

QUALITY SURVEILLANCE OF REFILL DRINKING WATER DEPOTS IN INDONESIA: A LABORATORY EVALUATION FOR SDG 6

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Abstract

Safe drinking water is a fundamental human need and a key indicator for achieving Sustainable Development Goal (SDG) 6, particularly Target 6.1 on universal access to safe and affordable drinking water. In Indonesia, Refill Drinking Water Depots (Depot Air Minum Isi Ulang/DAMIU) have rapidly expanded as an affordable and accessible alternative to bottled water and municipal supplies. However, studies show that many DAMIU do not comply with health standards under Minister of Health Regulation No. 43/2014 on depot sanitation and Regulation No. 2/2023 on drinking water quality. This study aims to develop an evaluation quality surveillance system for DAMIU based on health laboratory testing and local policy analysis. A mixed-methods evaluative approach was applied, using laboratory testing of physical, chemical, and microbiological parameters and sanitation observations with standardized checklists. Secondary data were obtained from local health office reports, regulations, and academic literature. The study covered four geographic and regulatory settings: Dumai, Jambi, Makassar, and Yogyakarta. The findings show that most DAMIU do not fully comply with national drinking water quality standards. Physical parameters, including pH and Total Dissolved Solids (TDS), were generally acceptable. However, excessive iron (Fe) and manganese (Mn) concentrations were found in Jambi and Dumai, mainly due to raw water characteristics. Microbiological contamination by Total Coliform and *Escherichia coli* was widespread in Makassar and Yogyakarta, associated with inadequate UV lamp maintenance, improper micro-filter calibration, and poor operator hygiene. Sanitation and operator certification were also inadequate. Institutional monitoring coordination remained weak, while public health laboratories (Labkesmas) were not fully integrated into routine surveillance. This study concludes that DAMIU surveillance should integrate accredited laboratories, local governments, and community participation to support local policy development and advance SDG 6 in Indonesia.

Keywords: DAMIU; drinking water quality monitoring; health laboratory; local policy; SDG 6; surveillance model.



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1. Introduction

1.1. Background and Global Context (SDG 6)

Access to safe, clean, and affordable drinking water is a fundamental human right and a core pillar of global public health. In 2015, the United Nations established the Sustainable Development Goals (SDGs), with Goal 6 aiming to "ensure availability and sustainable management of water and sanitation for all" by 2030 (United Nations, 2015). Specifically, Target 6.1 calls for universal and equitable access to safe and affordable drinking water.

Achieving this target requires not only raw water availability but also robust supply networks and rigorous quality assurance systems capable of preventing waterborne illnesses such as cholera, dysentery, typhoid, and chronic heavy metal toxicity (WHO, 2022).

In many rapidly urbanizing developing nations, centralized municipal water supply infrastructure (e.g., Perusahaan Daerah Air Minum / PDAM in Indonesia) struggles to keep pace with demographic growth, industrial expansion, and spatial sprawl (Tortajada & Biswas, 2018). As a result, millions of households rely on decentralized, small-scale water service providers to meet daily domestic consumption needs. While these informal or semi-formal systems fill a critical supply gap, they often operate under fragmented regulatory oversight, creating significant vulnerabilities in drinking water safety (Sorenson et al., 2012).

1.2. The Expansion of DAMIU in Indonesia

In Indonesia, decentralized drinking water provision is dominated by Refill Drinking Water Depots, locally known as Depot Air Minum Isi Ulang (DAMIU). Over the past two decades, DAMIU have expanded rapidly across urban, sub-urban, and rural areas. This growth is driven primarily by economic factors: refill water from DAMIU costs significantly less—often 4 to 5 times cheaper—than major commercial branded bottled water (Air Minum Dalam Kemasan / AMDK), while being far more convenient than boiling tap or well water at home (Sudarmi et al., 2020).

For low- and middle-income households, DAMIU represent a vital socio-economic mechanism for obtaining drinking water. However, the rapid proliferation of DAMIU has outpaced the institutional and regulatory capacity of local governments to monitor and enforce quality standards. Thousands of depots operate with basic filtration systems—typically consisting of silica sand filters, activated carbon, micro-filters (1 to 5 microns), and ultraviolet (UV) or ozone disinfection units—without routine maintenance or professional oversight (Effendi et al., 2021).

