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Assessing Spring Vulnerability through Land-Use Change and Community-Based Observations in Ngaliyan Sub-District, Semarang City

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ABSTRACT

Changes in land use in peri-urban areas have become a critical environmental concern because they may affect groundwater recharge and the sustainability of springs used by local communities. This study aimed to assess spring vulnerability through land-use change and community-based observations in the Ngaliyan Sub-District, Semarang City, Indonesia. A quantitative descriptive approach was applied by integrating multitemporal spatial analysis and community perception data. Land-use changes from 2016 to 2024 were identified using Google Earth imagery and analyzed using ArcGIS 10.8. A 500-m buffer zone was generated around 12 active springs to quantify changes in vegetation, settlements, industrial areas, agricultural land, and open fields. Primary data were collected through structured questionnaires involving 100 spring users selected by purposive sampling. The results showed that several spring buffer zones experienced vegetation loss, accompanied by the expansion of residential and industrial areas. Springs located in areas with intensive land conversion were more frequently associated with perceived declines in discharge and seasonal availability. Conversely, springs surrounded by relatively stable vegetation were perceived to have more stable water conditions. Although the physical quality of spring water was generally considered satisfactory, localized signs of vulnerability were observed in areas exposed to increasing anthropogenic pressure. These findings indicate that integrating spatial land-use analysis and community-based observations can support the early identification of spring vulnerability in data-limited peri-urban environments. The study emphasizes the need to conserve vegetated recharge areas and integrate community participation into local water resource management.

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1. INTRODUCTION

Water availability is fundamental for sustaining human life, ecological balance, and regional development. However, water demand continues to increase, whereas its natural availability remains relatively limited in space and time (Setyowati & Setyaningsih, 2021). Changes in land cover and land use reduce vegetation and plant cover, thereby altering natural hydrological conditions (Jatmika et al., 2024). This condition is commonly associated with development activities that do not adequately consider environmental carrying capacity, resulting in the reduction of water catchment areas, particularly in urban and peri-urban regions (Zaman & Hidayah, 2023). Extensive land conversion can also lead to the expansion of impermeable surfaces, which reduces infiltration and groundwater recharge while increasing surface runoff. These processes may influence the water balance system and shift hydrogeological functions over time and space (Maria, 2014; Christanto et al., 2024; Maulana et al., 2023).

Springs represent an important natural groundwater source that supports domestic water needs in many communities. A spring is a location where groundwater naturally emerges from below the ground surface to the land surface (Firizqi et al., 2019). The water that emerges from springs may flow as surface water through river channels. The existence and characteristics of springs are determined by geological features, including lithology, porosity, permeability, and topography (Ferencz, 2025). At the site level, the Ngaliyan Sub-District forms an upstream transition area and a runoff zone for rivers crossing six watersheds: Tugu, Banjir Kanal Barat, Blorong, Plumbon, Bringin, and Silandak. These perennial rivers have a parallel drainage pattern flowing northward into the Java Sea. Groundwater in this area occurs in unconfined and confined aquifers of the Damar and Kaligesik formations, which are structurally influenced by local fault systems. Located between 100 and 250 m a.s.l., the area is characterized by rolling-to-hilly relief, local height differences of 50–200 m, and dominant slopes of 2–25%, reaching up to 40% in steep areas. This geomorphic condition interacts with local climatic characteristics, with up to 125 rainy days and annual rainfall of 2,770–3,480 mm.

Spring water remains an essential alternative water source in areas not fully served by piped water supply systems. Communities often use springs as supplementary or primary water sources where public water services are limited (Faisal & Atmaja, 2019). However, many springs experience a decrease in discharge due to environmental changes around their recharge areas. Vegetated spring areas function as absorption zones for rainwater infiltration, whereas impermeable land surfaces resulting from development may hinder infiltration, increase erosion risk, and contribute to spring degradation or closure (Cahyaningrum et al., 2023). In the long term, temporal changes in spring conditions are also influenced by agricultural expansion, urbanization, and deforestation, which modify recharge processes and alter local groundwater systems (Siddik et al., 2022).

