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Article

Risk Assessment of Household Water Facilities Based on Physicochemical Water Quality and Sanitary Inspection in Urban Bengkulu, Indonesia

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Abstract. Safe household water should be acceptable, chemically stable, and protected from sanitary hazards to support urban public health. However, facilities in dense settlements remain vulnerable to contamination from wastewater, limited sanitation, groundwater dependence, and inadequate protection. This condition is evident in Bengkulu, where residents use piped water, dug wells, and bore wells with different vulnerability levels. Integrated assessment combining physicochemical measurement, sanitary inspection, and spatial mapping is needed to identify priorities. This study aimed to assess water-facility risk based on physicochemical water quality and sanitary inspection in Bengkulu. Sanitary risk was assessed using a standardized sanitary inspection checklist adapted from WHO-based household water facility inspection principles, and risk categories were determined from the cumulative sanitary hazard score. A quantitative cross-sectional study was conducted on 2,772 facilities. Data were analyzed using descriptive statistics, Kruskal–Wallis, Chi-square, Cramer's V, Spearman correlation, ordinal logistic regression, and spatial mapping. Results showed that 60.89% were low risk, 31.64% medium risk, and 7.47% high risk. Dug wells showed higher risk, while odor, turbidity, facility type, and septic-tank distance were key determinants. Spatial mapping indicated that high-risk urban villages should be prioritized for sanitation improvement, monitoring, and interventions.

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1. Introduction

Access to safe water is a basic community need and an essential component of improving environmental health, because household water is used for drinking, cooking, bathing, washing, and daily hygiene and sanitation activities. In urban areas, household water-quality problems have become increasingly complex due to population density, expansion of residential areas, limited sanitation infrastructure, and potential pollution from domestic activities. Household groundwater quality in Indonesia has been shown to be influenced by household and environmental factors, including sanitation conditions, type of water source, and the potential for fecal contamination in groundwater-based sources [1-2].

Household water facilities in urban areas generally consist of piped/tap water, dug wells, and bore wells or deep groundwater sources, each of which has different risk characteristics. Household water facilities in urban areas generally consist of piped/tap water, dug wells, and bore wells or deep groundwater sources, each of which has different risk characteristics. Recent international studies emphasize that household water safety should not be assessed only from the availability of water sources, but also from the interaction between water-source type, sanitation infrastructure, household behavior, and environmental conditions around the facility [3].

Piped facilities may be affected by distribution-network conditions, flow continuity, pipe leakage, and household-level water-storage practices, whereas dug wells and bore wells are more strongly influenced by facility construction, water-source depth, soil characteristics, and proximity to pollution sources such as septic tanks, drainage channels, stagnant water, and domestic activities around the house. In urban Indonesia, the coexistence of on-site sanitation systems and groundwater use may increase the risk of well contamination, although distance-related factors should be analyzed together with hydrogeological conditions, well construction, and local environmental characteristics [4-6].

Therefore, risk assessment of household water facilities should be conducted comprehensively by integrating measurements of physicochemical water quality, such as TDS, electrical conductivity (EC), pH, temperature, turbidity, color, odor, and taste, with sanitary inspection to identify contamination pathways and determine risk-based intervention priorities [7], [8]. This approach is in line with recent water-safety research, which recommends combining water-quality testing and sanitary inspection because both methods provide complementary information for identifying hazards and protecting household water sources [9].

Assessment of household water quality is not sufficient if it relies only on physicochemical measurements; it also needs to be combined with sanitary inspection of water facilities so that potential contamination risks can be identified more comprehensively. Physicochemical parameters such as total dissolved solids (TDS), electrical conductivity (EC), pH, temperature, turbidity, color, odor, and taste provide an initial picture of water-quality conditions and changes in water characteristics that may affect suitability and user acceptance [10]. However, these parameters do not fully explain contamination risk factors originating from the environment surrounding water facilities, such as unprotected well construction, close distance to septic tanks, drainage channels, stagnant water, and other domestic pollution sources. Therefore, water-safety management should use a risk-based approach through water safety plans and sanitary inspection, because sanitary inspection can serve as a simple, checklist-based field risk-assessment tool that can identify conditions that may create hazards in water-supply systems, especially in small-scale supplies or resource-limited areas [11].

Critical reviews of water-safety assessment also indicate that sanitary inspection and water-quality testing should be used in a complementary manner, because the relationship between sanitary conditions and microbiological water quality may vary according to facility type, construction, and local environmental context. Water facilities that appear physically acceptable are not necessarily free from risk when they are located close to pollution sources or have weak structural protection. Conversely, facilities with sound construction, a safe distance from septic tanks, adequate protective floors, and a well-maintained surrounding environment tend to have lower contamination risk, especially for household groundwater sources such as dug wells and bore wells [12]. Recent studies also show that household water-safety assessment increasingly uses integrated and risk-based approaches, including sanitary inspection, water-quality analysis, statistical modeling, and spatial mapping, to support targeted environmental health interventions [13-15].

In Indonesia, household water-quality assessment should refer to applicable environmental health standards, including Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023. This regulation provides environmental health quality standards for water media, including drinking water and water for hygiene and sanitation purposes. It can therefore be used as a reference for assessing household water-quality parameters. The use of this standard is important because household water safety is not only determined by the physical acceptability of water but also by compliance with quality requirements and the sanitary condition of the facility. Therefore, reporting the proportion of samples that do not meet the required standards is important to provide a clearer regulatory interpretation of household water-quality conditions.

Bengkulu City was selected as the study location because it represents a coastal urban area with heterogeneous household water sources, rapid settlement growth, and varying environmental sanitation conditions. The city contains densely populated residential zones where household water facilities are often located close to septic tanks, drainage channels, and domestic-waste sources. These conditions are particularly relevant for shallow groundwater-based facilities, such as dug wells, because the risk of contamination may increase when well construction, soil condition, groundwater depth, and sanitation distance are inadequate. The 12 selected urban villages were included because they represent areas with diverse household water-facility types, different settlement densities, and varying levels of sanitation vulnerability, making them suitable for identifying spatial differences in household water-facility risk.

The real condition in urban Bengkulu shows that residents still rely on multiple household water sources, including piped water, dug wells, and bore wells or deep groundwater. This pattern reflects the unequal availability and reliability of safe water access at the household level. In several residential areas, population density, limited yard space, and the close position of wells and septic tanks may create environmental pathways for contamination. Therefore, the study of household water-facility risk in Bengkulu City is urgent because it can provide local evidence for identifying vulnerable facility types and priority areas for water-safety intervention. Such evidence is needed to support practical interventions, including routine monitoring, improvement of water-source protection, septic-tank distance control, and spatially targeted sanitation programs.

