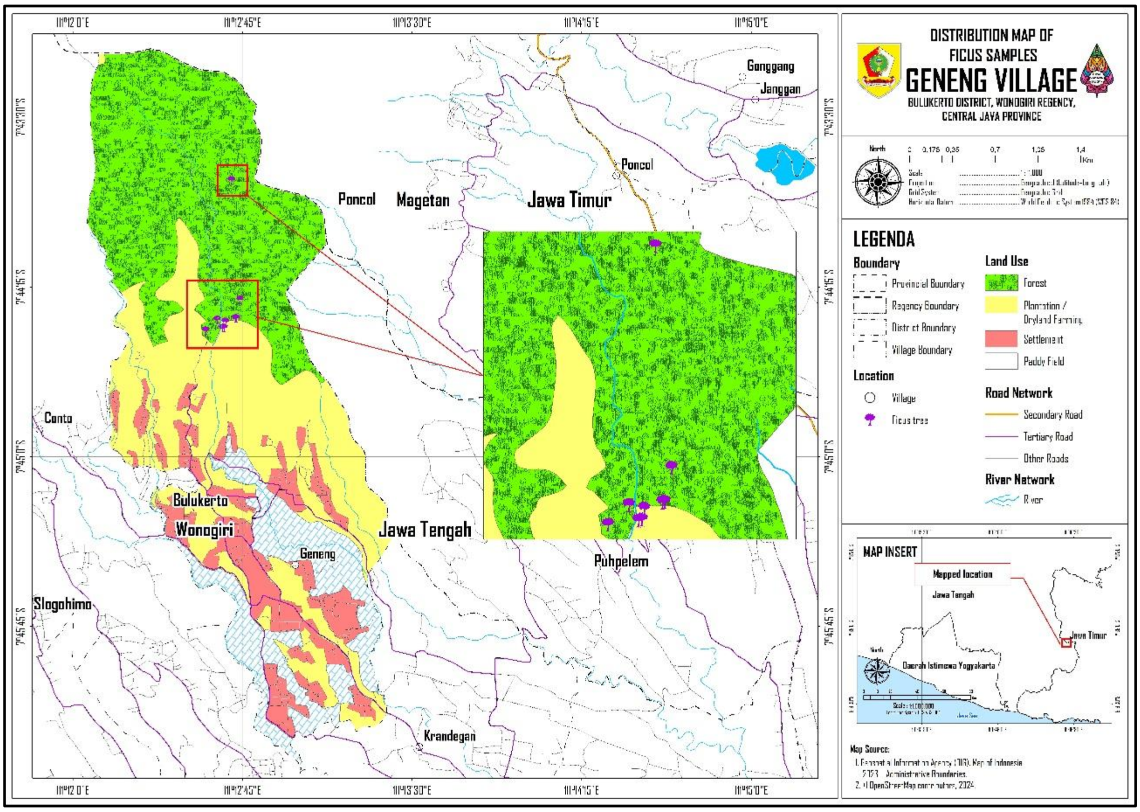

Figure 4. Distribution Map of Banyan *(Ficus)* in Gendol Hill

The presence of woody vegetation, particularly *Ficus*, is relevant because its root system can potentially strengthen soil aggregation, create macropores, and maintain preferential flow pathways that support downward infiltration. On steep slopes, this ecological function also intersects with slope stabilization, as roots increase soil cohesion and reduce the risk of surface erosion in recharge zones. The widely planted banyan *(Ficus)* constitutes a woody vegetation element that may strengthen micro-scale recharge functions. Figure 4 shows that *Ficus* points are concentrated in forested areas and near spring locations, indicating its role as vegetation that develops/is planted in hydrologically relevant spaces. The role of *Ficus* in spring ecological conditions includes maintaining micro-moisture and shading around outlets, supporting infiltration and water retention through roots, litter, and organic matter, and providing physical protection to discharge zones by reducing erosion and sedimentation on steep slopes.