1.3. Regulatory Frameworks and Compliance Challenges

To ensure public safety, the Indonesian Ministry of Health (Kementerian Kesehatan) has established legal frameworks governing DAMIU operations:

1. Minister of Health Regulation No. 43/2014 (Permenkes No. 43/2014): Defines health, sanitation, and hygiene requirements for drinking water depots, specifying structural standards, equipment calibration, container washing protocols, and mandatory health checks for operators.
2. Minister of Health Regulation No. 2/2023 (Permenkes No. 2/2023): Sets updated national environmental health and drinking water quality standards, replacing earlier regulations (Permenkes No. 492/2010). It establishes strict maximum allowable limits for physical, chemical, and microbiological parameters in water intended for human consumption.

Despite these regulations, national and regional evaluations reveal widespread non-compliance. DAMIU frequently fail both physical-chemical parameters and microbiological criteria (Putri & Kusuma, 2019). The causes are multifaceted: raw water sources are often contaminated at the origin; filtration equipment is rarely serviced according to technical specifications; operator hygiene is minimal; and municipal health offices (Dinas Kesehatan) face severe budget and manpower constraints that limit routine inspections.

1.4. Research Problem and Objectives

While numerous localized studies have evaluated DAMIU quality within individual municipalities, comprehensive cross-regional studies that combine multi-parameter laboratory diagnostics with local institutional and policy analyses remain scarce. Water quality hazards vary geographically based on hydrogeology (e.g., peatlands vs. volcanic aquifers) and local governance strength.

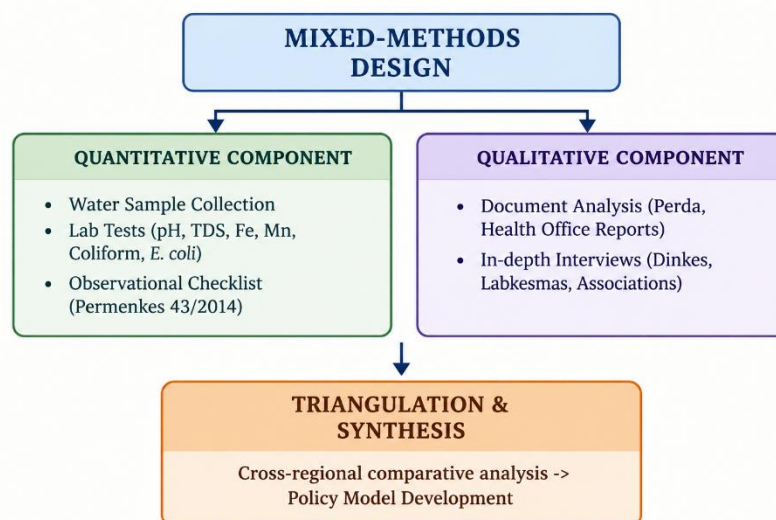
Therefore, this study aims to:

1. Evaluate the physical, chemical, and microbiological compliance of DAMIU drinking water across four geographically diverse regions in Indonesia: Dumai, Jambi, Makassar, and Yogyakarta.
2. Assess operational sanitation and hygiene practices at the depot level in accordance with Permenkes No. 43/2014.
3. Analyze local institutional oversight, regulatory frameworks, and public health laboratory integration.
4. Develop an Evaluation Quality Surveillance that connects health laboratories, municipal governments, depot operators, and community participation to support SDG 6 targets.

2. Method

2.1. Research Design

This study utilized an evaluative, convergent parallel mixed-methods design, combining quantitative empirical laboratory testing with qualitative institutional and policy assessments (Creswell & Creswell, 2018). The quantitative component measured specific physical, chemical, and microbiological water quality parameters and quantified sanitation compliance scores. The qualitative component evaluated governance structures, inter-agency coordination, and local regulatory frameworks (*Peraturan Daerah / Perda*).



Source: data processed by the authors (2026).

Figure 1. Research Design

2.2. Study Locations

Research was conducted in four strategic regions in Indonesia, selected to reflect diverse hydrogeological conditions, raw water sources, and administrative environments:

1. Dumai City (Riau Province): Coastal region dominated by peatlands and organosol soils; raw water exhibits high organic content, acidity, and elevated heavy metal concentrations.
2. Jambi City (Jambi Province): Riverine basin and lowland alluvial plain; raw water sources (groundwater and surface water) contain high iron and manganese concentrations.
3. Makassar City (South Sulawesi Province): Highly populated urban coastal center; relies on surface water reservoirs and deep wells with dense surrounding urban activity.
4. Yogyakarta City (D.I. Yogyakarta Province): Volcanic slope aquifer system with dense shallow groundwater wells; susceptible to microbial contamination from septic systems due to high urban population density.

