HIGIENE: Jurnal Kesehatan Lingkungan

*Environmental Health Journal*

ORIGINAL RESEARCH

# Water Safety Plan-Based Risk Assessment of a Community Water Supply System in Ciamis, Indonesia

*Running title: Water Safety Plan Risk Assessment*

**Darwin Safiu[1]*, Muhammad Kahfi[2], Nur Rahmah[3], Iwan Suryadi[4]**

[1]Public Health Study Program, University of Siliwangi, Tasikmalaya, West Java, Indonesia

[2]Safety Enginering Study Program, Technology and Health Sciences Institute of Tri Tunas Nasional, Makassar, South Sulawesi, Indonesia

[3]Public Health Study Program, University of Alauddin Islamic State, Makassar, South Sulawesi, Indonesia

[4]Environmetal Health Study Program, Poltekkes Kemenkes Makassar, Makassar, South Sulawesi, Indonesia

***Corresponding author:** Darwin Safiu | Email: darwinsafiu@unsil.ac.id | ORCID: [0009-0003-7443-6288]

| Received | Revised | Accepted | Published |
|---|---|---|---|
| 15 October 2025 | 2 February 2026 | 2 March 2026 | 13 April 2026 |

## Abstract

**Background:** Community-managed water supply systems can be vulnerable to contamination when preventive controls are limited. **Objective:** To identify hazards, assess risk levels, and develop mitigation priorities for a community water supply system using the Water Safety Plan (WSP) approach from source to point of use. **Methods:** A mixed qualitative-quantitative case study was conducted at KKM X in Mekarjaya Village, Ciamis Regency, Indonesia. Field sanitary inspection, structured interviews with system managers, and document review were combined with semi-quantitative risk scoring using probability and impact criteria adapted from AS/NZS 4360:2004. **Results:** Six high-priority risk entries (scores 12-20) were identified, representing five major risk mechanisms because turbidity appeared at both source and distribution stages. The highest score involved upstream contamination from domestic waste and nearby septic systems (20). Other priorities were rainy-season turbidity, absence of disinfection, electricity-dependent supply interruption, and distribution-pipe leakage (12 each). **Conclusion:** WSP-based management should prioritize source protection, simple filtration, controlled chlorination, backup power, leakage control, and more frequent water-quality monitoring.

**Keywords:** Water Safety Plan; community water supply; risk assessment; drinking-water safety; waterborne disease

## Research Highlights

- WSP assessment identified six high-priority risk entries, with upstream domestic/septic contamination receiving the highest score (20).
- The risk profile linked source protection, treatment barriers, power reliability, pipeline integrity, and monitoring into a single source-to-tap assessment.
- Priority actions include source-zone protection, filtration, chlorination, backup power, leakage control, and water-quality testing every 1-3 months.

## 1 Introduction

Clean water is a fundamental and indispensable need for sustaining life and supporting daily activities. Its availability not only affects the standard of living of communities but also serves as an essential component in maintaining sanitation and environmental hygiene. However, many remote areas of Indonesia continue to face difficulties in obtaining adequate clean water. The infrastructure gap between urban and rural areas remains an obstacle to achieving the Sustainable Development Goals (SDGs) [1]. Aquifers are subsurface geological formations that store water reserves essential for wells and springs. Materials that form aquifers, such as sandstone, gravel, and limestone, function both to store and naturally filter water. A major advantage of groundwater is that its discharge is generally more stable across seasons than surface water, which is more readily affected by weather anomalies. Other alternative water-supply sources include rainwater, which can be collected and used for various purposes. Rainwater harvesting is a long-established conservation practice that remains relevant, particularly in areas experiencing water scarcity. Contemporary rainwater-harvesting technologies can substantially increase clean-water availability while reducing pressure on conventional water reserves. Desalination technology for converting seawater into freshwater has also continued to develop as an alternative water source, especially in coastal areas with freshwater deficits. Although cost and ecological impacts remain important challenges, desalination has considerable potential to contribute to solutions for the global water crisis. Drinking-water treatment is a vital process for ensuring the safety of water intended for consumption. Through processes such as filtration, disinfection, and demineralization, pathogens and contaminants can be removed. A properly functioning treatment system can transform water that is initially unsuitable for consumption into drinking water that meets health standards and can be consumed safely. Public understanding of the importance of hygienic drinking water must also be continuously strengthened. Education regarding reliable water sources, appropriate storage methods, and the importance of treating or disinfecting water before consumption is an essential step in preventing waterborne diseases [2].