Role of Banyan *(Ficus)* in Spring Quantity

The presence of banyan *(Ficus)* was observed at almost all spring-emergence locations in Gendol Hill. Springs are understood as groundwater-system outputs where the groundwater table or piezometric surface intersects the land surface; therefore, spring characteristics can be organized using classification schemes based on discharge, controlling geology, temperature/chemistry, and flow regimes (Keegan-Treloar *et al.*, 2022). Spring quantity results are presented in Table 1.

Tabel 1. Meinzer Discharge Classification of Springs

Spring	Spring Discharge (L/s)	Class	Discharge Range (L/s)	Geological Formation	Flow Regime
Singodalem 1	1,68	V	1 – 10	Qvsl	Parenial
Singodalem 2	0,11	VI	0,1 – 1	Qvsl	Parenial
Singodalem Etan 1	1,34	V	1 – 10	Qvsl	Parenial
Singodalem Etan 2	1,14	V	1 – 10	Qvsl	Parenial
Ngampyangan 1	0,49	VI	0,1 – 1	Qvsl	Parenial
Ngampyangan 2	0,009	VII	0,1 – 1	Qvsl	Parenial
Adem Ayem	0,18	VI	0,1 – 1	Qvsl	Parenial
Etan Gendol 1	2,51	V	1 – 10	Qvsl	Parenial
Etan Gendol 2	0,6	VI	0,1 – 1	Qvsl	Parenial
Gintung-gintung	0,38	VI	0,1 – 1	Qvsl	Parenial

Source(s): Author's own work

Tabel 2. *Ficus* Presence and Spring Quantity

Spring	Banyan (*Ficus*)	Number of *Ficus*	Ficus Diameter (cm)	Spring Discharge (L/*s*)
Singodalem 1	Yes	1	10	1,68
Singodalem 2	No	-	-	0,11
Singodalem Etan 1	Yes	1	40	1,34
Singodalem Etan 2	No	-	-	1,14
Ngampyangan 1	Yes	1	40	0,49
Ngampyangan 2	Yes	7	5 – 10	0,009
Adem Ayem	Yes	4	40 – 50	0,18
Etan Gendol 1	Yes	1	50	2,51
Etan Gendol 2	Yes	4	50 – 60	0,6
Gintung-gintung	Yes	4	70 – 100	0,38

Source(s): Author's own work

All springs were classified as perennial, i.e., flowing throughout the year (Casati *et al.*, 2024), indicating that the local aquifer system is still capable of sustaining baseflow despite differences in discharge magnitude. Spring quantity varied among sites, and hydrologically such variation commonly reflects differences in recharge conditions, aquifer properties, and groundwater storage dynamics at the spring scale. Springs can be classified by discharge, emergence mechanism, flow period, temperature, and the material transporting the water (Nisa & Umar, 2024). This study applied the Meinzer classification. According to Meinzer, springs in Geneng fall into class V (1–10 L/s), namely Singodalem 1, Singodalem Etan 1, and Singodalem Etan 2; class VI (0,1–1 L/s), namely Singodalem 2, Ngampyangan 1, Adem Ayem, Etan Gendol 2, and Gintung-gintung; and class VII (0,01–0,1 L/s), namely Ngampyangan 2.

Spring emergence in Geneng Village, Bulukerto, occurs at slope-break zones. In volcanic landforms, morphological change indicated by slope breaks or topographic incision can trigger groundwater emergence from an aquifer (Keegan-Treloar *et al.*, 2022). All ten springs are depression-type springs. Depression springs form when the land surface cuts the groundwater table within porous media or where the groundwater table is truncated by abrupt slope changes (Tóth *et al.*, 2022). In this system, vegetation can potentially influence discharge primarily by modifying soil properties such as porosity, preferential flow pathways, and water retention, which in turn affect infiltration and local groundwater recharge; however, the magnitude of such effects strongly depends on site conditions (Shi *et al.*, 2021; Xiao *et al.*, 2024).