Research on household water-facility risk in urban Bengkulu remains limited, particularly studies that integrate physicochemical water-quality parameters, sanitary inspection, facility type, and spatial distribution of risk at the household level. Previous water-quality studies commonly focused on selected parameters, microbiological contamination, household water treatment behavior, or a single type of water source. However, designing appropriate household water-improvement interventions requires an approach that can identify vulnerable facility types, dominant factors associated with increased risk, and areas that should be prioritized for monitoring. This study addresses this gap by combining field water-quality measurement, sanitary inspection, statistical analysis, and spatial mapping. The novelty of this study lies in its integrated household-level risk assessment, which combines physicochemical water-quality parameters, sanitary inspection scoring, facility type, regulatory compliance, and spatial risk prioritization to identify priority areas for household water-safety intervention in urban Bengkulu.

Based on this background, the research hypothesis was that household water-facility risk in urban Bengkulu differs significantly according to facility type, physicochemical water quality, and sanitary conditions, and that facilities located near potential pollution sources have a higher probability of being classified into higher-risk categories. Therefore, this study aimed to analyze the risk of household water facilities based on physicochemical water quality and sanitary inspection in urban Bengkulu. Specifically, this study sought to describe the distribution of household water-facility risk categories, compare water-quality parameters by facility type, analyze the relationship between sanitary indicators and risk categories, identify dominant factors associated with increased risk, and determine priority areas for household water-improvement interventions.

2. Experimental Section

2.1. Study Design, Location, and Sample

This study used a quantitative observational design with a cross-sectional approach. This design was used to analyze physicochemical water quality, sanitation conditions, water-source type, and household water-facility risk categories during one observation period. The study was conducted in urban residential areas of Bengkulu City, covering the urban villages of Surabaya, Cempaka Permai, Sidomulyo, Sukamerindu, Kampung Kelawi, Pasar Bengkulu, Lingkar Barat, Tanjung Jaya, Semarang, Padang Harapan, Jalan Gedang, and Tanjung Agung.

The study sample consisted of 2,772 household water facilities. The sample was selected using a total sampling or census approach, in which all eligible household water facilities recorded in the 12 selected urban villages were included in the study. Each sample represented one water-facility point with information on location, facility type, water-quality parameters, sanitation conditions, and risk category. The inclusion criteria were household water facilities that were actively used by residents, accessible during field observation, and could be directly inspected and measured. Facilities that were inactive, inaccessible, or had incomplete observation data were excluded from the analysis. The analyzed water-facility types included piped/tap water, dug wells, and bore wells/deep groundwater.

2.2. Study Variables

The dependent variable in this study was the water-facility risk category, which was classified as low, moderate, or high risk. The independent variables included water-facility type, physicochemical water-quality parameters, organoleptic indicators, sanitary indicators, and location. The analyzed water-quality parameters consisted of TDS, EC, pH, temperature, turbidity, odor, taste, and color. The sanitary indicators included the distance between the water source and the septic tank, well depth, well-floor condition, environmental conditions surrounding the facility, and potential sources of contamination around the water facility.

2.3. Sanitary Inspection and Risk Classification

Sanitary inspection was conducted using a structured checklist to identify potential sanitary risk factors around each household water facility. The checklist included indicators related to water-source protection, well-floor condition, distance from septic tanks, drainage condition, environmental cleanliness, and the presence of potential contamination sources around the facility. Each checklist item was recorded as “Yes” or “No”. A “Yes” response indicated the presence of a sanitary risk factor and was scored 1, whereas a “No” response indicated the absence of a sanitary risk factor and was scored 0.

Table 1. Sanitary Inspection Scoring Matrix for Household Water-Facility Risk Classification

Number of "Yes" Responses	Risk Category	Interpretation
0–2	Low risk	Few sanitary risk factors were identified around the water facility.
3–5	Moderate risk	Several sanitary risk factors were present and may increase contamination potential.
≥6	High risk	Multiple sanitary risk factors were identified, indicating higher contamination potential.

The total sanitary risk score was calculated by summing all "Yes" responses for each household water facility. The final score was then used to classify the facilities into three risk categories: low, moderate, and high risk. Facilities with 0-2 sanitary risk indicators were classified as low risk, facilities with 3-5 indicators were classified as moderate risk, and facilities with six or more indicators were classified as high risk. This classification was used as the dependent variable in the statistical analysis and as the basis for spatial risk mapping.

2.4. Data Collection and Processing Procedures

Each water facility was classified into low-, moderate-, or high-risk categories based on observations of water quality and facility sanitation conditions. The survey data were compiled into a research database. Data processing included standardizing urban-village names, grouping water-facility types, coding categorical variables, and developing numerical variables for statistical analysis. Risk categories were coded ordinally as follows: low risk = 1, moderate risk = 2, and high risk = 3.

Data were collected through field surveys involving direct observation, measurement of water-quality parameters, organoleptic examination, sanitary inspection of water facilities, and recording of location coordinates. Each household water facility was observed directly to identify the facility type, surrounding sanitation conditions, distance from potential pollution sources, well-floor condition, well depth, and other environmental factors that could influence water-facility risk.

Water-quality parameters were measured directly in the field using portable instruments. Total dissolved solids (TDS), electrical conductivity (EC), pH, and temperature were measured using a Hanna Instruments HI98194 portable multiparameter water-quality meter. Turbidity was measured using a Hanna Instruments HI98703 portable turbidity meter. Odor, taste, and color were assessed through field-based organoleptic observation. Before field measurement, all instruments were calibrated or verified according to the manufacturer's instructions. The pH meter was calibrated using standard buffer solutions of pH 4.01, 7.00, and 10.01. The EC/TDS meter was calibrated or checked using a standard conductivity solution, and the temperature sensor was verified using a calibrated thermometer. The turbidity meter was calibrated using standard turbidity solutions before measurement. The instrument probes were rinsed with distilled water before and after each measurement to prevent cross-contamination between samples.

Each water facility was classified into low, moderate, or high-risk categories based on the sanitary inspection score and field water-quality observations. The survey data were then compiled into a research database. Data processing included checking data completeness, standardizing urban-village names, grouping water-facility types, coding categorical variables, and developing numerical variables for statistical analysis. Risk categories were coded ordinally as follows: low risk = 1, moderate risk = 2, and high risk = 3.