Water is a basic human need that is vital for survival, health, and ecosystem functioning. The provision of clean and hygienic water is not merely a fundamental right but also a central pillar of sustainable development. The importance of clean-water provision is especially pronounced in areas facing water scarcity or contamination, where health problems, including waterborne diseases, may become more severe. Access to clean water remains a major challenge in many parts of the world, particularly in developing countries where public infrastructure remains inadequate and socioeconomic factors limit community access to essential public services [3]. Health problems associated with poor water sanitation continue to represent a major global concern. One of the most evident consequences of poor water quality is acute diarrhea, with incidence patterns that may fluctuate in urban areas and their surroundings. This condition can be life-threatening because, in addition to gastrointestinal disturbance, it can cause severe dehydration when treatment is delayed. Water supplies contaminated by pathogens or bacteria are an important route through which disease can be transmitted from the environment to the human body. In densely populated settlements, clean-water quality may fail to meet health standards because domestic wastewater can infiltrate community groundwater sources. Poorly controlled environmental conditions may therefore contribute to an increase in water-related infectious diseases and other serious health threats [3].

Clean water and adequate sanitation are fundamental to public health. Without these services, disease transmission can occur more rapidly, particularly in densely populated environments. Adequate fulfillment of clean-water and sanitation needs strongly influences quality of life. Communities with sufficient access to both services generally have better physical health, higher productivity, and improved living standards. Effective clean-water management also contributes to maintaining ecosystem resilience. Conserving water resources and protecting their quality are therefore essential measures for sustaining environmental continuity [4].

Internationally, Sustainable Development Goal 6.1 targets universal access to safe drinking water, making the provision and monitoring of drinking-water quality essential [5]. Water is indispensable for human survival, and the availability of clear and potable water is critical for protecting public health. In many countries, including Indonesia, poor drinking-water sanitation is an important contributor to infectious diseases such as diarrhea, cholera, and typhoid, which can substantially affect community quality of life [6]. Community-based communal water-supply systems play a crucial role in expanding access to adequate drinking water in semi-urban and rural areas of Indonesia. Water used by communities must meet safety criteria for physical, chemical, and microbiological quality. Failure to control the safety of water-supply systems can increase the risk of contamination by pathogenic microorganisms, which may contribute to diarrhea, skin diseases, and gastrointestinal infections as waterborne health outcomes [7]. The most effective approach to continuously ensuring drinking-water safety is a comprehensive assessment and management system that monitors the entire process from water abstraction to delivery to consumers. This approach is referred to as a Water Safety Plan (WSP), or Rencana Pengamanan Air Minum (RPAM) in Indonesia [8].

KKM X is a community-based communal water provider in Mekarjaya Village, Ciamis Regency, West Java, that operates two Pamsimas units serving 280 household connections, public facilities, and micro, small, and medium enterprises. Raw water is abstracted from a deep borewell; however, the borewell depth was not specified in the source manuscript. Although the system has operated for a considerable period, it faces important challenges, including deterioration of physical water quality in the form of increased turbidity during the rainy season, vulnerability to contamination in the area surrounding the borewell, and the absence of a standardized chemical treatment process before water is distributed to consumers. To minimize health risks, the World Health Organization recommends the Water Safety Plan (WSP), also referred to in Indonesia as the Rencana Pengamanan Air Minum (RPAM) [9]. The WSP emphasizes comprehensive and preventive risk assessment across the entire water-supply chain, from the catchment, treatment, storage, and distribution stages to the point of use. The principal benefits of WSP implementation include risk mitigation and cost efficiency, improved customer satisfaction, and better coordination and monitoring. The approach can also support improvements in treatment practices, minimize waterborne disease risks, ensure drinking-water safety, and improve public health more broadly [10]. Accordingly, this study was conducted to analyze critical points along the KKM X water-supply chain and to develop a draft mitigation and improvement plan that is technically and managerially applicable.

## 2 Materials and Methods

### 2.1 Study design and setting

This study used a descriptive mixed qualitative-quantitative case-study design with a semi-quantitative risk-assessment framework based on the World Health Organization Water Safety Plan concept and the AS/NZS 4360:2004 risk-management approach [9,11]. The assessment was conducted at KKM X, a community-managed water supply facility in Mekarjaya Village, Ciamis Regency, West Java, Indonesia.

