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Household Drinking Water Source, Treatment, Storage, and Weather Conditions in Relation to Drinking Water Quality in Klaten District, Indonesia

Desy Vidi Kurniasari[1)], Arsita Eka Prasetyawati[2,5)], Hafi Nurinasari[3,5)], Siti Khoiriyah[4)], Cynthia Permata Sari[4)]

[1)]Master's of Public Health Study Program, Faculty of Medicine, Universitas Sebelas Maret, Indonesia
[2)]Department of Public Health and Prevention Medicine, Faculty of Medicine, Universitas Sebelas Maret, Indonesia
[3)]Department of Obstetric and Gynecology, Faculty of Medicine, Universitas Sebelas Maret, Indonesia
[4)]Department of Environmental Science, Postgraduate School, Universitas Sebelas Maret, Indonesia
[5)]Universitas Sebelas Maret Hospital, Sukoharjo, Central Java, Indonesia

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ABSTRACT

Background: Safe drinking water remains a major public health challenge in Indonesia, where contamination continues to contribute to diarrheal disease burden. Household drinking water quality surveillance coverage in Klaten District remains far below the national target. This study analyzed the association between water source protection, household water treatment, water storage conditions, and climatic factors with household drinking water quality in Klaten District.

Subjects and Methods: A cross-sectional study was conducted among 390 households from 26 subdistricts in Klaten District, selected via equal-allocation subsampling from the 2025 National Household Drinking Water Quality Surveillance Program (SKAMRT) using two-stage cluster sampling (15 households/subdistrict). Drinking water quality was classified as safe or unsafe based on five parameters (E. coli, Total Dissolved Solids, pH, nitrate, nitrite) per Ministry of Health Regulation No. 2/2023. Associations were assessed using Chi-square and Fisher's exact tests, followed by multiple logistic regression with backward stepwise elimination ($\alpha = 0.05$).

Results: Of 390 households, 202 (51.8%) had unsafe drinking water. Unprotected water sources were the only significant determinant of unsafe water quality (Adjusted OR = 1.61; 95% CI: 1.05–2.47; p = 0.029). Water treatment, storage type, and weather conditions showed no statistically significant association. Spatial analysis identified five subdistricts with very high risk (>80% non-compliant): Polanharjo (93.3%), Wonosari (86.7%), Bayat, Tulung, and Klaten Tengah (80.0% each). Model calibration was adequate (Hosmer-Lemeshow p = 0.741).

Conclusion: Unprotected water sources represent an independent determinant of unsafe household drinking water quality in Klaten District. Interventions should prioritize water source protection, household water safety education, and expansion of SKAMRT surveillance coverage to support SDGs 6.1 achievement by 2030.

Keywords: drinking water, household water, water quality, source protection, water treatment

Correspondence:
Arsita Eka Prasetyawati. Department of Public Health and Prevention Medicine, Faculty of Medicine, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta, Central Java 57126, Indonesia. Email: arsita.ep@staff.uns.ac.id.

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BACKGROUND

Safe drinking water is a fundamental human right and a key determinant of population health. Globally, approximately 2 billion people still lack access to safely managed drinking water, with a substantial proportion consuming water contaminated with *Escherichia coli* (UNICEF and WHO, 2023). Furthermore, diarrhoeal diseases associated with unsafe water, inadequate sanitation, and poor hygiene remain a leading cause of preventable mortality, accounting for more than 443,000 deaths among children under five years of age annually (WHO, 2024).

In Indonesia, the 2018 National Basic Health Research Survey (Riskesdas) reported that only 7% of households had access to safely managed drinking water, whereas the 2023 Indonesian Health Survey (SKI) found that 89.6% of households had access to at least basic drinking water services (Health Research and Development, 2019; Health Policy Agency, 2024). This substantial disparity highlights that access to improved water sources does not necessarily guarantee microbiological safety at the point of consumption, as contamination may occur during collection, transportation, storage, or household handling of water (Cassivi *et al.*, 2021). To ensure drinking water safety, the Indonesian Ministry of Health Regulation No. 2 of 2023 establishes five priority surveillance parameters: *E. coli* (0 CFU/100 mL), Total Dissolved Solids (TDS ≤ 1,000 mg/L), pH (6.5-8.5), nitrate (≤ 50 mg/L), and nitrite (≤ 3 mg/L), which serve as indicators of microbiological, chemical, and physical water quality (Ministry of Health of the Republic of Indonesia, 2023).