Comparisons of nearby spring pairs provide descriptive evidence of a possible association between *Ficus* presence and spring quantity because the paired sites occur within similar geological settings, thereby reducing broad-scale environmental variation. In the Singodalem pair, Singodalem 1 (with *Ficus*) ecorded a discharge of 1.68 L/s, whereas Singodalem 2 (without *Ficus*) recorded 0.11 L/s. Likewise, in the Singodalem Etan pair, Singodalem Etan 1 (with *Ficus*) recorded 1.34 L/s compared with 1.14 L/s at Singodalem Etan 2 (without *Ficus*). These paired comparisons suggest a possible site-specific association between *Ficus* presence and spring discharge. However, because this study employed a descriptive observational design, the observed patterns should not be interpreted as evidence of a causal relationship. Furthermore, the differences in spring discharge were not uniform across all sites, indicating that additional hydrogeomorphological factors (slope position, spring outlet characteristics, weathering-zone thickness, aquifer properties, and preferential groundwater flow pathways), likely interact with vegetation in influencing spring discharge.

Across all sites, the relationship between *Ficus* diameter/abundance and discharge is not linear. This variation indicates that vegetation effects do not operate independently but interact with hydro-geomorphological controls and aquifer characteristics that may be more dominant in determining discharge at particular springs. Nevertheless, evidence that old-growth *Ficus* is associated with increased groundwater/soil water storage and soil properties that support water retention strengthens the plausibility of *Ficus* as an element of local hydrological restoration (Barros *et al.*, 2024).

Tabel 3. *Ficus* Presence and Spring Water Quality

Spring	Banyan (*Ficus*)	*E. coli*	Salinity (Sal)	DO (ppm)	EC (µS/cm)	Temperature (°C)
Singodalem 1	Yes	Negative (-)	0.95	2.65	59	27.52
Singodalem 2	No	Negative (-)	0	2.03	0	24.97
Singodalem Etan 1	Yes	Negative (-)	0	3.13	0	23.88
Singodalem Etan 2	No	Negative (-)	0	3.15	0	23.76
Ngampyangan 1	Yes	Positive (+)	0.06	2.75	114	22.34
Ngampyangan 2	Yes	Positive (+)	0.06	3.19	118	24.68
Adem Ayem	Yes	Negative (-)	0.18	3.46	340	22.18
Etan Gendol 1	Yes	Negative (-)	0.07	3.09	141	22.31
Etan Gendol 2	Yes	Negative (-)	0	1.93	0	25.08
Gintung-gintung	Yes	Positive (+)	0	4.99	0	20.70

Source(s): Author's own work

Role of Banyan *(Ficus)* in Spring Quality

The presence of *Ficus* at most spring sites provides a basis to evaluate whether woody vegetation correlates with physico-chemical and microbiological water-quality parameters. *Ficus* may act indirectly through changes in soil properties (porosity, aggregation, preferential flow pathways) and microclimate (shading), but the direction and magnitude of water-quality responses depend strongly on site conditions and local pollution sources (Shi *et al.*, 2021; Xiao *et al.*, 2024). Based on field measurements and laboratory tests of physico-chemical and microbiological indicators (Table 3), spring water quality in Gendol Hill varies primarily due to the combined influence of local hydrogeology and contamination sources around recharge or discharge zones, rather than solely due to *Ficus* presence.

Microbiological parameters are the primary determinant for direct consumption because the presence of *Escherichia coli* indicates fecal contamination and is associated with increased health risks if water is not treated (Stupar *et al.*, 2022). Seven springs tested negative for *E. coli* (Singodalem 1–2, Singodalem Etan 1–2, Adem Ayem, Etan Gendol 1–2), while three springs tested positive (Ngampyangan 1, Ngampyangan 2, and Gintung-gintung). This pattern indicates that *Ficus* cannot be positioned as a single protective factor against fecal contamination, because *E. coli*-positive springs occurred at sites where *Ficus* was also present, whereas two springs without *Ficus* (Singodalem 2 and Singodalem Etan 2) remained *E. coli*-negative. Fecal contaminants may enter via human/livestock activities near outlets, local surface runoff, or percolation from sanitation facilities, and their transport to springs depends on media permeability, unsaturated-zone thickness, and subsurface flow connectivity (Mbae *et al.*, 2024).