2.5. Data Analysis

Data were analyzed descriptively and inferentially. The stages of data analysis in this study were as follows

2.5.1 Descriptive Analysis

Descriptive analysis was used to describe the distribution of water-facility types, risk categories, water-quality characteristics, and risk distribution across urban villages. Categorical data were presented as frequencies and percentages, whereas numerical data were presented as means, medians, minimum values, and maximum values. Percentages were calculated using the following formula:

$$P = (f / n) \times 100\%$$

where P is the percentage, f is the category frequency, and n is the total sample size.

2.5.2 Kruskal-Wallis Test

The Kruskal-Wallis test was used to analyze differences in water-quality parameters according to water-facility type and risk category. This test was selected because field water-quality parameters showed substantial variation in their values. The Kruskal-Wallis formula is

$$H = [12 / N(N + 1)] \Sigma(R_i^2 / n_i) - 3(N + 1)$$

where H is the Kruskal-Wallis statistic, N is the total number of observations, R_i is the sum of ranks in the i-th group, n_i is the sample size in the i-th group, and k is the number of groups.

2.5.3. Chi-square Test

The Chi-square test was used to examine the relationship between categorical variables and risk categories, such as facility type, turbidity, odor, taste, color, and well-floor condition. The Chi-square formula is:

$$\chi^2 = \Sigma[(O_i - E_i)^2 / E_i]$$

where χ^2 is the Chi-square value, O_i is the observed frequency, and E_i is the expected frequency.

2.5.4 Cramer's V

The strength of association among categorical variables was analyzed using Cramer's V. This analysis was used to determine whether the association between each categorical variable and risk category was strong or weak. The formula for Cramer's V is:

$$V = \sqrt{[\chi^2 / N(k - 1)]}$$

where V is Cramer's V, χ^2 is the Chi-square value, N is the number of samples, and k is the smaller number of categories between rows and columns

2.5.5 Spearman rank Correlation Test

The Spearman rank correlation test was used to analyze the relationship between numerical variables and ordinal risk categories. The analyzed variables included septic-tank distance, well depth, TDS, EC, pH, and temperature. The Spearman correlation formula is

$$\rho = 1 - [6\Sigma d_i^2 / n(n^2 - 1)]$$

where ρ is the Spearman correlation coefficient, d_i is the rank difference between variables, and n is the number of observations.

2.5.6 Ordinal Logistic Regression

Ordinal logistic regression was used to identify dominant factors associated with an increase in risk category. This model was selected because the dependent variable was an ordered risk category, namely low, moderate, and high risk. The ordinal logistic regression model is expressed as follows:

$$\log[P(Y \le j) / P(Y > j)] = \alpha_j - (\beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p)$$

where Y is the risk category, j is the ordinal-category threshold, α_j is the threshold, β is the regression coefficient, and X is the independent variable.

$$OR = e^{\beta}$$

An OR greater than 1 indicates increased odds that a water facility belongs to a higher risk category, whereas an OR less than 1 indicates reduced odds of higher risk.

2.5.7 Determination of Priority Intervention Areas

Priority areas were determined based on the number of high-risk facilities, the proportion of high-risk facilities, the combined proportion of moderate- and high-risk facilities, and the dominance of more vulnerable facility types. This approach was used to provide more targeted and risk-based direction for household water-improvement interventions.

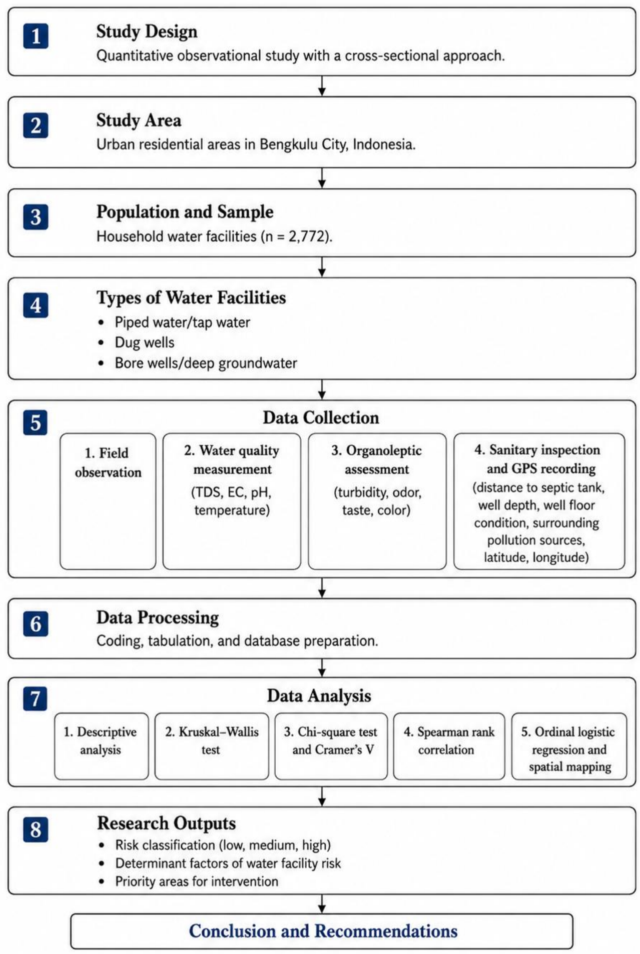

Figure 1. Flowchart of Research

3. Results and Discussion

3.1. Characteristics of Household Water Facilities

This study analyzed 2,772 household water facilities distributed across several urban villages in residential areas of Bengkulu City. The analyzed facilities consisted of piped/tap water, dug wells, and bore wells/deep groundwater. The most common facility type was piped/tap water, comprising 971 points or 35.03%. This number was relatively comparable to dug wells, which accounted for 964 points or 34.78%, whereas bore wells/deep groundwater accounted for 837 points or 30.19% (Table 2). This composition indicates that communities in the study area still use diverse water sources, including both piped systems and groundwater sources.