Household behaviors in water management represent critical determinants of drinking water quality at the point of consumption, shaped by knowledge, attitudes, social norms, and infrastructure access within the environmental health framework (Betera et al., 2024; Okpanachi et al., 2025; Junaid et al., 2026). Household water quality can be compromised through two primary mechanisms: secondary contamination during storage when treated water is recontaminated through improper containers or unsanitary handling (Shayo and Ligate, 2026); and ainfall-induced infiltration whereby precipitation creates surface runoff carrying fecal material into shallow wells and springs (Genter et al., 2021). In areas with alluvial soils like Klaten's Mount Merapi region, high soil permeability and shallow groundwater tables significantly amplify this vulnerability to seasonal contamination (Genter, Willetts and Foster, 2021; Shayo and Ligate, 2026).

Klaten District (population: 1,302,648; area: 655.56 km²) is known as the "City of Thousand Springs." However, of 189,253 water facilities in Klaten, only 2.53% have been assessed according to physical, chemical, and microbiological standards. The National Drinking Water Quality Surveillance Program (SKAMRT) achievement reached only 3.33% by August 2025, substantially below the Indonesia's 2025–2029 National Medium-Term Development Plan (RPJMN) target of 33% (Health Office, 2024). Prior studies have not simultaneously integrated behavioral, environmental, and weather variables within a single analytical framework, nor conducted spatial analysis of water contamination risk by subdistrict in Klaten. Therefore, this study aimed to analyze the relationship between water source, treatment, storage, and weather conditions with household drinking water quality in Klaten District.

SUBJECTS AND METHOD

Study Design and Setting

This was a cross-sectional observational study conducted in Klaten District, Central Java, Indonesia, from September 2025 to March 2026. The study encompassed all 26 subdistricts representing diverse geographic characteristics from Mount Merapi slopes to lowlands. Data collection included household surveys and water quality laboratory analysis using standardized protocols aligned with the SKAMRT 2025 guidelines.

Population and Sample

The target population comprised all 1,020 households in Klaten District enrolled in the SKAMRT 2025 national surveillance database. Sample size was determined using the single proportion formula (95% confidence level, 5% margin of error, estimated unsafe water prevalence 50%), yielding a minimum sample of 385 households; 390 households were enrolled. An equal allocation sampling design was applied, selecting 15 households per subdistrict across all 26 subdistricts to ensure proportional spatial representation (Levy, 2008; Thompson, 2012) The inclusion criteria for interviewed households were as follows: the household head or a household member aged ≥18 years, who provided written informed consent, and whose household had complete laboratory data for all five parameters. Households with incomplete laboratory data were replaced through random selection within the same village cluster.

Study Variables

Dependent Variable

Drinking water quality was classified as safe or unsafe based on the standards specified in Indonesia's Ministry of Health Regulation (Permenkes) No. 2 of 2023. It was categorized as safe if all five parameters (*E. coli*, total dissolved solids [TDS], pH, nitrate, and nitrite) met the prescribed standards, and unsafe if at least one parameter exceeded the permissible limit.

Independent Variables

Water source Protected water sources included piped water supplied by the Regional Water Supply Company (PDAM) or the Community-Based Drinking Water Supply System Management Group (KPSPAM), protected dug wells, boreholes, protected springs, and packaged drinking water) or unprotected (unprotected dug well or open surface water source).

Water storage was classified as safe when drinking water was stored in a closed container with a tight-fitting lid, a gallon container, or a narrow-mouth vessel, and unsafe when stored in an open container.

Water treatment was categorized as appropriate (boiling, filtration, ultraviolet [UV] disinfection, or chlorination) or inappropriate (no treatment or incomplete treatment).

Weather conditions at the time of water sampling were recorded as rainy or non-rainy.

Confounding variables

Household head's education level, household density, and water storage container hygiene were included as potential confounding variables in the analysis. Household head's education level was categorized as primary school or lower and secondary school or higher.

Household density was classified as <5 or ≥5 household members, while water storage container hygiene was assessed as clean or unclean based on the presence of visible dirt or biofilm on the interior or exterior surfaces of the storage container.