For physico-chemical indicators, salinity across all springs was very low (0–0.95), indicating freshwater conditions and minimal salt intrusion influence. Variability in electrical conductivity (EC) primarily reflects total dissolved ions affected by lithology, residence time, subsurface flow paths, and the intensity of water–rock interaction; therefore, EC is better interpreted as an indicator dominated by geological–hydrogeological control than by a single vegetation factor. No clear linkage was observed between *Ficus* occurrence and salinity or EC.

Dissolved oxygen (DO) values ranged from 1.93 to 4.99 ppm, while water temperature ranged from 20.70 to 27.52°C, indicating variability in physico-thermal conditions among springs. The highest DO occurred at Gintung-gintung (4.99 ppm), which also had the lowest temperature (20.70°C), whereas the highest temperature occurred at Singodalem 1 (27.52°C) with moderate DO (2.65 ppm). These extremes are consistent with the basic principle that oxygen solubility tends to decrease as temperature increases, suggesting that temperature differences may act as an important control on DO variation at spring outlets, in addition to aeration/turbulence at the discharge point and flow conditions after emerging at the surface. Low DO at Etan Gendol 2 (1.93 ppm; 25.08°C) and Singodalem 2 (2.03 ppm; 24.97°C) further indicates that DO is not controlled by temperature alone, but may also be influenced by outlet conditions governing gas exchange with the atmosphere and localized oxygen consumption by organic matter. At the inter-spring scale, Table 3 supports the interpretation that DO dynamics are more strongly related to the combination of thermal conditions and outlet physical characteristics; therefore, any attempt to attribute DO variation to vegetation should account for these covariates and ideally be supported by repeated measurements over time.

Ficus at spring sites in Geneng can be positioned as a riparian woody-vegetation component that indirectly shapes water-quality conditions at discharge zones, rather than as the sole determinant of parameter values. In process terms, *Ficus* may influence quality through three primary pathways: microclimate modulation around outlets (shading and local humidity) that can stabilize water temperature and surrounding conditions; soil stabilization and buffering functions via litter and root systems that reduce runoff energy, erosion and sediment inputs, and improve soil structure so that natural infiltration and filtration processes become more effective (Zhou *et al.*, 2024) and effects on soil–water biogeochemical dynamics through increased soil organic matter and microbial activity that influence solute transformation before water reaches the outlet (Nurrohmah *et al.*, 2025). These mechanisms align with the understanding that woody vegetation can modify soil structure and hydraulic properties through macropore formation, aggregation, and preferential flow pathways, which under certain conditions contribute to water retention and natural filtration. Thus, the role of *Ficus* can be framed as an ecological–hydrological contribution that strengthens micro-environmental stability around springs, particularly temperature and outlet conditions, while microbiological safety and mineralization variability still require more specific management approaches such as source protection, sanitation, and routine monitoring.

Conclusion

This study found that *Ficus* was present at most spring locations in Gendol Hill and showed a descriptive association with spring discharge patterns in several nearby spring pairs. However, the observed relationship was not consistent across all springs, indicating that hydrogeomorphological conditions and local environmental characteristics remain important controls on spring quantity. No consistent association was observed between *Ficus* presence and microbiological or physico-chemical water-quality parameters, suggesting that vegetation alone cannot explain water-quality variability. These findings highlight the importance of integrating vegetation conservation with spring protection, sanitation management, and long-term monitoring to better understand the ecological processes supporting spring sustainability.