The use of multiple household water sources in urban Bengkulu indicates that water-safety management should not be designed with a single-source approach. Although piped/tap water was the most common facility type, the nearly equal proportions of dug wells and bore wells show that groundwater remains an important household water source. Recent groundwater studies show that groundwater quality is influenced by hydrogeochemical processes, source depth, land-use pressure, and local environmental conditions [16-17]. However, piped water should not automatically be interpreted as risk-free because distribution-network conditions, pipe leakage, intermittent flow, and household storage may also affect water quality. Therefore, the comparable proportion of piped water, dug wells, and bore wells in this study indicates the need for differentiated monitoring strategies according to facility type and surrounding sanitary conditions.

Table 2. Distribution of Household Water-Facility Types

Water-facility type	Number	Percentage
Piped/tap water	971	35.03%
Dug wells	964	34.78%
Bore wells/deep groundwater	837	30.19%
Total	2,772	100.00%

The relatively large proportion of dug wells and bore wells indicates that groundwater remains a major household water source in the urban area. This condition suggests that community dependence on groundwater sources is still high; therefore, water quality and sanitary protection of these facilities require attention. Groundwater managed independently by households may experience microbiological contamination when facility construction, distance from contamination sources, and surrounding sanitary protection do not meet adequate standards [18-19].

3.2. Distribution of Water-Facility Risk Categories

Most household water facilities in this study were classified as low risk. Nevertheless, the proportion of facilities in the moderate- and high-risk categories remained substantial, reaching 39.11% of all samples (Table 3). This finding indicates that nearly four out of ten household water facilities still have vulnerability to water-quality deterioration. This condition highlights the need for greater attention to facilities categorized as moderate and high risk, particularly through regular water-quality monitoring, improvement of physical facility construction, protection of water sources, and control of sanitary risk factors around water-source locations. Thus, the findings confirm that the availability of household water facilities does not fully guarantee water safety unless accompanied by adequate sanitary protection and quality monitoring.

The finding that 39.11% of facilities were classified as moderate or high risk confirms that household water safety requires preventive surveillance, not only end-point water testing. Although 60.89% of facilities were classified as low risk, the moderate- and high-risk groups remain important because these facilities may become sources of water-quality deterioration if sanitary hazards are not controlled. Recent studies emphasize that drinking-water quality may change due to environmental pressure, rainfall, temperature variation, and contamination pathways around water sources [20]. Therefore, the risk categories in this study should be interpreted as a practical basis for identifying facilities that require routine inspection, early corrective action, and stronger household-level water-source protection.

Table 3. Distribution of Water-Facility Risk Categories

Risk category	Number	Percentage
Low risk	1,688	60.89%
Moderate risk	877	31.64%
High risk	207	7.47%
Total	2,772	100.00%

This finding also strengthens the importance of a risk-based water-safety assessment approach. Water-safety assessment cannot rely solely on water-quality testing at a single point in time, because test results only describe actual conditions when samples are collected. Therefore, water-quality testing should be complemented by sanitary inspection to identify hazards, contamination pathways, and weaknesses in the protection of water facilities. Sanitary inspection and water-quality analysis are complementary instruments for determining the safety level of household water sources [21-22].

The proportion of moderate and high risk also indicates that water facilities that appear visually acceptable are not always safe for use, especially when well construction is poorly protected, facilities are located close to septic tanks or other contamination sources, and are affected by surface runoff and seasonal variation. Accordingly, preventive interventions such as routine sanitary inspection, periodic water-quality testing, improvement of well curbs and protective floors, closure or covering of water sources, regulation of safe distances from pollution sources, and household education are essential to ensure that water used by communities is not only available in sufficient quantity but also safe in quality and sustainable [23].

3.3. Risk Categories by Water-Facility Type

Dug wells had the highest proportion of high-risk facilities compared with other facility types, at 9.75%. Bore wells or deep groundwater facilities had a high-risk proportion of 7.89%, whereas piped/tap water showed the lowest high-risk proportion, at 4.84%. The Chi-square test indicated a significant association between water-facility type and risk category, with Chi-square = 28.879 and $p < 0.001$ (Table 4). However, the Cramer's V value of 0.072 indicated that the strength of this association was weak. In other words, although water-facility type was statistically associated with risk category, variation in sanitary risk was not fully determined by facility type alone. Other factors, such as construction quality, source depth, well-floor and well-curb conditions, presence of covers, drainage systems, distance to septic tanks, residential density, local hydrogeological conditions, and household maintenance practices, also contribute to the risk level of water facilities [24-25].

The higher risk observed in dug wells and bore wells is consistent with recent groundwater-quality assessments showing that groundwater characteristics vary according to source depth, aquifer interaction, surrounding land use, and pollution pressure [26]. This supports the interpretation that groundwater-based facilities are more sensitive to local environmental and sanitary conditions than piped sources. However, the weak Cramer's V value provides a contrasting argument: facility type alone cannot fully explain household water-facility risk. Therefore, dug wells should be considered more vulnerable, but the final risk level still depends on construction quality, protective floor condition, septic-tank distance, drainage, and household maintenance.

Table 4. Distribution of Risk Categories by Water-Facility Type

Water-facility type	Low risk	Moderate risk	High risk	Total
Piped/tap water	641 / 66.01%	283 / 29.15%	47 / 4.84%	971
Bore wells/deep groundwater	510 / 60.93%	261 / 31.18%	66 / 7.89%	837
Dug wells	537 / 55.71%	333 / 34.54%	94 / 9.75%	964
Total	1,688	877	207	2,772
Chi-square test result	$\chi^2 = 28.879$; df = 4; $p < 0.001$			
Strength of association	Cramer's V = 0.072 (weak)			

The higher proportion of high-risk facilities among dug wells can be explained by their physical and structural characteristics, which are more vulnerable to surrounding environmental influences. Dug wells generally have shallower depths and more open physical protection than bore wells, making them more easily affected by surface runoff, stagnant water, well-floor and curb conditions, distance to septic tanks, and domestic activities around the water source. These conditions increase the likelihood of contaminant entry, particularly when wells are not equipped with adequate covers, watertight floors, proper drainage channels, and safe distances from pollution sources [27]. This finding is consistent with studies in urban Indonesia showing that household groundwater use alongside on-site sanitation systems can increase pollution risk. However, contamination is not determined only by the horizontal distance between water sources and sanitation facilities; it is also influenced by facility construction, groundwater-table depth, local hydrogeological conditions, and environmental management practices around households [28].