Land-use conversion has become a major pressure affecting groundwater conservation and spring sustainability in developing urban regions. In Indonesia, the conversion of forests and agricultural fields into built-up areas places pressure on the soil's ability to absorb and store water and may reduce groundwater levels (Leopold, 1968; Putri Anisah et al., 2021). The reduction in permeable infiltration zones may interfere with aquifer recharge systems and baseflow regulation, with potential consequences for the discharge and quality of connected springs. Regionally, Semarang City is experiencing strong development pressure owing to limited land availability in the main urban core, which has encouraged urban expansion toward peripheral areas in the west and south, particularly the Ngaliyan Sub-District (Aprillia & Pigawati, 2018). Consequently, urban expansion has led to the systematic conversion of vegetative cover into impermeable surfaces, which increases surface runoff and inhibits infiltration, often resulting in declining groundwater storage and lower spring yields (Widiatmaka, 2007).

The Ngaliyan Sub-District is experiencing demographic and spatial transformations that may increase the pressure on local water resources. According to Statistics Indonesia, the population increased from 126,734 in 2016 to 146,628 in 2024, while the population density increased from 3,336 to 4,348 people per km ^{2} over the same period. This demographic growth reflects the increasing demand for residential spaces and supporting infrastructure, which may accelerate the conversion of non-built-up land into residential and industrial areas. Water is a key factor determining regional sustainability, and land exploitation combined with uncontrolled socioeconomic changes can reduce the environment's capacity to provide water resources (Masitoh & Rusydi, 2020). Furthermore, the land suitable for settlements increased from 2,617.37 ha in 2016 to 2,677.92 ha in 2019, with wetland areas increasingly converted into agricultural and residential land (Tyo & Sudarsono, 2021). Consequently, pressure on catchment and recharge areas may threaten the sustainability of springs that are still utilized by communities in the Ngaliyan sub-district.

The relationship between land-use change and spring degradation has been widely discussed at broader watershed scales; however, localized spring vulnerability in peri-urban areas remains insufficiently understood. A major research gap remains in explaining how fragmented peri-urban development affects small-scale springs that directly support domestic water needs. Spatial approaches and user perceptions have also not been integrated effectively in evaluating localized hydrogeological changes. Most previous studies have emphasized either physical spring conditions or broader land-use change patterns; fewer studies have linked micro-scale land use conversion within spring buffer zones with empirical observations from local water users. Therefore, this study aims to address this gap by analyzing multitemporal land-use changes within localized spring buffer zones in the Ngaliyan Sub-District from 2016 to 2024 and examining the spatial distribution of springs in relation to their perceived conditions.

This study investigates whether greater conversion of vegetation into settlements and industrial zones spatially coincides with more frequent community reports of declining spring water quantity and physical quality. By establishing a connection between spatial land-use dynamics and community-based empirical data, this study seeks to provide a comprehensive understanding of the threats posed by peri-urban expansion to local spring sustainability. The novelty of this study lies in the integration of multitemporal land-use analysis, a 500-m spring buffer assessment, and community-based observations as an early indication of spring vulnerability in a data-limited peri-urban environment.

2. METHOD

2.1. Materials and Respondent Selection

The materials used in this study consisted of primary and secondary data to support the assessment of spring vulnerability in the Ngaliyan Sub-District. Primary data were collected using structured, closed-ended multiple-choice questionnaires administered to spring users in the community, particularly concerning participants' perceptions of land-use changes and spring conditions. Respondents were selected using purposive sampling based on their direct dependence on the observed springs for daily household water needs. Face-to-face interviews were conducted in April 2025. The perception data reflected users' experiences of spring conditions; therefore, they were supported by field observations and spatial mapping to strengthen the interpretation of spring vulnerability.

The secondary data consisted of Google Earth imagery from 2016 and 2024, land use interpretation data, and spatial distribution data of springs in the Ngaliyan Sub-District. The spatial distribution data of the 12 active springs were used to identify geographic locations and establish baseline coordinates for the subsequent proximity analysis.

2.2. Land-Use Data Preparation

Spatial data preprocessing included the analysis of multitemporal land-use dynamics from 2016 to 2024 using high-resolution Google Earth imagery with a spatial resolution of 1 meter. The images from both years were selected from the dry season to minimize cloud cover. Visual image analysis was performed at a scale of 1:10,000 using ArcGIS 10.8. Land use was classified into five categories–namely, vegetation, settlement, industry, plantation/agriculture, and open field–based on key visual interpretation elements such as morphology, color, texture, shape, pattern, and association. To ensure reliable results, independent validation and field ground truthing were conducted throughout the study area to confirm the accuracy of land-use classification against actual ground conditions.