Data Collection and Laboratory Analysis

1. Household characteristics and water management practices were collected using structured questionnaires aligned with the Household Drinking Water Quality Surveillance (*SKAMRT*) 2025 protocol, administered by trained enumerators (sanitarian officers from 34 community health centers) following a full-day technical training.
2. Environmental Health Inspection (*IKL*) forms were used to record water source risk factors and climatic conditions (Ministry of Health, 2025).
3. Water samples were collected in sterile containers following WHO guidelines. Laboratory analysis measured five parameters per Permenkes No. 2/2023: *E. coli* (colony count on CD/EC plate, incubated 35°C for 24 hours), Total Dissolved Solids (TDS meter, in situ), pH (pH meter, in situ), nitrate and nitrite (photometric colorimetric method, Tier 1 laboratory).

All analyses used quality-controlled procedures with daily data verification via the SIPEKAM application.

Data Analysis

Descriptive analysis characterized the study population. Bivariate analysis examined associations between each independent variable and drinking water quality using chi-square tests; Fisher's exact test was applied when expected cell frequencies were <5. Variables with $p<0.25$ in bivariate analysis were advanced to multiple binary logistic regression with backward stepwise elimination to identify independent determinants. Multicollinearity was assessed using Variance Inflation Factor (VIF<10 threshold); model fit was evaluated using Hosmer-Lemeshow goodness-of-fit test (adequate fit: $p>0.05$); and discriminative ability was assessed using Area Under the Receiver Operating Characteristic (AUC-ROC) curve. Spatial analysis using Geographic Information System (GIS) mapping was conducted to visualize subdistrict-level risk distribution. All analyses used STATA version 17.0 with $\alpha=0.05$.

Research Ethics

Research ethical issues including informed consent, anonymity, and confidentiality were carefully addressed throughout the study. Ethical approval was obtained from the Research Ethics Committee at Poltekkes Kemenkes Semarang No. 136/EA/F.XXIII.-38/2026. All participants provided written informed consent.

RESULTS

Sample Characteristics

Of 390 households enrolled, respondents had a mean age of 48.1 years (SD=12.2 years). The majority were male (67.2%) and had completed senior high school education (64.4%). Most households had 3–4 members (58.7%), with a mean household size of 3.8 (SD=1.4). Overall, 202 households (51.8%) had unsafe drinking water based on at least one parameter exceeding the threshold. Detailed sample characteristics are presented in Table 1.

Table 1. Sample Characteristics and Drinking Water Quality Status

Characteristic	Category	n	%
Sex			
Male		262	67.2
Female		128	32.8
Age (years)		*Mean ± SD: 48.1 ± 12.2 years*	
18–30		33	8.5

Characteristic	Category	n	%
31–45		128	32.8
46–60		168	43.1
>60		61	15.6
Education			
Did not complete SD/MI		1	0.3
Completed SD/MI		43	11.0
Completed SLTP/MTS		20	5.1
Completed SLTA/MA		251	64.4
Completed D1/D2/D3/D4		26	6.7
Completed S1/S2/S3		49	12.6
Occupation			
Laborer/Driver/Housemaid		158	40.5
Self-employed		69	17.7
Private employee		54	13.8
PNS/TNI/Polri/BUMN/BUMD		36	9.2
Farmer		22	5.6
Others/Unemployed		51	13.1
Household Size		*Mean ± SD: 3.8 ± 1.4 persons*	
1–2 persons		66	16.9
3–4 persons		229	58.7
≥5 persons (overcrowded)		95	24.4
Drinking Water Quality			
Safe (Meets all standards)		188	48.2
Unsafe (≥1 parameter exceeds threshold)		202	51.8

Bivariate Analysis

Bivariate analysis revealed that unprotected water sources were significantly associated with unsafe drinking water quality (OR= 1.71; 95% CI=1.12–2.61; p=0.012). Water treatment showed a borderline association (OR= 0.47; 95% CI=0.21–1.09; p=0.074). Storage container type showed no significant association (OR=1.14; 95% CI=0.48–2.70; p=0.771). Weather conditions showed no statistically significant association (p= 0.451), though rainy conditions trended toward increased risk (OR=2.39). Among confounders, neither household head's education (p=0.997) nor household density (p= 0.473) were significant and were excluded from the final model. Variables with p<0.25 (water source, water treatment, weather) were retained for multivariate analysis. Detailed results are presented in Table 2.