3.4. Risk Distribution by Urban Village

Based on the number of high-risk cases, Surabaya urban village had the largest problem burden, with 68 facilities, followed by Cempaka Permai with 37 facilities, Sidomulyo with 35 facilities, and Sukamerindu with 29 facilities. However, when viewed from the combined proportion of moderate and high risk, Sidomulyo had the highest vulnerability level, reaching 69.44% (Table 5). The difference between absolute numbers and risk proportions indicates that the distribution of household water-facility risk is spatially uneven across urban villages. Urban villages with a large number of high-risk cases should be prioritized because they represent a high population-level problem burden, whereas urban villages with a high proportion of moderate-high risk indicate a greater concentration of vulnerability among existing water facilities. Therefore, priority setting for interventions should not consider only the number of cases, but should also account for risk proportion, residential environmental characteristics, household density, patterns of water-source use, and local sanitation conditions [29-30].

The contrast between Surabaya and Sidomulyo shows that spatial risk should be interpreted from two perspectives: absolute burden and proportional vulnerability. Surabaya had the largest number of high-risk facilities, indicating a larger population-level problem burden, whereas Sidomulyo had the highest combined proportion of moderate- and high-risk facilities, indicating a stronger concentration of vulnerability. This phenomenon suggests that intervention priority should not be based on one indicator only. Areas with many high-risk facilities require broad public-health intervention, while areas with high proportional vulnerability require focused sanitary improvement for most existing facilities.

Table 5. Urban Villages with Moderate-To-High Risks Requiring Attention

Urban Village	Total Samples	Low risk	Moderate risk	High risk	Moderate + high risk
Sidomulyo	540	165	340	35	69.44%
Kampung Kelawi	165	63	94	8	61.82%
Sukamerindu	262	142	91	29	45.80%
Cempaka Permai	349	190	122	37	45.56%
Pasar Bengkulu	105	58	33	14	44.76%
Lingkar Barat	79	46	24	9	41.77%
Tanjung Jaya	60	35	22	3	41.67%
Surabaya	458	271	119	68	40.83%
Semarang	120	113	5	2	5.83%
Padang Harapan	277	265	8	2	3.61%
Jalan Gedang	255	255	0	0	0.00%
Tanjung Agung	45	45	0	0	0.00%

Figure 2 presents the spatial risk-priority map of household water-facility vulnerability in urban Bengkulu. The map shows that risk was not evenly distributed across the 12 urban villages. Surabaya was identified as a priority area because it had the highest number of high-risk facilities, while

Sidomulyo showed the highest combined proportion of moderate- and high-risk facilities. Cempaka Permai and Sukamerindu also showed important spatial vulnerability because they had relatively large numbers of high-risk facilities. This spatial pattern indicates that household water-facility risk is influenced not only by the type of water source but also by local settlement density, sanitation pressure, groundwater dependence, and the distribution of potential pollution sources around household water facilities.

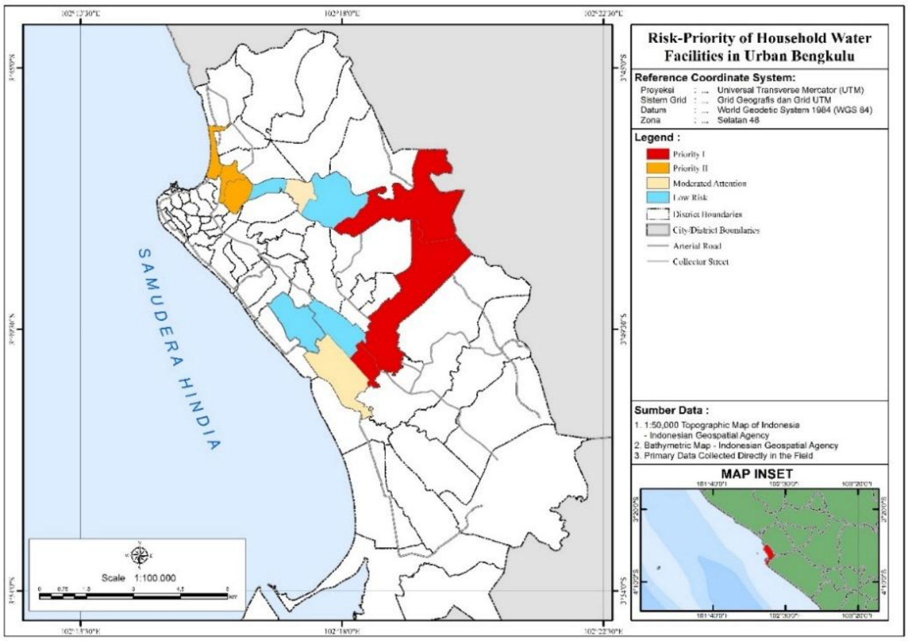

Figure 2. Spatial Risk-Priority Map of Household Water-Facility Vulnerability in Urban Bengkulu

The spatially uneven distribution of risk strengthens the importance of GIS-based interpretation in household water-safety assessment. Recent studies show that GIS combined with water-quality assessment can identify vulnerable groundwater zones, support area-based prioritization, and provide clearer information for water-resource management than tabular summaries alone [31]. Therefore, the spatial map in this study provides practical evidence for prioritizing Surabaya, Sidomulyo, Cempaka Permai, and Sukamerindu as areas requiring more intensive monitoring and sanitation intervention.

The spatial pattern of risk across urban villages confirms that household water-safety problems are strongly influenced by local context. Household and environmental factors, such as source type, sanitation conditions, domestic-waste management, facility construction quality, proximity to septic tanks or other pollution sources, and settlement characteristics, may contribute to variation in groundwater quality across areas. Household groundwater quality in Indonesia is influenced by household and environmental variables; therefore, strategies for controlling water-quality risks should be adapted to local conditions [1].

This finding is also consistent with other studies emphasizing that the coexistence of household groundwater use and on-site sanitation systems can increase pollution risk, particularly in dense urban residential areas with inadequate water-source protection [23]. Therefore, areas with high numbers of cases require problem-burden-based interventions, whereas areas with high risk proportions require vulnerability-concentration-based interventions through spatial risk mapping, routine sanitary inspection, periodic water-quality testing, facility improvement, and strengthened household education on water-source protection.

3.5. Characteristics of Water-Quality and Sanitation Parameters

Overall, the median TDS value of 123 mg/L and median EC value of 200 µS/cm indicate that most water samples had dissolved-solids content and electrical conductivity within the low-to-moderate range. The median pH value of 6.80 indicates that the water tended to be near neutral, whereas the mean water temperature of 30.34°C reflects water-temperature characteristics commonly found in tropical regions (Table 6). Physicochemical parameters such as TDS, EC, pH, temperature, and turbidity are important initial indicators in assessing water-quality characteristics, because they can describe dissolved-mineral levels, chemical stability, environmental influences, and potential changes in water quality in household sources.