The active springs included in this study are those that exhibited continuous natural flow, were physically accessible for observation, and were still used by the community. Based on the data saturation principle, the total sample size was set at 100 respondents for this descriptive and localized perception study. The proportion of respondents across the 12 active springs varied according to uneven user density and the number of local community members directly dependent on each spring. Respondents were selected based solely on their status as active spring users who relied on the observed springs for daily domestic needs.

2.3. Field Set-up and Data Processing

Data obtained from the questionnaires captured respondents' perceptions regarding spring water conditions, specifically focusing on perceived shifts in water quantity and physical quality characteristics. Concurrently, field observations were used to document the immediate environmental conditions surrounding the springs, including the physical status of the sites, localized vegetation, and adjacent land-use practices. Questionnaire responses were tabulated as frequencies and percentages to quantify the distribution of these community perspectives.

Questionnaire responses were summarized using frequency and percentage distributions to describe community perceptions regarding spring water quantity, seasonal availability, physical quality, and utilization patterns. The descriptive results were subsequently integrated with spatial analysis outputs to evaluate the relationship between localized land-use changes and perceived spring vulnerability.

For the spatial component, multitemporal land use datasets from 2016 and 2024 were processed to detect changes in built-up and nonbuilt-up land within the designated 500-m spring buffer zones. The integrated dataset was then synthesized through descriptive analysis using comparative tables and spatial maps to evaluate the relationship between localized land use modifications and reported trends in spring water degradation.

2.4. Data Parameters

The parameters evaluated in this study consisted of perceived spring conditions and land-use change as a supporting variable. The spring water quantity parameter assessed reported changes in discharge, which were categorized as either decreased or remained stable based on user observations. Physical quality parameters were assessed based on users' perceived changes in water clarity, odor, taste, and color. Perceived seasonal availability was also examined based on respondents' observations of water availability during the dry and rainy seasons. Land-use change parameters were analyzed based on the dynamics of built-up and non-built-up land.

2.5. Spatial Analysis

Spatial analysis was conducted to identify localized patterns of land-use change in relation to spring locations in the Ngaliyan Sub-District. To advance beyond basic map overlay methods, a structured buffer and proximity analysis was executed using ArcGIS 10.8. Fixed circular buffer zones with a radius of 500 meters were generated around each of the 12 active mapped springs to capture the immediate local recharge and protection zones. Within these localized proximal zones, the specific land use composition and its multitemporal shifts from 2016 to 2024, encompassing vegetation, settlements, industry, plantations/agriculture, and open fields, were quantified in hectares and percentages.

This proximity-based quantification provided the basis for interpreting local spring vulnerability to anthropogenic encroachment. Finally, the spatial relationship between localized land use dynamics within the buffers and perceived spring conditions from user observations was evaluated descriptively to determine how micro-scale environmental change influenced long-term spring sustainability.

3. RESULTS AND DISCUSSION

3.1. Land-use change

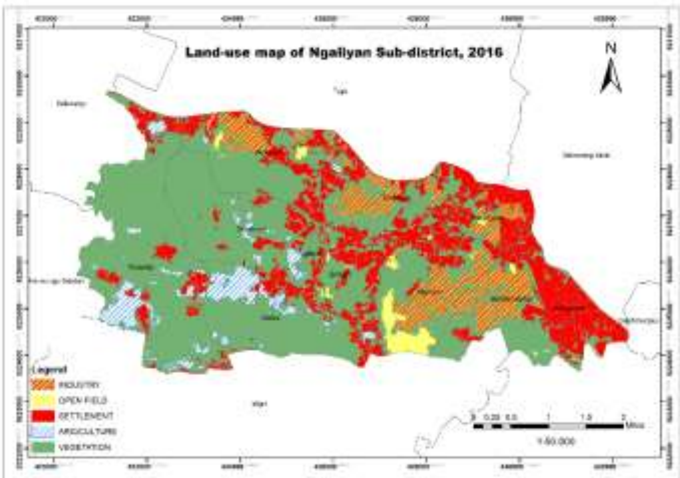

Figure 1. Land-use map of Ngaliyan Sub-district, 2016

The 2016 land use map depicts the initial conditions of land use in the Ngaliyan Sub-District, which was dominated by vegetation and built-up land, such as residential and industrial areas, concentrated in several parts of the area. This condition was used as the baseline for analyzing land-use changes in the following period.