Table 2. Bivariate Analysis of Factors Associated with Unsafe Drinking Water Quality

Variables	Safe n (%)	Unsafe n (%)	OR (95% CI)	p
Water Source				
Protected	134 (53.2)	118 (46.8)	Ref.	
Unprotected	55 (39.9)	83 (60.1)	1.71 (1.12–2.61)	0.012
Water Treatment				
Appropriate	172 (47.3)	192 (52.7)	Ref.	
Not appropriate	17 (65.4)	9 (34.6)	0.47 (0.21–1.09)	0.074

Variables	Safe n (%)	Unsafe n (%)	OR (95% CI)	p
Storage Container				
Closed/Safe (ref.)	179 (48.6)	189 (51.4)	Ref.	
Open/Unsafe	9 (40.9)	13 (59.1)	1.14 (0.48–2.70)	0.771
Weather Condition				
Sunny/Dry (ref.)	186 (48.6)	197 (51.4)	Ref.	
Rainy	2 (28.6)	5 (71.4)	2.39 (0.44–12.99)	0.451

Multivariate Analysis

Multiple logistic regression with backward stepwise elimination identified unprotected water source as the sole statistically significant independent determinant of unsafe drinking water quality (Adjusted OR=1.61; 95% CI=1.05–2.47; p=0.029). Water treatment and weather conditions remained in the final model but were not statistically significant (p=0.183 and p= 0.386, respectively). The overall model was statistically significant (LR $\chi^2(3)$=9.09; p=0.028). No multicollinearity was detected (all VIF values 1.00–1.02). The Hosmer-Lemeshow goodness-of-fit test indicated adequate model calibration ($\chi^2(8)$=0.11; p=0.741). However, the AUC-ROC (0.57) and pseudo-R^2 (0.017) indicated limited discriminative ability, suggesting substantial unmeasured determinants. Results are presented in Table 3.

Table 3. Final Multiple Logistic Regression Model: Independent Determinants of Unsafe Drinking Water Quality

Variables	aOR	95% CI		p
		Lower limit	Upper limit	
Unprotected water source	1.61	1.05	2.47	0.029
No water treatment	0.56	0.24	1.31	0.183
Rainy weather conditions	2.09	0.40	11.02	0.386
Model Fit Statistics				
Statistics		**Value**		
Likelihood ratio χ^2 (3)		9.09 (p = 0.028)		
McFadden's pseudo R^2		0.017		
Hosmer–Lemeshow χ^2 (8)		0.109 (p = 0.741)		
Area under the ROC curve (AUC)		0.568		

Spatial Risk Distribution

GIS spatial analysis revealed substantial variation in drinking water quality across the 26 subdistricts of Klaten District (Table 4). Non-compliant (unsafe) rates ranged from a high of 93.3% in Polanharjo to a low of 26.7% in Ceper, Jatinom, and Karangdowo, while Gantiwarno was the only subdistrict in which all 15 sampled households met the national drinking water quality standard. Of the 26 subdistricts, 13 (50.0%) had non-compliant rates exceeding 50%, and five (19.2%) were classified as Very High Risk (>80%). Subdistricts in the central-to-northern lowland zone of Klaten showed consistently higher contamination, corresponding to areas with shallow alluvial aquifers and high soil permeability associated with Mount Merapi's volcanic geological deposits. Detailed subdistrict-level risk distribution is presented in Table 4.

Table 4. Subdistrict-Level Drinking Water Quality Risk Distribution, Klaten District 2025

Subdistrict	n	Safe		Unsafe		Risk Category
		(n)	(%)	(n)	(%)	
Very High Risk (>80%) — 5 Subdistricts						
Polanharjo	15	1	6.7	14	93.3	Very High
Wonosari	15	2	13.3	13	86.7	Very High
Bayat	15	3	20.0	12	80.0	Very High
Tulung	15	3	20.0	12	80.0	Very High
Klaten Tengah	15	3	20.0	12	80.0	Very High
High Risk (61–80%) — 6 Subdistricts						
Cawas	15	4	26.7	11	73.3	High
Pedan	15	4	26.7	11	73.3	High
Ngawen	15	4	26.7	11	73.3	High
Juwiring	15	5	33.3	10	66.7	High
Klaten Selatan	15	5	33.3	10	66.7	High
Karangnongko	15	5	33.3	10	66.7	High
Moderate Risk (41–60%) — 7 Subdistricts						
Karanganom	15	7	46.7	8	53.3	Moderate
Kebonarum	15	7	46.7	8	53.3	Moderate
Klaten Utara	15	8	53.3	7	46.7	Moderate
Delanggu	15	9	60.0	6	40.0	Moderate
Trucuk	15	9	60.0	6	40.0	Moderate
Wedi	15	9	60.0	6	40.0	Moderate
Prambanan	15	9	60.0	6	40.0	Moderate
Low Risk (21-40%) - 6 Subdistricts						
Ceper	15	11	73.3	4	26.7	Low
Jatinom	15	11	73.3	4	26.7	Low
Karangdowo	15	11	73.3	4	26.7	Low
Jogonalan	15	10	66.7	5	33.3	Low
Manisrenggo	15	10	66.7	5	33.3	Low
Kemalang	15	10	66.7	5	33.3	Low
Very Low Risk (≤20%) — 2 Subdistricts						
Kalikotes	15	13	86.7	2	13.3	Very Low
Gantiwarno	15	15	100.0	0	0.0	Very Low
Total	**390**	**188**	**48.2**	**202**	**51.8**	**–**