Table 6. Descriptive Statistics of Water-Quality and Sanitation Parameters

Parameter	Mean	Median	Minimum	Maximum
TDS	150.18	123.00	2.33	1,934.00
EC	245.30	200.00	7.36	3,823.00
pH	6.58	6.80	3.00	10.60
Temperature	30.34	30.40	20.00	43.20
Distance to septic tank	11.23	10.00	1.00	50.00
Well depth	7.38	7.00	1.00	20.00

In addition to descriptive statistics, selected water-quality parameters were compared with the quality standards stated in Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023. This comparison was conducted to determine the percentage of samples that met and did not meet the required standards. The assessed parameters included TDS, pH, turbidity, and odor because these parameters are directly related to the physicochemical and organoleptic acceptability of household water.

Table 7. Compliance of Household Water-Quality Parameters with Regulation of the Minister of Health No. 2 of 2023

Parameter	Standard	Meeting Requirements	Not Meeting Requirements/TMS
TDS	<300 mg/L	2,571 (92.75%)	201 (7.25%)
pH	6.5–8.5	1,533 (55.30%)	1,239 (44.70%)
Turbidity	<3 NTU	2,558 (92.28%)	214 (7.72%)
Odor	Odorless	2,647 (95.49%)	125 (4.51%)

The compliance analysis showed that most household water samples met the required standards for TDS, turbidity, and odor. A total of 201 samples (7.25%) did not meet the TDS standard, 214 samples (7.72%) did not meet the turbidity standard, and 125 samples (4.51%) did not meet the odor requirement. The highest non-compliance was found in pH, where 1,239 samples (44.70%) were outside the required range of 6.5–8.5. This finding indicates that pH imbalance was the most prominent regulatory non-compliance issue among household water facilities in urban Bengkulu. Therefore, reporting the percentage of Not Meeting Requirements/TMS samples provides a clearer regulatory interpretation than presenting only mean and median values.

The regulatory compliance results provide a stronger interpretation than descriptive statistics alone. Although the median TDS and pH values appeared relatively acceptable, the TMS analysis showed that 44.70% of samples did not meet the pH requirement. This contrast shows that mean and median values may mask a substantial proportion of non-compliant samples. Recent groundwater studies indicate that pH, TDS, EC, turbidity, and related hydrochemical parameters are important indicators for identifying groundwater suitability and potential quality deterioration [32-34].

Therefore, the high proportion of pH non-compliance should be considered an important monitoring signal in urban Bengkulu, even when other parameters such as TDS, turbidity, and odor show lower non-compliance percentages.

Although most physicochemical values were within a relatively acceptable range, these results cannot be used as the sole basis for concluding household water safety. Physicochemical parameters more strongly describe the general condition of water at the time of measurement, whereas contamination risk, particularly microbiological contamination, is greatly influenced by sanitation conditions, facility construction, protection of water sources, and the presence of pollution sources around the location. Therefore, interpretation of TDS, EC, pH, temperature, and turbidity should be combined with sanitary inspection to produce a more comprehensive risk assessment. An integrated approach combining water-quality testing and identification of sanitary risk factors is important for determining monitoring priorities, corrective actions, and sustainable protection of household water facilities [35].

3.6. Differences in Water-Quality Parameters by Facility Type

The Kruskal-Wallis test showed significant differences in TDS, EC, pH, and temperature according to the type of water facility used by households. Bore wells or deep groundwater had higher median TDS and EC values than piped/tap water and dug wells, whereas piped/tap water showed the lowest median TDS and EC values among all facility types (Table 8). These differences indicate that physicochemical water characteristics are influenced by the type and origin of the water source. Deep groundwater generally has a longer contact time with soil layers and geological materials, allowing mineral dissolution and dissolved ions to increase TDS and EC values. In contrast, piped/tap water tends to have undergone more controlled treatment and distribution processes, resulting in relatively lower dissolved-solids content and electrical conductivity.

The significant differences in TDS, EC, pH, and temperature among facility types indicate that water-source origin influences physicochemical water characteristics. Recent groundwater-quality studies confirm that dissolved solids and electrical conductivity are strongly affected by mineral dissolution, aquifer material, recharge processes, and anthropogenic inputs [36-37]. However, higher TDS and EC values in bore wells or deep groundwater do not automatically indicate unsafe water; instead, they may reflect source-specific hydrochemical characteristics. Thus, differences among facility types should be interpreted together with regulatory compliance, sanitary inspection, and local hydrogeological context.

Table 8. Summary of Water-Quality Parameters by Facility Type

Parameter	Piped/tap water	Bore wells/deep groundwater	Dug wells	Test result
TDS	92.00	150.00	121.00	$p < 0.001$
EC	163.00	249.00	203.00	$p < 0.001$
pH	6.71	6.90	6.65	$p < 0.001$
Temperature	30.50	30.00	30.50	$p < 0.001$

Higher TDS and EC values in deep groundwater do not necessarily indicate that the water is unsuitable for use; instead, they reflect differences in chemical composition among water-source types. TDS and EC are more appropriately understood as initial indicators describing dissolved-mineral content, relative salinity, and ionic characteristics of water. Therefore, differences in values across facility types should be interpreted carefully by considering hydrogeological context, source conditions, treatment systems, and possible environmental influences around the source. Periodic monitoring remains necessary because changes in TDS, EC, pH, and temperature may serve as early indications of water-quality changes caused by either natural processes or domestic and environmental activities surrounding the water source [38].

3.7. Relationship between Physical Water Conditions and Risk Categories

The analysis showed that physical water indicators, namely turbidity, odor, taste, and color, were significantly associated with increased risk categories of household water facilities. Among these organoleptic indicators, odor showed the strongest association with risk category, as indicated by a Cramer's V value of 0.203. In addition, well-floor condition was also significantly associated with risk category (Table 9). This finding suggests that changes in physical water characteristics and facility construction conditions, particularly well-floor condition, can serve as important markers of potential water-quality disturbance and increased sanitary risk in household water facilities.