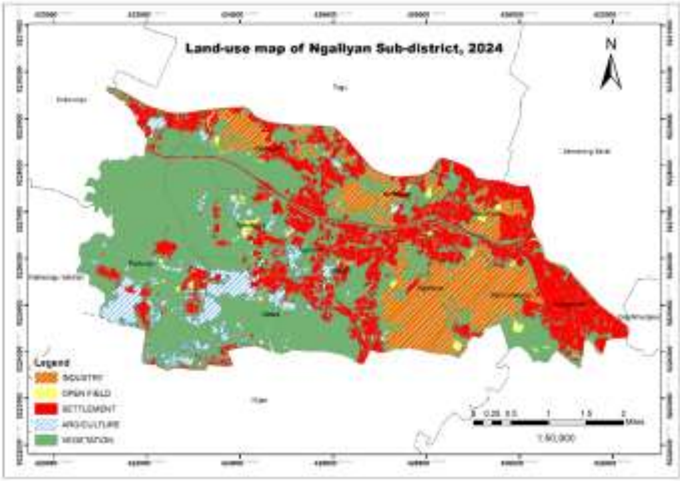

Figure 2. Land-use map of Ngaliyan Sub-district, 2024

Compared with the initial conditions in 2016, the 2024 land use map (Figure 2) shows more intensive built-up development in the Ngaliyan Sub-District. In 2024, built-up land development was significant, marked by a transition from vegetation and open land to built-up land, such as residential and industrial areas.

Table 1. Land-use change in Ngaliyan Sub-District in Hectares from 2016 to 2024

Village	2016					2024				
	Vegetation (ha)	Industry (ha)	Settlement (ha)	Plantation/ Agriculture (ha)	Open Field (ha)	Vegetation (ha)	Industry (ha)	Settlement (ha)	Plantation/ Agriculture (ha)	Open Field (ha)
Tambak Aji	214.55	76.12	143.93	2.4	0	179.52	90.23	158.24	5.7	3.2
Wates	363.03	0.2	53.43	86.11	0	342.62	0.2	69.95	86.93	2.9
Bringin	179.93	0.5	110.8	3.19	4.71	145.52	0.6	140.79	11	1.1
Bambangkerep	197.02	88.44	46.39	0	3.17	132.61	144.09	48.23	0	9
Kalipancur	52.04	0.4	190.67	0	1.1	51.9	0.4	189.43	0	2.5
Podorejo	735.83	0	64.13	89.3	0	709.95	0	71.88	103.8	3.1

Regarding land-use changes across the sub-district, the most substantial transformation occurred in Bambangkerep Village, where the vegetation cover decreased by 64.41 ha (32.7%). This green space was primarily converted into built-up areas, as evidenced by an expansion of industrial zones by 55.65 ha (62.9 %) and a minor increase of 1.84 ha (4.0%) in residential settlements. Similarly, Tambak Aji Village experienced pronounced urban development, with industrial land increasing by 14.11 ha (18.5%) and settlements expanding by 14.31 ha (9.9%), while the vegetation cover declined by 35.03 ha (16.3%). These spatial modifications indicate a continuous trend of peri-urban expansion encroaching upon areas that potentially function as local infiltration and recharge zones. In contrast, Kalipancur Village remained relatively stable throughout the study period, showing only a negligible decline in vegetation cover of 0.14 ha (0.3%).

The observed pattern indicates that land-use change in the Ngaliyan Sub-District was not spatially uniform. Villages located closer to industrial and residential growth centers experienced more intensive land conversion, whereas areas with limited development pressure retained more stable vegetation cover. This finding is important because the conversion of vegetated land into built-up surfaces may reduce infiltration capacity, increase runoff, and weaken local groundwater recharge processes. Therefore, land-use change in Bambangkerep and Tambak Aji represents a potential pressure on spring sustainability, especially where springs are located near expanding built-up areas.