Total: 26 subdistricts, n = 390; Safe = 188 (48.2%); Unsafe = 202 (51.8%).
Risk categories (based on the proportion of unsafe/non-compliant households): Very Low ≤20%; Low 21–40%; Moderate 41–60%; High 61–80%; Very High >80%.

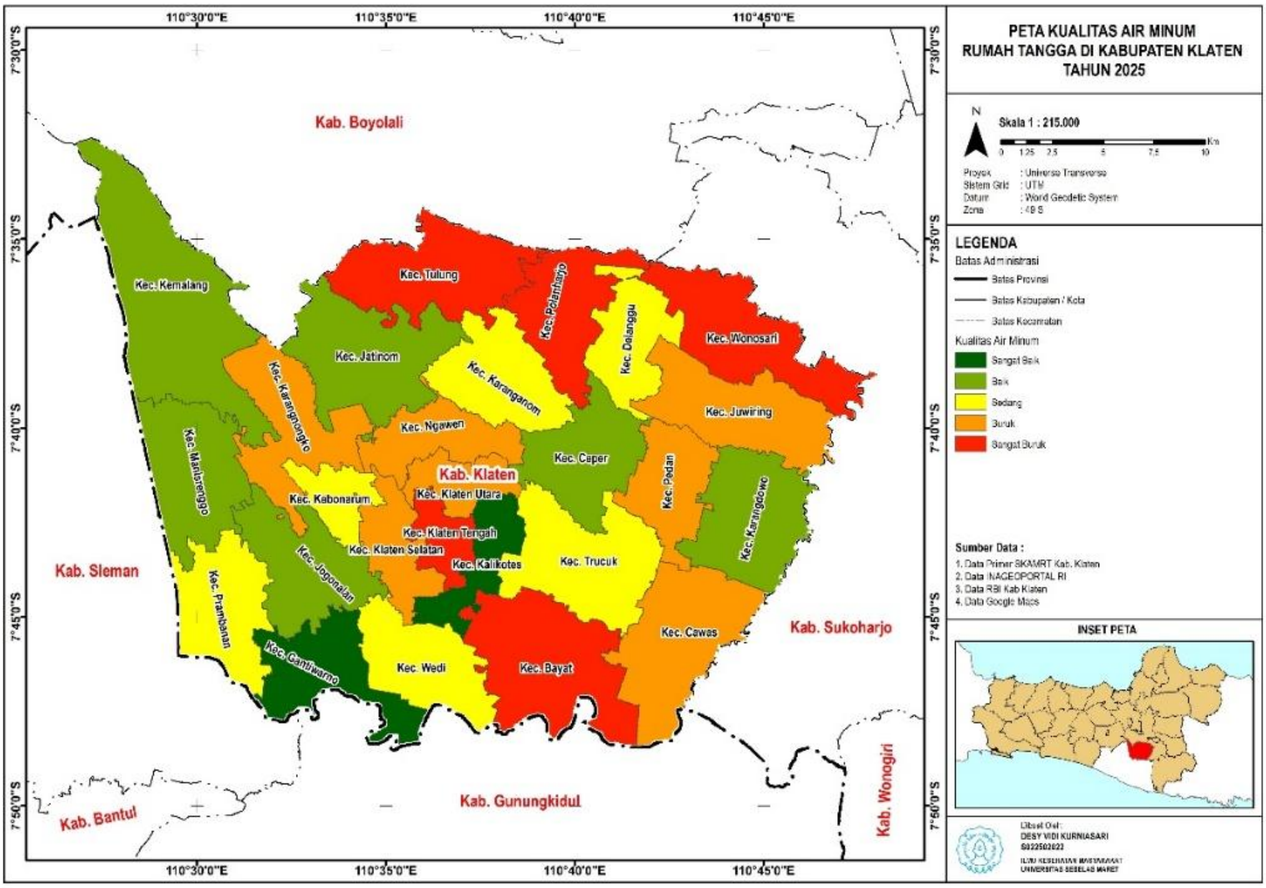

Figure 1. Spatial Distribution of Household Drinking Water Quality, Kabupaten Klaten, 2025