The significant association of turbidity, odor, taste, and color with risk categories suggests that organoleptic indicators remain useful for initial household water screening. These indicators are important because they are directly observable by residents and may reflect suspended particles, organic matter, source disturbance, or possible contamination pathways. Recent groundwater-quality studies include turbidity and other physicochemical parameters as important indicators because they may reflect changes in water quality and source protection [39-40]. However, organoleptic indicators cannot replace laboratory testing because visually acceptable water may still contain microbiological contaminants. Therefore, organoleptic complaints should not be treated only as aesthetic problems, but also as early signals for sanitary inspection and further water-quality testing.

Table 9. Association between Physical Water Indicators and Risk Categories

Variable	Chi-square test result	p-value	Interpretation
Turbidity	chi-square = 97.089	$p < 0.001$	Significant association
Odor	chi-square = 114.544	$p < 0.001$	Significant association
Taste	chi-square = 11.985	$p = 0.002$	Significant association
Color	chi-square = 55.528	$p < 0.001$	Significant association
Well floor	chi-square = 6.854	$p = 0.032$	Significant association

Organoleptic indicators, such as turbid, odorous, flavored, or colored water, are important early signals in assessing water-quality risk. These conditions may reflect disturbances in water quality caused by organic matter, dissolved minerals, microbiological activity, environmental pollution, or contaminant entry from the area surrounding the source. Although organoleptic examination cannot replace laboratory analysis, it remains practically valuable for the early identification of water facilities that may be problematic. Therefore, water facilities with complaints of odor, taste, color, turbidity, or noncompliant well-floor conditions should be prioritized for further sanitary inspection, water-quality testing, and improvement of construction and source protection [41-42].

3.8. Relationship between Numerical Parameters and Risk Categories

The Kruskal-Wallis test showed significant differences in TDS and temperature values according to household water-facility risk categories, whereas EC and pH did not show significant differences among risk categories (Table 10). This finding indicates that not all physicochemical parameters have the same sensitivity in distinguishing risk levels of water facilities. TDS and temperature may reflect variation in source characteristics, surrounding environmental influences, mineral dissolution processes, and physical water conditions at the time of measurement. In contrast, the nonsignificant results for EC and pH indicate that sanitary risk is not always directly reflected by all physicochemical parameters, particularly because contamination risk can also be influenced by microbiological factors, facility construction, and environmental conditions around the water source. Therefore, physicochemical parameters such as TDS, EC, pH, and temperature should be understood as initial water-quality indicators that must be interpreted together with sanitary inspection results and water-source characteristics [43].

The significant differences in TDS and temperature across risk categories indicate that some physicochemical parameters may respond to source characteristics and environmental conditions. However, the nonsignificant differences in EC and pH show that not all chemical indicators are equally sensitive to sanitary risk. This contradictory pattern reinforces the argument that sanitary risk is not always directly reflected by numerical parameters alone. Recent evidence shows that temperature and rainfall-related environmental variability can influence drinking-water quality and contamination risk [44-46]. Therefore, field measurements of TDS, temperature, pH, and EC should be interpreted together with sanitary inspection, facility condition, and surrounding environmental context rather than as independent indicators of water safety.

Table 10. Differences in Water-Quality Parameters by Risk Category

Parameter	Test result	p-value	Interpretation
TDS	H = 12.331	p = 0.002	Significantly different
EC	H = 1.188	p = 0.552	Not significantly different
pH	H = 0.367	p = 0.832	Not significantly different
Temperature	H = 16.499	p < 0.001	Significantly different

Spearman correlation analysis showed that the distance to the septic tank had a significant negative relationship with risk category, with rho = -0.250 and $p < 0.001$. This means that the farther the septic tank is from the water source, the lower the tendency for a water facility to fall into a higher risk category. This finding is consistent with environmental sanitation principles stating that proximity between domestic pollution sources and water sources can increase the likelihood of contaminant entry, especially in shallow groundwater-based facilities such as dug wells.

Nevertheless, septic-tank distance cannot be interpreted as the sole determinant of risk, because contamination potential is also influenced by well-construction quality, well-floor and curb conditions, the presence of covers, groundwater-table depth, groundwater-flow direction, soil permeability, rainfall, residential density, and local hydrogeological characteristics. Accordingly, risk assessment of water facilities should use an integrated approach that combines information on the distance to pollution sources, sanitary inspection, construction conditions, physicochemical parameters, and microbiological testing. This approach is important because the relationship between sanitary-inspection factors, distance to pollution sources, and groundwater contamination may differ according to water-facility type and local context [8].

3.9. Dominant Factors Associated with Increased Risk

Ordinal logistic regression results indicated that water odor was the factor most strongly associated with an increase in the risk category of household water facilities. Water facilities with odor had approximately 4.58 times greater odds of being in a higher risk category than facilities without odor. In addition, turbid water was also associated with increased odds of risk, at 2.57 times. By facility type, dug wells had 1.62 times greater odds of being classified into a higher risk category compared with piped/tap water, whereas bore wells or deep groundwater had 1.31 times greater odds (Table 11). These findings indicate that directly observable physical indicators, particularly odor and turbidity, play an important role as early signals for identifying water facilities that may experience quality disturbances and higher sanitary risk [47-48].

The regression results show that odor and turbidity were stronger predictors of higher risk than several numerical parameters. This finding indicates that direct physical changes in water may provide practical warning signs for identifying facilities that require further attention. Recent water-quality studies show that physical and physicochemical indicators can help identify potential water-quality deterioration and guide further monitoring [49], [50]. However, odor and turbidity should be interpreted as screening indicators, not as definitive evidence of microbiological contamination.

Therefore, odor and turbidity can be used as practical field indicators for prioritizing household water facilities that require more detailed laboratory testing and sanitary improvement.

Table 11. Ordinal Logistic Regression Results for Water-Facility Risk Factors

Variable	Odds ratio	p-value	Interpretation
Turbid water	2.57	$p < 0.001$	Increases the odds of higher risk
Odorous water	4.58	$p < 0.001$	Increases the odds of higher risk
Bore wells/deep groundwater	1.31	$p = 0.007$	Higher risk than piped/tap water
Dug wells	1.62	$p < 0.001$	Higher risk than piped/tap water
pH	0.90	$p = 0.010$	Associated with changes in risk level
Water color	1.38	$p = 0.167$	Not significant in the multivariable model
TDS	1.10	$p = 0.164$	Not significant in the multivariable model

These results indicate that increased risk in household water facilities is influenced not only by water-source type but also by a combination of field physical indicators, sanitation conditions, and facility-construction characteristics. Odorous and turbid water may reflect contamination by organic matter, microbiological activity, entry of materials from the surrounding environment, or disturbance in source protection. Although organoleptic indicators cannot replace laboratory testing, their presence is important as an initial screening basis in household water-quality surveillance. Thus, the findings support the use of an integrated approach that combines physical observation of water, sanitary inspection, identification of facility type, and water-quality testing to obtain a more comprehensive risk profile and determine intervention priorities for household water facilities [10], [18].