3.2. Spatial Distribution and Condition of Springs

Figure 3. Spatial distribution of springs across villages in Ngaliyan Sub-district

The spatial distribution of springs was obtained from field observations, which identified 25 springs in the Ngaliyan Sub-District. These springs are dispersed throughout several villages, with the highest number found in Wates Village (eight springs), followed by Podorejo Village (six springs). Of the 25 springs, 12 are active and utilized by the community, 11 are unused, and two are inactive. Active springs are those that still flow and are used by the community, whereas inactive springs no longer flow or can no longer be used. Perception data were collected directly from users of the 12 active springs.

The distribution of springs demonstrates that local water resources in the Ngaliyan Sub-District are spatially connected to both geomorphological conditions and surrounding land use patterns. The presence of active, unused, and inactive springs in the same subdistrict suggests that spring sustainability varies according to local environmental pressure. Springs that remain active and are still used by the community indicate the continuing importance of groundwater emergence points for domestic water supply, whereas inactive springs may reflect changes in local hydrological conditions or disturbance around spring protection zones.

To evaluate the specific vulnerability of active water sources, a 500-m fixed buffer analysis was conducted around the 12 active springs. This localized approach isolates microcatchment land compositions and provides direct indicators of immediate anthropogenic pressure. The quantified land use shifts within these protection zones are presented in Table 2 and visualized in Figure 4.

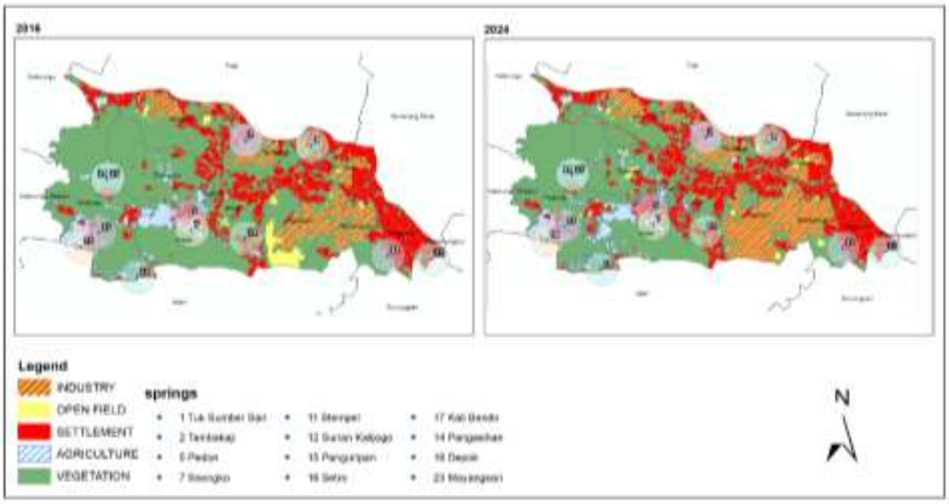

Figure 4. Spatial comparison of localized land-use composition within the 500-meter spring buffer zones in 2016 (left) and 2024 (right)

Table 2. Quantified land-use composition within the 500-meter spring buffer zones in 2016 and 2024.

springs	2016					2024				
	Vegetation (ha)	Industry (ha)	Settlement (ha)	Plantation/ Agriculture (ha)	Open Field (ha)	Vegetation (ha)	Industry (ha)	Settlement (ha)	Plantation/ Agriculture (ha)	Open Field (ha)
Tuk Sumber Sari	36.70	10.03	30.43	0	0	33.11	10.19	31.44	0.33	2.09
Tambakaji	31.58	21.57	20.38	1.42	0	28.73	23.91	20.68	1.64	0
Pedon	33.01	0	29.44	16.00	0	32.51	0	33.75	11.60	0.59
Snongko	47.96	0	16.63	13.86	0	47.13	0	17.35	12.42	1.54
Stempel	51.65	0.67	24.80	1.33	0	45.64	1.32	30.40	0.92	0.16
Sunan Kalijogo	46.05	0	29.65	0	1.0	45.91	0	29.79	0	1.0
Mayangsari	12.30	0.46	28.45	0	0	11.74	0.46	30.13	0	0.74
Pangasihan	69.37	0	9.09	0	0	69.19	0	9.26	0	0
Panguripan	69.37	0	9.09	0	0	69.19	0	9.26	0	0
Setro	14.11	0	8.36	26.79	0	13.83	0	8.86	26.57	0
Kalibendo	53.26	0	10.97	14.23	0	47.63	0	13.07	17.57	0.03
Depok	30.62	0	7.92	7.42	0	29.29	0	8.33	8.33	0