### 2.2 Study unit, sampling, and assessment scope

The unit of analysis was the community water supply system itself rather than a population sample; therefore, no population-based sample-size calculation was performed. The assessment followed the supply system from source to point of use and covered five functional compartments: catchment/intake, treatment, storage, distribution, and point of use. Field assessment included the borewell and pump, transmission lines, reservoir, distribution network across three hamlets, and consumer taps. Operational information was obtained from KKM management personnel involved in system operation and maintenance.

### 2.3 Variables and measurements

Data were collected using three complementary techniques. First, a sanitary inspection was conducted to assess the physical condition of the borewell, pump and transmission system, reservoir, distribution pipelines, and selected consumer endpoints. Second, structured interviews with KKM managers explored operational history, daily service continuity, technical disruptions such as electricity outages and pipe leakage, tariff administration, and customer complaints about water quality. Third, document review covered available draft standard operating procedures, the system flow diagram, and records of periodic laboratory testing, which the source manuscript reported as being conducted at six-month intervals.

The WSP assessment was organized into four steps: (1) mapping the source-to-tap water supply chain; (2) identifying actual and potential hazardous events and physical, chemical, or microbiological hazards in each system compartment; (3) scoring the probability and health/operational impact of each hazard; and (4) developing a mitigation and improvement plan comprising technical controls, operational-management measures, monitoring, and verification activities.

### 2.4 Risk scoring and data analysis

Risk was scored semi-quantitatively as the product of probability (P) and impact (I): Risk score = P x I. Probability was rated from 1 (very rare) to 4 (frequent or continuous), whereas impact was rated from 1 (minor or insignificant) to 5 (catastrophic or very severe public-health impact). Scores of 1-4 were classified as low risk, 5-9 as medium risk, and 10-20 as high-priority risk. Observational, interview, and documentary findings were integrated to justify the assigned scores and to formulate prioritized control measures. No inferential statistical analysis was performed.

## 3 Results

### 3.1 Water supply system mapping

KKM X has operated a community water supply system since 2016. The system initially used a spring with simple filtration and subsequently shifted to a deep borewell to accommodate increasing demand. The source-to-tap chain consisted of five compartments. At the catchment/intake stage, groundwater was pumped from the borewell using an electric pump. At the treatment stage, no physical filtration or chemical disinfection/chlorination unit was reported; raw water was conveyed directly to the storage reservoir. The storage stage used a covered concrete reservoir that was reportedly cleaned every three months. Water was then distributed through pipelines to three hamlets in Mekarjaya Village. At the point of use, the system served 280 connections comprising households, a mosque, a school, and small enterprises.

### 3.2 Hazard identification and risk prioritization

The integrated field assessment identified eight risk entries across the source, treatment, production, storage, distribution, and monitoring components (Table 1). Six entries were classified as high priority and two as medium priority. The highest score (20) was assigned to potential pathogenic microbial and domestic-waste contamination at the raw-water source. Five additional high-priority entries received scores of 12: rainy-season turbidity at the source, absence of disinfection, electricity-dependent interruption of pumping, pipeline leakage with potential secondary contamination, and downstream distribution of turbid water. Because turbidity was represented at both source and distribution stages, these six high-priority entries corresponded to five major risk mechanisms in the overall risk profile.

**Table 1. Hazard identification and semi-quantitative risk assessment for the KKM X community water supply system**

| No. | Hazard / hazardous event | System component | Main cause | P | I | Score | Priority | Health and operational rationale |
|---|---|---|---|---|---|---|---|---|
| 1 | Pathogenic microbial and domestic-waste contamination | Raw-water source (intake) | Solid-waste accumulation near the borewell and nearby septic systems not meeting the stated safe-separation requirement | 4 | 5 | 20 | High | Potential fecal infiltration into the source and increased risk of diarrheal disease outbreaks |
| 2 | High turbidity | Raw-water source (intake) | Surface/rainwater infiltration associated with leakage or inadequate protection of the borewell structure | 4 | 3 | 12 | High | Reduced physical acceptability and transport/protection of microorganisms by suspended particles |
| 3 | Persistent survival of pathogenic microorganisms | Treatment | Absence of a raw-water disinfection/chlorination facility | 3 | 4 | 12 | High | Water is distributed without a microbiological inactivation barrier, allowing pathogens to reach consumers |
| 4 | Complete/intermittent supply interruption | Production (pump) | Full dependence of the pumping system on grid electricity | 4 | 3 | 12 | High | Power outages stop water production and interrupt service continuity |
| 5 | Secondary environmental contamination | Distribution (pipeline) | Pipeline leakage associated with heavy vehicle loads and excavation activities | 3 | 4 | 12 | High | Negative pressure at leaks may draw contaminated soil water into the distribution system |
| 6 | Distribution of visibly turbid water | Distribution (pipeline) | Upstream turbid water is conveyed without additional settling or treatment | 4 | 3 | 12 | High | Turbidity is carried to consumers and reported as an aesthetic/quality complaint |
| 7 | Delayed detection of contamination | Monitoring | Laboratory water-quality testing is performed only every six months | 2 | 4 | 8 | Medium | Sudden contamination may remain undetected between scheduled sampling events |
| 8 | Sediment-related deterioration of water quality | Storage (reservoir) | Sediment accumulation and an insufficiently frequent reservoir-cleaning interval | 2 | 3 | 6 | Medium | Potential sludge accumulation at the reservoir base and reduced effective storage condition |