References

Afonso, A. C., Saavedra, M. J., Gomes, I. B., Simões, M., & Simões, L. C. (2025). Current microbiological challenges in drinking water. *Journal of Water Process Engineering*, *72*(4), 107614. https://doi.org/10.1016/j.jwpe.2025.107614

Bruijnzeel, L. A., Peña-Arancibia, J. L., Sheil, D., Ziegler, A. D., Zhang, J., Zwartendijk, B. W., Birkel, C., Sun, G., Wang, Y., & Zhang, X. (2025). Potential for improved groundwater recharge and dry-season flows through forest landscape restoration on degraded lands in the tropics. *Forest Ecosystems*, *14*(1), 100376. https://doi.org/10.1016/j.fecs.2025.100376

Casati, T., Navarra, A., Filippini, M., & Gargini, A. (2024). Assessing the long-term trend of spring discharge in a climate change hotspot area. *Science of The Total Environment*, *957*(2), 177498. https://doi.org/10.1016/j.scitotenv.2024.177498

Chang, Y., Liu, X., Cao, B., Wang, Y., & Shen, Y. J. (2024). Effects of vegetation restoration on runoff and its components in the mountainous Haihe River Basin. *Journal of Hydrology: Regional Studies*, *53*(7), 101803. https://doi.org/10.1016/j.ejrh.2024.101803

Barros, B. F., Amaral, R. do, Fonseca, M. T., Santos, G. P. dos, Souza, G. B. de, Costa, S. de A. P., & Scotti, M. R. (2024). Old-growth Ficus trees provide soil water and carbon storage to urban greenspaces in a Brazilian metropolis. City and Environment Interactions, 24, 100171. https://doi.org/10.1016/j.cacint.2024.100171

Havyarimana, C., Suranto, S., Masharabu, T., & Hidayat, A. (2026). A bibliometric and systematic assessment of land use/cover change research on freshwater catchments: Trends from the past decade (2014–2024). *Watershed Ecology and the Environment*, *8*, 63–74. https://doi.org/10.1016/j.wsee.2025.11.003

Jain, H. (2023). Groundwater vulnerability and risk mitigation: A comprehensive review of the techniques and applications. *Groundwater for Sustainable Development*, *22*, 100968. https://doi.org/10.1016/j.gsd.2023.100968

Keegan-Treloar, R., Irvine, D. J., Solórzano-Rivas, S. C., Werner, A. D., Banks, E. W., & Currell, M. J. (2022). Fault-controlled springs: A review. *Earth-Science Reviews*, *230*, 104058. https://doi.org/10.1016/j.earscirev.2022.104058

Lin, X., Zhang, S., Zhao, X., Li, R., Wang, S., Yang, L., & Chen, X. (2025). Global thresholds for the climate-driven effects of vegetation restoration on runoff and soil erosion. *Journal of Hydrology*, *647*, 132374. https://doi.org/10.1016/j.jhydrol.2024.132374

Locke, K. A. (2024). Modelling relationships between land use and water quality using statistical methods: A critical and applied review. *Journal of Environmental Management*, *362*(2), 121290. https://doi.org/10.1016/j.jenvman.2024.121290

Mbae, M., Hansen, P., Way, C., Mills, F., Willetts, J., & Evans, B. (2024). Onsite sanitation systems and contamination of groundwater : A systematic review of the evidence for risk using the source-pathway-receptor model. Plos Water, 3(7), 1–23. https://doi.org/10.1371/journal.pwat.0000167

Moazeni, S., & Cerdà, A. (2024). The impacts of forest fires on watershed hydrological response. A review. *Trees, Forests and People*, *18*(5), 100707. https://doi.org/10.1016/j.tfp.2024.100707

Mooney, S., Lavallee, S., O'Dwyer, J., Majury, A., O'Neill, E., & Hynds, P. D. (2024). Private groundwater contamination and risk management: A comparative scoping review of similarities, drivers and challenges across two socio-economically developed regions. *Science of The Total Environment*, *922*, 171112. https://doi.org/10.1016/j.scitotenv.2024.171112

Nisa, F. U., & Umar, R. (2024). Spring water system classifications and their methods of study: An overview of the current status and future perspectives. *Journal of Earth System Science*, *133*(1). https://doi.org/10.1007/s12040-023-02218-7

Nurrohmah, D. P., Hapsari, A. T., Insani, M. S., Astuti, R. I. P., Fortuna, V. S. D., & Ramli, M. (2025). Keanekaragaman Biota Sungai Sebagai Bioindikator Kualitas Sungai di Wilayah Jatimalang Kabupaten Sukoharjo. *Biota : Jurnal Ilmiah Ilmu-Ilmu Hayati*, *10*(2), 127–138. https://doi.org/10.24002/biota.v10i2.9807