As shown in Table 2 and Figure 4, there was a clear spatial variation in land use composition within the 500-m buffer zones of the 12 active springs between 2016 and 2024. The most notable built-up expansion occurred around the Tuk Sumber Sari and Tambakaji springs. In Tambakaji, industrial land within the buffer increased from 21.57 ha in 2016 to 23.91 ha in 2024, accompanied by a reduction in vegetation cover from 31.58 ha to 28.73 ha. This pattern of increased impermeable surfaces corresponds with user perceptions of declining spring yields due to the reduction in localized recharge areas.

In contrast, springs in the western sector, such as Pangasihan and Panguripan, demonstrated high environmental stability. Their 500-m buffer zones remained heavily dominated by vegetation (approximately 69 ha), with no industrial intrusion and minimal changes in settlements. This preserved natural cover aligns with the stable water availability reported by respondents. Other springs, such as Setro and Kalibendo, were characterized by a higher but relatively stable proportion of plantation and agricultural land over the eight-year study period.

Table 3. Perceived spring water quantity.

Village	Springs	Perceived discharge trend (No. of respondents)		Perceived dry season availability (No. of respondents)		Perceived rainy season availability (No. of respondents)	
		decreased	remained stable	consistently sufficient	occasionally decreased	consistently sufficient	occasionally decreased
Tambakaji	Tuk Sumber Sari	10		5	5	10	
	Tambakaji	9	1	4	6	8	2
Wates	Pedon		10	4	6	10	
	Snongko	5	5	8	2	10	
Bringin	Stempel		10	9	1	10	
Bambangkerep	Sunan Kalijogo		10	10		10	
Kalipancur	Mayangsari		5	3	4	5	
Podorejo	Pangasihan		5	5		5	
	Panguripan	2	3	3	2	5	
	Setro		10	8	2	5	
	Kalibendo	2	8	5	5	10	
	Depok	3	2	2	3	5	

Buffer analysis strengthens the interpretation that spring vulnerability is closely related to land use composition in the immediate surrounding area. Springs located within buffers experiencing vegetation loss and built-up expansion were more frequently associated with perceived discharge decline, whereas springs surrounded by stable vegetation showed more stable conditions. This relationship supports the assumption that vegetated areas around springs play an important role in maintaining infiltration and local groundwater recharge. Therefore, the 500-meter buffer analysis provides a useful spatial basis for identifying localized pressure on spring sustainability.

Based on the interviews, community perceptions regarding changes in spring water yield varied markedly across the surveyed villages in the Ngaliyan Sub-District. In the Tambakaji village, all ten respondents perceived a notable decline in the seasonal discharge of Tuk Sumber Sari Spring, and nine respondents reported a similar downward trend for Tambakaji Spring. Despite these reported discharge reductions, some local users still considered baseline water availability to be relatively sufficient during the dry season. Similarly, in the Wates village, five respondents noted a perceived decrease in the flow of Snongko Spring; however, the overall supply was considered adequate to meet immediate community requirements.

Conversely, in Podorejo Village, although residents reported minor flow fluctuations across three localized springs, general water availability was perceived as structurally steady. In the remaining villages, respondents generally observed reliable spring performance, with no reported indications of declining water yields. These variations indicate that perceived spring quantity is influenced not only by the presence or absence of water, but also by seasonal reliability, daily use patterns, and the intensity of land-use change surrounding each spring.

The strongest perceived decline occurred in springs located in areas with more intensive land conversion, particularly Tambakaji. This finding is consistent with the spatial buffer results, which showed reduced vegetation and increased industrial or settlement areas around the springs. The convergence between spatial evidence and user perception suggests that community-based observations can serve as early indicators of spring vulnerability, especially in areas with unavailable long-term discharge measurements.

Table 4. Perceived physical quality of spring water based on user observations.