*Note: P = probability; I = impact. Risk score = P x I. Low = 1-4; medium = 5-9; high priority = 10-20. Source data were processed from the 2026 field report.*

### 3.3 Mitigation and improvement plan

The proposed improvement plan combined physical-engineering controls with operational management and community participation (Table 2). Technical priorities included protecting the borewell perimeter, controlling rainy-season turbidity, introducing controlled chlorination, securing backup electrical power, and improving the integrity of distribution pipelines. Management priorities included increasing laboratory monitoring from six-monthly testing to every 1-3 months, increasing reservoir cleaning from every three months to every 1-2 months, and developing a formal disinfection SOP. Community-level actions included hygiene and environmental-sanitation education and a rapid leakage-reporting channel.

**Table 2. Proposed technical and managerial risk-mitigation plan for KKM X**

| Intervention category | Target risk | Proposed mitigation action | Success indicator | Monitoring / verification |
|---|---|---|---|---|
| Technical engineering | Upstream contamination and septic systems | Clean the borewell perimeter; establish a protected sanitary zone; relocate or provide watertight containment for nearby septic systems that violate the stated 10-m safety radius | Borewell structure and protection zone isolated from external contamination | Visual sanitary inspection of the source area monthly by KKM personnel |
| Technical engineering | Rainy-season turbidity | Raise and improve the borewell apron; install simple multimedia filtration before the reservoir | Raw-water turbidity consistently meets the applicable physical requirement | Routine turbidity measurement using a portable turbidimeter |
| Technical engineering | Absence of disinfection | Install an automatic chlorine feeder; apply a controlled chlorine dose | Water samples negative for Escherichia coli and total coliforms | Daily free-residual-chlorine testing at the distal distribution point; source target: 0.2-0.5 mg/L |
| Technical engineering | Electricity outage | Provide an automatic backup generator sized to the pump demand | Water-supply continuity maintained during power interruptions | Generator maintenance and fuel-use logbook |
| Technical engineering | Distribution leakage | Replace damaged segments with mechanically resistant HDPE pipe; stabilize pipeline pressure zones | Non-Revenue Water reduced to below 15% | Monthly water-balance audit comparing the reservoir master meter with aggregate customer meters |
| Management strategy | Maintenance and monitoring quality | Increase laboratory water-quality testing from every 6 months to every 1-3 months; clean the reservoir every 1-2 months; develop a formal disinfection SOP handbook | Standardized and documented operational compliance within KKM | Annual internal audit and review of customer-complaint records |
| Community empowerment | Low public participation | Provide hygiene/healthy-behavior education and environmental-sanitation communication around the source-protection area; establish a WhatsApp-based rapid leakage-reporting channel | Increased active participation and leakage-response time <24 hours | Monthly summary of community reports and resolved complaints |

*Note: HDPE = high-density polyethylene; NRW = Non-Revenue Water; SOP = standard operating procedure. The mitigation matrix is a proposed improvement plan and was not evaluated as an implemented intervention in the source study.*

## 4 Discussion

The WSP-based assessment identified a risk profile extending across the entire community water supply chain. Six entries were classified as high priority, but these represented five principal risk mechanisms because turbidity was identified both at the source and again as a downstream distribution consequence. The highest-priority condition was potential microbial contamination of the raw-water source from surrounding domestic waste and septic systems. The remaining major risks involved turbidity, lack of disinfection, dependence on electricity for pumping, and distribution-pipe leakage. These findings illustrate the central WSP principle that water safety depends on multiple preventive barriers rather than on a single treatment or end-point test [8,9].