3.10. Determination of Priority Intervention Areas

Based on the determination of priority areas for household water-improvement interventions, Surabaya, Sidomulyo, and Cempaka Permai were assigned as Priority I areas (Table 12). Surabaya was prioritized because it had the largest number of high-risk facilities, namely 68 facilities, indicating the highest absolute problem burden. Sidomulyo was assigned as Priority I because it had a very large combined proportion of moderate and high risk, at 69.44%, indicating a dominant concentration of water-facility vulnerability in the area. Meanwhile, Cempaka Permai was also included in Priority I because it had a relatively large number of high-risk facilities and a large sample size, meaning that intervention in this area could generate a broader public-health impact. This pattern demonstrates that determining priority areas should not be based solely on the number of high-risk cases, but also on the proportion of moderate-high risk, the spatial distribution of risk, and the size of the population or number of affected facilities. This risk-based priority approach is consistent with the principle of risk-based drinking-water surveillance, which emphasizes concentrating resources in areas with greater potential hazards and public-health impacts [51-53].

The priority classification in this study shows that household water intervention should be implemented in stages according to both problem burden and vulnerability concentration. Surabaya was prioritized because it had the largest number of high-risk facilities, whereas Sidomulyo was prioritized because it had the highest combined proportion of moderate- and high-risk facilities. This difference provides an important argument that priority setting should not rely on a single indicator. Recent evidence shows that GIS-based groundwater-quality assessment can support decision-making by identifying vulnerable zones and guiding targeted monitoring [54-56]. Therefore, the designation of Priority I and Priority II areas should be used as a practical basis for staged intervention, starting from areas with the highest problem burden and the highest concentration of moderate-to-high-risk facilities.

Table 12. Priority Areas for Household Water-Improvement Interventions

Priority	Urban Village	Basis for Consideration
Priority I	Surabaya	Largest number of high-risk facilities, namely 68 facilities
Priority I	Sidomulyo	Very large combined proportion of moderate-high risk, namely 69.44%
Priority I	Cempaka Permai	Large number of high-risk facilities and large sample size
Priority II	Sukamerindu	Relatively large number of high-risk facilities, namely 29 facilities
Priority II	Kampung Kelawi	Combined proportion of moderate-high risk reaching 61.82%
Priority II	Pasar Bengkulu	Relatively high percentage of high-risk facilities, namely 13.33%

Sukamerindu, Kampung Kelawi, and Pasar Bengkulu were assigned as Priority II areas because they still showed important risk indicators that need to be controlled, although their urgency was below that of Priority I areas (Table 12). Sukamerindu had a relatively large number of high-risk facilities, namely 29 facilities, and therefore still requires targeted monitoring and facility improvement. Kampung Kelawi had a combined moderate-high risk proportion of 61.82%, indicating a concentration of vulnerability in most inspected water facilities. Pasar Bengkulu also requires attention because it had a relatively high percentage of high-risk facilities, at 13.33%. Differences in the basis for prioritization across areas indicate that household water-facility problems are spatially uneven and influenced by local context, including residential conditions, water-source type, environmental sanitation, household density, and facility maintenance practices. Therefore, intervention strategies should be implemented in stages through routine sanitary inspection, periodic water-quality testing, improvement of facility construction, water-source protection, household education, and spatial risk mapping to ensure that areas with the greatest problem burden and highest risk concentration receive appropriate priority for action [57].

Overall, the findings show that household water-facility risk in urban Bengkulu is a multidimensional issue influenced by water-source type, physicochemical characteristics, organoleptic conditions, sanitary inspection indicators, septic-tank distance, and spatial context. The results also show that apparently acceptable water-quality values do not always indicate full compliance with standards or low sanitary risk. Therefore, the main contribution of this study is the integration of physicochemical testing, sanitary inspection, regulatory compliance analysis, ordinal risk modelling, and spatial mapping to identify household water facilities and urban villages that require priority intervention. This integrated approach provides a stronger basis for household water-safety management than descriptive water-quality assessment alone.

This study has several limitations that should be acknowledged. Although the discussion refers to the possibility of fecal contamination and microbiological risks in household water facilities, this study did not directly measure microbiological parameters such as total coliform, fecal coliform, or *Escherichia coli*. Therefore, the findings should not be interpreted as direct evidence of microbiological water safety or fecal contamination. The risk classification in this study was based on physicochemical parameters, organoleptic indicators, sanitary inspection, facility characteristics, and spatial distribution. Future studies should include microbiological testing, especially E. coli analysis, to provide a more comprehensive assessment of household water safety and to validate the sanitary risk classification used in this study.

4. Conclusion

The majority of household water facilities in urban Bengkulu were categorized as low risk, with 60.89% of facilities in the low-risk category, 31.64% in the moderate-risk category, and 7.47% in the high-risk category. However, the combined proportion of moderate- and high-risk facilities reached 39.11%, indicating that household water safety remains an important environmental health concern. Risk levels varied by facility type, with dug wells showing the highest proportion of high-risk facilities at 9.75%, followed by bore wells/deep groundwater at 7.89%, and piped/tap water at 4.84%. These findings indicate that groundwater-based facilities, particularly dug wells, are more vulnerable to inadequate construction, surrounding sanitation conditions, and potential contamination sources.

Odor, turbidity, facility type, and septic-tank distance were important indicators associated with increased household water-facility risk. Odorous water had the strongest association with higher risk, followed by turbid water, while shorter septic-tank distance increased the likelihood of higher risk classification. Spatial prioritization showed that Surabaya, Sidomulyo, Cempaka Permai, Sukamerindu, Kampung Kelawi, and Pasar Bengkulu require greater intervention through routine water-quality monitoring, sanitary inspection, improvement of well construction, drainage management, and control of safe distances between water sources and septic tanks. Overall, this study emphasizes the need for risk-based household water-quality surveillance to support targeted, evidence-based, and sustainable water-safety interventions in urban Bengkulu.

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