2.3. Sampling Strategy and Data Collection

1. Quantitative Data Collection

- a. Water Sampling: Water samples were collected from active, licensed and unlicensed DAMIU selected via stratified random sampling across the four study areas ($n = 40$ depots per region, total $N = 160$ depots). Samples were taken directly from the depot filling taps into sterile glass containers for microbiological testing and polyethylene bottles for physical-chemical testing, following standard sampling protocols (SNI 19-0428-1998). Samples were stored in iceboxes (4°C) and transported to accredited regional health laboratories (*Labkesmas*) within six hours of collection.
- b. Laboratory Parameters & Methods:
 - 1) *Physical Parameters*: pH (electrometric method using digital pH meter) and Total Dissolved Solids / TDS (gravimetric/gravimetric-conductometric method).
 - 2) *Chemical Parameters*: Total Iron (Fe) and Total Manganese (Mn) determined using Atomic Absorption Spectrophotometry (AAS) or Colorimetric Spectrophotometry.
 - 3) *Microbiological Parameters*: Total *Coliform* and *Escherichia coli* enumerated using the Most Probable Number (MPN) method or Membrane Filtration method, expressed as MPN/100 mL.
- c. Sanitation Inspection:

Observational assessments were conducted at each depot using a standardized inspection checklist derived from Minister of Health Regulation No. 43/2014. The checklist evaluated 25 items across three main domain categories:

 - 1) *Location and Facility Building Conditions* (cleanliness, vector control, distance from pollution sources).
 - 2) *Equipment and Maintenance Protocols* (filter tube condition, micro-filter replacement logs, UV sterilizer lamp wattage and life-hours, container washing mechanisms).
 - 3) *Operator Hygiene and Health* (personal protective wear, health certificates, handwashing habits).

2. Qualitative Data Collection

Secondary data and institutional insights were collected through:

- a. Document Review: Analysis of municipal health office annual reports, national regulatory texts (Permenkes 43/2014 and Permenkes 2/2023), and local executive/legislative policies (*Perda* or *Perwali*).
- b. Semi-Structured Interviews: Key informant interviews ($N = 24$) conducted with municipal Health Office officials (*Dinas Kesehatan*), heads of Regional Public Health Laboratories (*Labkesmas*), officers from the Department of Industry and Trade (*Disperindag*), and leadership from local DAMIU owner associations (*Asosiasi Pengusaha Depot Air Minum / APDAM*).

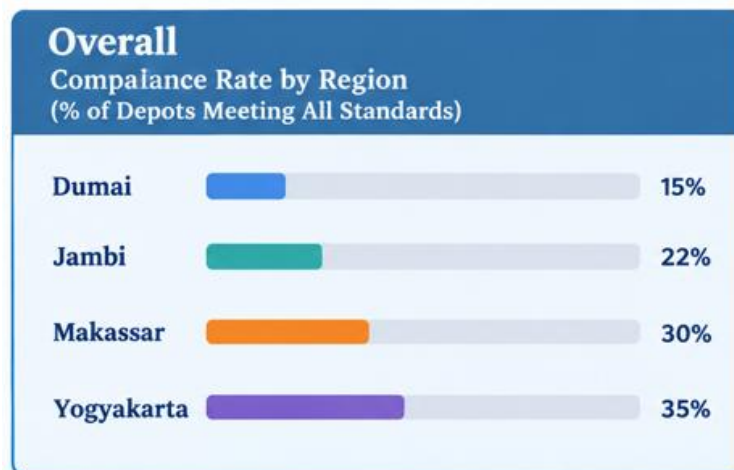
2.4. Data Analysis

Quantitative laboratory data were compared against the maximum allowable limits defined in Minister of Health Regulation No. 2/2023. Compliance rates were calculated as percentages. Descriptive statistics (mean, standard deviation, range) were computed using SPSS software. Qualitative interview transcripts and regulatory documents were analyzed using thematic content analysis to identify governance gaps, structural barriers, and institutional coordination bottlenecks.