Village	Springs	Perceived clarity		Perceived odor		Perceived taste		Perceived color	
		clear	slightly turbid	odorless	Distinct Odor	Tasteless	Unpleasant taste	no significant change	slightly turbid during the rainy
Tambakaji	Tuk Sumber Sari	10		10		10		10	
	Tambakaji	10		10		10		10	
Wates	Pedon	10		10		10		10	
	Snongko	6	4	10		10		10	
Bringin	Stempel	10		10		10		9	1
Bambangkerep	Sunan Kalijogo	10		10		10		10	
Kalipancur	Mayangsari	5		5		5		5	
Podorojo	Pangasihan	5		5		5		5	
	Panguripan	5		5		5		5	
	Setro	10		10		10		10	
	Kalibendo	10		10		10		10	
	Depok	5		5		5		5	

Based on respondents' perceptions, the physical quality of spring water in the Ngaliyan sub-district was generally considered favorable. This is supported by the descriptive data in Table 4, where most respondents indicated that the water was clear, odorless, and tasteless. However, because this evaluation relied strictly on sensory and visual indicators reported by users, the lack of quantitative water sampling constitutes a key limitation of this study. Therefore, systematic laboratory testing is necessary in future research to analyze chemical and microbiological parameters and ensure compliance with clean water standards.

Although most respondents reported good physical water quality, localized indications of slight turbidity were recorded in several springs, particularly during the rainy season. This condition may be associated with surface runoff, soil disturbance, and land use activities around spring areas.

Therefore, the generally favorable perception of water quality should not be interpreted as evidence of complete water safety because visual and sensory observations cannot detect dissolved chemical substances or microbiological contamination.

Table 5. Spring water utilization patterns, daily access frequency, and volume of use.

Village	Spring	Utilization of Spring Water				Daily Use of Spring Water				Daily Amount of Spring Water Use (L)				
		bathing	Washing	Cooking	Drinking	once a day	2–3 times	> 3	Piped water unavailable	< 50	50-100	100-150	> 150	Do not know
Tambakaji	Tuk Sumber Sari	10	10	10	8			10					8	2
	Tambakaji	10	10	10				10			6		4	
Wates	Pedon	10	10			3			7	10				
	Snongko	10	10			2		2	6	10				
Bringin	Stempel	10	10			7	3				10			
Bambangkerep	Sunan Kalijogo	10	10			8				3	7			
Kalipancur	Mayangsari	5		5	5	2	2				5			
Podorojo	Pangasihan	5	5			4		1			5			
	Panguripan	5	5			5				2	2			1
	Setro	10	7			2	2					10		
	Kalibendo	8			7	9		1		7				3
	Depok	3	3			2	3	2		2	3			

In the Ngaliyan Sub-District, residents utilize spring water to meet daily household needs, including bathing, washing, cooking, and drinking. Based on the survey data, the majority of respondents in Tambakaji Village used spring water more than three times daily, with an average consumption exceeding 150 liters per day. In Wates Village, residents primarily used spring water for bathing and washing as an alternative supply when tap water was unavailable, with an average daily consumption of less than 50 liters. Similarly, many residents in Bringin and Bambangkerep Villages utilized spring water daily for bathing and washing, consuming between 50 and 100 liters on average.

A large proportion of residents in the Kalipancur and Podorejo villages relied on spring water for bathing and washing. Specifically, the Mayangsari and Kalibendo springs were used by several respondents for drinking water. Overall, daily spring water utilization across the sub-district varied between one and more than three times per day, with average household consumption ranging from less than 50 L to more than 150 L daily.

These findings show that spring water still has substantial social and domestic importance for local communities. Springs are not merely physical hydrological features but are essential household water sources, particularly in areas with limited or unreliable piped water access. Therefore, the vulnerability of springs should be considered not only an environmental issue but also a community water security issue. Declining discharge or deteriorating quality may directly affect household activities, especially in communities that depend on springs for bathing, washing, cooking, and drinking.

3.3. Land-use changes to Spring Conditions

Land-use changed significantly from 2016 to 2024, particularly for residential and industrial development. These changes correspond with perceived pressure on local springs, especially in areas where vegetation has been converted into built-up land. Poorly managed land-use change can have serious impacts on springs, resulting in decreased quality and availability (Maroneze et al., 2023). In Tambakaji Village, the land use assessment documented a decrease in vegetation of 35.03 ha along with an increase in built-up areas, including residential land of 14.31 ha (10.0%) and industrial land of 14.11 ha (18.5%). This trend is consistent with the reported year-over-year decline in perceived spring water discharge.