Pandit, A., Batelaan, O., Pandey, V. P., & Adhikari, S. (2024). Depleting spring sources in the Himalayas: Environmental drivers or just perception? *Journal of Hydrology: Regional Studies*, *53*(1), 101752. https://doi.org/10.1016/j.ejrh.2024.101752

Pantha, S., Timilsina, S., Pantha, S., Manjan, S. K., & Maharjan, M. (2022). Water quality index of springs in mid-hill of Nepal. *Environmental Challenges*, *9*, 100658. https://doi.org/10.1016/j.envc.2022.100658

Rey, D. M., Briggs, M. A., Walvoord, M. A., & Ebel, B. A. (2023). Wildfire-induced shifts in groundwater discharge to streams identified with paired air and stream water temperature analyses. *Journal of Hydrology*, *619*, 129272. https://doi.org/10.1016/j.jhydrol.2023.129272

Rodríguez-Jiménez, E., Cruz-Pérez, N., Koritnik, J., García-Gil, A., Marazuela, M. Á., & Santamarta, J. C. (2024). Revealing the impact of wildfires on groundwater quality: Insights from Sierra de la Culebra (Spain). *Chemosphere*, *365*, 143375. https://doi.org/10.1016/j.chemosphere.2024.143375

Shi, X., Mao, D., Song, K., Xiang, H., Li, S., & Wang, Z. (2024). Effects of landscape changes on water quality: A global meta-analysis. *Water Research*, *260*, 121946. https://doi.org/10.1016/j.watres.2024.121946

Shi, X., Qin, T., Yan, D., Tian, F., & Wang, H. (2021). A meta-analysis on effects of root development on soil hydraulic properties. *Geoderma*, *403*, 115363. https://doi.org/10.1016/j.geoderma.2021.115363

Stupar, Z., Levei, E. A., Neag, E., Baricz, A., Szekeres, E., & Moldovan, O. T. (2022). Microbial water quality and health risk assessment in karst springs from Apuseni Mountains, Romania. Frontiers in Environmental Science, Volume 10-2022. https://doi.org/10.3389/fenvs.2022.931893

Tóth, Á., Kovács, S., Kovács, J., & Mádl-Szőnyi, J. (2022). Springs regarded as hydraulic features and interpreted in the context of basin-scale groundwater flow. *Journal of Hydrology*, *610*(1), 127907. https://doi.org/10.1016/j.jhydrol.2022.127907

Uddin, M. G., Nash, S., & Olbert, A. I. (2021). A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators*, *122*, 107218. https://doi.org/10.1016/j.ecolind.2020.107218

Wang, Z., Li, J., Hou, J., Zhao, K., Wu, R., Sun, B., Lu, J., Liu, Y., Cui, C., & Liu, J. (2024). Enhanced evapotranspiration induced by vegetation restoration may pose water resource risks under climate change in the Yellow River Basin. *Ecological Indicators*, *162*, 112060. https://doi.org/10.1016/j.ecolind.2024.112060

Xiao, T., Li, P., Fei, W., & Wang, J. (2024). Effects of vegetation roots on the structure and hydraulic properties of soils: A perspective review. *Science of The Total Environment*, *906*, 167524.

https://doi.org/10.1016/j.scitotenv.2023.167524

Yan, T., Shen, S. L., & Zhou, A. (2022). Indices and models of surface water quality assessment: Review and perspectives. *Environmental Pollution*, *308*, 119611. https://doi.org/10.1016/j.envpol.2022.119611

Zhou, S., Li, P., Zhang, X., Wang, Y., Yu, K., Shi, P., Xiao, L., Wang, T., & Chang, E. (2024). Runoff and erosion reduction benefits of vegetation during natural succession on fallow grassland slopes. *Science of The Total Environment*, *954*, 176211. https://doi.org/10.1016/j.scitotenv.2024.176211