3. Results and Discussion

3.1. Water Quality Parameter Compliance across Regions

Laboratory testing demonstrated substantial variation in compliance levels across the four study areas. Out of 160 sampled depots, only a small fraction satisfied all physical, chemical, and microbiological criteria established under Permenkes No. 2/2023.



Source: data processed by the authors (2026).

Figure 2. Overall Compliance Rate by Region (% of Depots Meeting All Standards)

Physical Parameters (pH and TDS)

Physical parameters showed high compliance overall. Average pH values across all regions fell within the allowable national threshold range of 6,5 to 8,5. Mean Total Dissolved Solids (TDS) were well below the 300 mg/L threshold prescribed by Permenkes No. 2/2023:

1. Dumai: Mean pH $6,8 \pm 0,4$; Mean TDS 112 ± 35 mg/L (100% compliant).

2. Jambi: Mean pH $7,1 \pm 0,3$; Mean TDS 145 ± 42 mg/L (97,5% compliant).
3. Makassar: Mean pH $7,4 \pm 0,3$; Mean TDS 188 ± 50 mg/L (100% compliant).
4. Yogyakarta: Mean pH $7,2 \pm 0,2$; Mean TDS 210 ± 38 mg/L (100% compliant).

Chemical Parameters (Iron and Manganese)

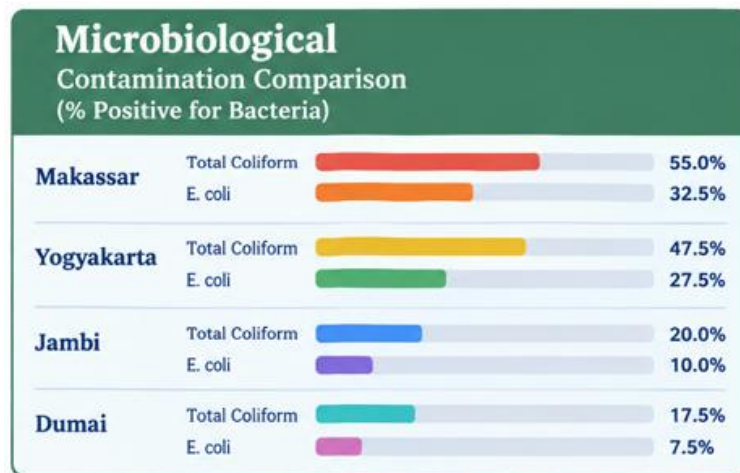
Chemical non-compliance was heavily concentrated in Dumai and Jambi, directly reflecting localized hydrogeological characteristics. Permenkes No. 2/2023 sets maximum limits of $0,2$ mg/L for Iron (Fe) and $0,1$ mg/L for Manganese (Mn).

1. Dumai: 62,5% of sampled DAMIU exceeded maximum limits for Iron (mean $\text{Fe} = 0,48 \pm 0,21$ mg/L), and 45,0% exceeded Manganese limits (mean $\text{Mn} = 0,26 \pm 0,11$ mg/L). Peatland raw water sources contain high organic acid loads and dissolved heavy metals that standard silica and activated carbon beds fail to remove without chemical coagulation or advanced ion exchange.
2. Jambi: 52,5% of DAMIU exceeded Iron limits (mean $\text{Fe} = 0,39 \pm 0,18$ mg/L), and 37,5% exceeded Manganese limits. Groundwater extracted from alluvial formations contains naturally reduced Fe^{2+} and Mn^{2+} ions that require aeration or specialized filter media (manganese greensand) to precipitate.
3. Makassar & Yogyakarta: Chemical parameters were fully compliant (100% within standards) as raw water sources in these volcanic and deep aquifer settings contained minimal heavy metal concentrations.

Microbiological Parameters (Total Coliform and E. coli)

Microbiological hazards represented the primary public health threat in Makassar and Yogyakarta. National standards mandate 0 MPN/100 mL for both *Total Coliform* and *Escherichia coli*.

1. Makassar: 55,0% of depots tested positive for *Total Coliform*, and 32,5% contained detectable *E. coli*.
2. Yogyakarta: 47,5% of depots tested positive for *Total Coliform*, and 27,5% contained *E. coli*.
3. Dumai & Jambi: Microbiological non-compliance was lower (17,5% and 20,0%, respectively), as operators in these regions often applied longer filtration steps or used commercial tankered water pre-treated with chlorine.



Source: data processed by the authors (2026).