Similarly, Podorejo village experienced changes in perceived spring conditions as residential land increased by 7.75 ha (12.08%), driven by a population growth of 3,015 people between 2016 and 2024. Additionally, agricultural land increased by 14.50 ha (16.24%). Agricultural activities around water sources may negatively affect spring conditions when land management does not consider conservation principles (Rais & Arnama, 2022). In contrast, Kalipancur village showed better spring stability because it experienced minimal land-use change and only slight vegetation loss of 0.14 ha (0.3%). Areas with abundant vegetation and relatively natural environments retained steadier discharge and better perceived physical quality, emphasizing that permeable surfaces are important for groundwater recharge.

This phenomenon is associated with the loss of spring function. Field surveys and direct visual observations revealed that two springs, Gondoriyo and Wates, were no longer functioning, as documented through the assessment of intensive development and vegetation clearing in their immediate surroundings. The conversion of vegetated areas into built-up areas can reduce the groundwater supply by limiting infiltration and recharge processes (Ngurah & Suryaputra, 2021). This land-use transition is directly related to the current condition of these springs, which have become inactive and are no longer usable.

The integration of spatial analysis and community perception reveals a consistent pattern: springs surrounded by more intensive land conversion tend to have higher perceived vulnerability, whereas springs located in relatively vegetated buffers tend to remain stable. This relationship does not imply direct hydrological causality because the study did not quantitatively measure discharge or groundwater levels. However, the spatial and perceptual evidence provides a strong descriptive indication that local land-use pressure may contribute to changes in spring performance.

In addition, this spatial pattern aligns with regional trends in suburban Semarang, where built-up expansion concentrates along highly accessible corridors. A comparable pattern was found in the Gunungpati District, where expanding residential development was associated with reduced discharge and the drying of multiple springs. Both districts share a similar peri-urban setting that is undergoing rapid structural transformation. However, from a hydrogeological perspective, Gunungpati is situated on the volcanic slopes of Mount Ungaran with dynamic spring systems, whereas Ngaliyan transitions into a mixture of hilly and sedimentary formations.

Furthermore, this study differs from previous research in terms of data source and analytical emphasis. Previous research in Gunungpati used physical field tracking of spring operational loss, whereas this study relied on descriptive user perceptions paired with micro-catchment mapping. Despite these methodological differences, both lines of evidence indicate that suburban areas under high development pressure experience a higher degree of spring vulnerability. The advantage of the present study lies in its integration of multitemporal land-use analysis, localized 500-meter buffer assessment, and community-based observations. This approach is useful for data-limited areas because it allows the early identification of vulnerable springs before long-term hydrological monitoring data become available.

The findings have important implications for local land management and water resource conservation. First, vegetated areas within spring buffer zones should be protected to maintain infiltration and reduce surface runoff. Second, residential and industrial development near active springs should be controlled through spatial planning and environmental monitoring. Third, community-based monitoring can be incorporated into local water management because spring users are able to observe changes in discharge, seasonal availability, and physical quality over time. Therefore, maintaining spring sustainability in the Ngaliyan Sub-District requires the integration of spatial planning, recharge area conservation, and community participation.

4. CONCLUSIONS

This study indicates a spatial association between multitemporal land-use shifts and perceived spring water vulnerability in the Ngaliyan Sub-District. Between 2016 and 2024, several spring buffer zones experienced vegetation loss accompanied by the expansion of residential and industrial land. Based on descriptive observations and user perception findings, areas with more intensive land conversion correspond closely with reported declines in spring water quantity and physical quality. In contrast, zones experiencing minimal land-use modifications reported more stable spring conditions.

The integration of multitemporal land-use analysis, localized 500-m buffer assessment, and community-based observations provides a practical approach for identifying early indicators of spring vulnerability in data-limited peri-urban environments. The findings suggest that springs located near expanding residential and industrial areas are perceived as more vulnerable to resource degradation than springs surrounded by well-preserved vegetation. Thus, the research objective of evaluating the relationship between land-use dynamics and spring conditions in the study area was achieved within the strict limits of qualitative indicators and community-based assessments.

These findings emphasize the need to protect vegetated recharge areas, control residential and industrial development near active springs, and integrate community participation into local water resource monitoring. However, because this study relied primarily on community perceptions and field observations, future research should include direct discharge measurements and laboratory-based water quality analysis to strengthen the assessment of spring vulnerability.

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