Figure 1 presents the spatial distribution of household drinking water quality across Klaten District, generated from 390 GPS-referenced sampling points evenly distributed across the district's 26 subdistricts. The color gradation reflects the proportion of non-compliant water quality samples per subdistrict, based on laboratory testing of five mandatory parameters, namely E. coli, total dissolved solids (TDS), pH, nitrate, and nitrite, in accordance with Indonesian Ministry of Health Regulation No. 2 of 2023 (Ministry of Health of the Republic of Indonesia, 2023).

The use of a five-class risk framework, ranging from very low to very high, for water quality mapping is consistent with several international studies employing GIS-based drinking water quality indices (DWQI), including a recent application in coastal Tamil Nadu, India, that integrated DWQI computation with GIS-based spatial classification to assess groundwater suitability for drinking purposes (Jesuraja et al., 2021).

DISCUSSION

This study identified unprotected water sources as the sole independent risk factor for unsafe household drinking water quality in Klaten District, with households using unprotected sources showing 1.61 times higher odds of unsafe water compared to those using protected sources (aOR= 1.61; 95% CI=1.05–2.47; p=0.029). This finding aligns with WHO guidelines and previous research demonstrating that infrastructure deficiency in water source protection directly influences microbiological contamination (Bain *et al.*, 2014; World Health Organization, 2017). In Klaten's geographic context, the porous alluvial soil from Mount Merapi, combined with high infiltration rates and shallow groundwater tables, renders shallow water sources extremely susceptible to seasonal fecal and chemical contamination (Genter, Willetts and Foster, 2021; Hendrayana *et al.*, 2023). Water treatment practices showed no significant protective effect, possibly reflecting secondary contamination during storage that counteracts treatment benefits, inconsistent treatment application, or inadequate boiling duration (Ghaudenson et al., 2021). Storage container type similarly showed no significant influence, perhaps because water safety is primarily compromised at the source level rather than during storage, or because the binary closed/open classification did not capture the full spectrum of storage contamination risks (Genter, Willetts and Foster, 2021; Ghaudenson, Priadi and Foster, 2021)

Spatial analysis revealed considerable geographic heterogeneity in water quality, with Non-Compliant rates ranging from full compliance in one subdistrict to 93.3% in another, across the district's 26 subdistricts. Five subdistricts in the central-to-northern lowland zone were classified as Very High Risk (>80%), consistent with the weather-sensitive water contamination concept whereby areas with shallow alluvial aquifers and high soil permeability are most vulnerable to seasonal contamination (Genter, Willetts and Foster, 2021; Hendrayana *et al.*, 2023). This spatial pattern underscores the necessity for a subdistrict risk-map-based intervention approach rather than a uniform district-wide strategy.

The model's limited discriminative ability (AUC-ROC=0.57; pseudo-R^2=0.017) indicates that critical unmeasured determinants exist beyond those examined, likely including detailed sanitation practices, water handling hygiene, precise source construction characteristics, and temporal water quality variation across seasons. Several limitations should be acknowledged. First, the cross-sectional design prevents causal inference. Second, a single water sample per household may not capture seasonal temporal fluctuations. Third, self-reported data on treatment and storage practices may be subject to social desirability bias. Fourth, sampling predominantly occurred during dry season (only 1.8% rainy conditions), limiting conclusions about rainfall effects on water quality.

In conclusion, unprotected water sources represent an independent determinant of unsafe household drinking water quality in Klaten District. Public health interventions must prioritize water source protection through infrastructure improvement, expand SKAMRT surveillance coverage using two-season sampling protocols, optimize SIPEKAM as a spatially risk-based early warning system, and implement subdistrict-targeted strategies to achieve Sustainable Development Goal 6.1 universal access to safe drinking water by 2030.

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CONFLICT OF INTEREST

The authors declare that this research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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