The absence of a disinfection barrier is particularly important from a public-health perspective. Where raw water may be exposed to environmental contamination, direct transmission to the distribution system leaves little protection against microbial hazards. Indonesian environmental-health requirements and drinking-water safety guidance emphasize microbiological safety and routine monitoring, while WSP-oriented practice treats disinfection as one component of a broader multiple-barrier system [7,9]. The source literature also highlights periodic microbiological testing for indicator organisms such as Escherichia coli and coliforms as part of operational assurance [12].

Distribution integrity represents a second critical barrier. Pipeline leakage may not only reduce service efficiency but also permit ingress of contaminated water or soil when internal pressure falls. Previous Indonesian evidence on water-supply losses has identified pipe leakage, damaged meters, non-standard connections, and operational factors as important contributors to water loss [13]. For KKM X, rapid leak detection, pressure management, replacement of vulnerable pipe segments, and routine water-balance auditing are therefore relevant both for service efficiency and for public-health protection.

The source-protection findings also support the need to manage sanitation conditions around the borewell. Nearby septic systems and accumulated solid waste can create pathways for fecal contamination, particularly when the structural protection of the water source is inadequate. Evidence from well-water studies in Indonesia similarly shows that environmental sanitation and separation from fecal-contamination sources are important determinants of microbiological water quality [14]. Source protection should therefore precede or accompany downstream treatment rather than being treated as a separate environmental issue.

Monitoring frequency is another practical weakness. Six-monthly laboratory testing may not detect short-duration contamination events between scheduled sampling dates. WSP implementation reviews emphasize the value of continuous or frequent operational monitoring combined with periodic verification testing, because risk management depends on timely detection of control failure [5,8,10]. In a community-managed system with limited resources, a tiered monitoring strategy can combine simple operational indicators, such as turbidity and free residual chlorine, with scheduled laboratory microbiological and chemical testing.

The proposed mitigation matrix translates the risk assessment into a staged improvement plan that combines infrastructure, operating procedures, monitoring, and community participation. This is consistent with the broader WSP literature, which describes benefits related to risk reduction, operational coordination, and more systematic water-safety management when preventive controls are maintained over time [10]. Nevertheless, the present study was a single-system case assessment based on sanitary inspection, interviews, document review, and semi-quantitative scoring. The provided source manuscript did not report independent post-assessment laboratory results, measured disease outcomes, or evaluation after implementation of the proposed controls. Consequently, the mitigation measures should be interpreted as prioritized recommendations rather than evidence that the intervention has already reduced waterborne disease or improved customer satisfaction.

## 5 Conclusion

The Water Safety Plan-based assessment of KKM X identified eight risk entries, including six high-priority entries representing five major risk mechanisms across source protection, treatment, pumping, distribution, and water-quality control. Upstream microbial contamination associated with domestic waste and nearby septic systems received the highest risk score (20), while rainy-season turbidity, absence of disinfection, electricity-dependent service interruption, and distribution leakage were major priorities with scores of 12. The proposed improvement plan prioritizes borewell protection, simple filtration, controlled chlorination, backup power, pipeline-leakage control, formal operating procedures, and more frequent water-quality monitoring. Implementation should be followed by documented operational verification and water-quality testing to determine whether risk levels are effectively reduced.

## 6 Declarations

### Ethics approval and consent to participate

This research does not involve medical interventions on humans or animals. Approval for observation and data collection is based on official permission from the Regional Drinking Water Company Tirta Sukapura, Tasikmalaya Regency

### Consent for publication

Not Applicable

### Funding

This research was conducted independently by the research team without receiving any specific grants from any funding agency

### Competing interests

The authors declare no financial or non-financial conflicts of interest in the publication of this article

### Author contributions (CRediT)

Conceptualization, D.S. and M.K.; Methodology, D.S., R.J., N.R.; Investigation, D.S., M.K., and I.S.; Formal Analysis, R.J and N.R.; Writing – Original Draft, D.S., R.J., M.K.; Writing – Review & Editing, R.J; Supervision, M.K.

### Data availability

Data supporting this research is available from the corresponding author upon reasonable request.

### Acknowledgments

The author would like to thank the leadership and technical staff of the Tirta Sukapura Regional Drinking Water Company (PERUMDA) in Tasikmalaya Regency and the Department of Public Health, Siliwangi University, for their support during the research.

### Generative AI statement

Generative AI was used to assist with English-language translation, language editing, structural reorganization, consistency checking, and manuscript formatting. The authors reviewed the output and remain responsible for the accuracy, originality, citations, and integrity of the manuscript.

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