Figure 3. Microbiological Contamination Comparison (% Positive for Bacteria)

3.2. Summary Table of Laboratory Diagnostics

The quantitative findings across all four study locations are summarized below:

Table 1. Findings

Parameter	Permenkes 2/2023 Standard	Dumai (n=40)	Jambi (n=40)	Makassar (n=40)	Yogyakarta (n=40)
pH	6,5 – 8,5	\$6,8 \pm 0,4\$ (100%)	\$7,1 \pm 0,3\$ (97,5%)	\$7,4 \pm 0,3\$ (100%)	\$7,2 \pm 0,2\$ (100%)
TDS (mg/L)	\$\le 300\$	\$112 \pm 35\$ (100%)	\$145 \pm 42\$ (100%)	\$188 \pm 50\$ (100%)	\$210 \pm 38\$ (100%)
Iron / Fe (mg/L)	\$\le 0,2\$	\$0,48 \pm 0,21\$ (37,5%)	\$0,39 \pm 0,18\$ (47,5%)	\$0,05 \pm 0,02\$ (100%)	\$0,04 \pm 0,01\$ (100%)
Manganese / Mn (mg/L)	\$\le 0,1\$	\$0,26 \pm 0,11\$ (55,0%)	\$0,19 \pm 0,09\$ (62,5%)	\$0,02 \pm 0,01\$ (100%)	\$0,01 \pm 0,01\$ (100%)
Total Coliform (MPN/100 mL)	0	17,5% non-compliant	20,0% non-compliant	55,0% non-compliant	47,5% non-compliant
E. coli (MPN/100 mL)	0	7,5% non-compliant	10,0% non-compliant	32,5% non-compliant	27,5% non-compliant

(Note: Percentages in parentheses represent the proportion of compliant depots for that parameter).

Source: data processed by the authors (2026).

3.3. Depot Sanitation Observations (Permenkes 43/2014)

Observational audits revealed significant operational sanitation gaps across all four regions. Aggregate compliance with the 25 inspection items reached only \$42,5\%\$ in Dumai, \$48,0\%\$ in Jambi, \$51,5\%\$ in Makassar, and \$56,0\%\$ in Yogyakarta.

Major operational defects identified during inspections included:

1. UV Sterilization Failures: Over \$60\%\$ of depots in Makassar and Yogyakarta operated UV sterilizer tubes that had exceeded their operational lifespan (\$>8.000\text{ hours}\$). UV glass sleeves were frequently coated in bio-film or mineral scale, severely reducing radiation intensity and microbial kill rates.
2. Infrequent Micro-filter Replacement: Micro-filter cartridges (\$1\text{ }\mu\text{m}\$ and \$5\text{ }\mu\text{m}\$) were rarely replaced on schedule. Operators reported changing filters

only when water flow rates visibly decreased, rather than following monthly replacement cycles.

3. Unhygienic Container Rinsing: Operators routinely used product water to rinse consumer-provided water 19-liter gallon containers without applying sanitizing agents. Inside container surfaces were frequently untouched by brushes, leading to cross-contamination from dirty consumer containers.
4. Lack of Operator Hygiene & Certification: Less than 20% of depot handlers held valid Sanitation Hygiene Certificates (*Sertifikat Laik Higiene Sanitasi* / SLHS). Handwashing facilities with soap were missing in over 70% of visited facilities.

3.4. Institutional and Policy Analysis

Qualitative interviews with municipal stakeholders revealed systemic governance challenges that inhibit effective quality surveillance:



Source: data processed by the authors (2026).

Figure 5. Systematic Governance Challenges

1. Fragmented Jurisdiction: DAMIU oversight is divided across multiple agencies without formal communication channels. Health Offices (*Dinas Kesehatan*) manage health audits, Industry and Trade Offices (*Disperindag*) issue business identification numbers (*NIB*), and Public Order Enforcement (*Satpol PP*) handles legal enforcement. Inter-agency data sharing regarding non-compliant depots was virtually non-existent.
2. High Testing Costs and Budget Deficits: Lab testing fees at Regional Public Health Laboratories (*Labkesmas*) range between IDR 300.000 and IDR 500.000 per sample set. Small DAMIU operators generating slim profit margins resist paying quarterly testing fees. Concurrently, municipal health offices lack operational budgets to subsidize routine surveillance testing.
3. Weak Local Legal Enablers: While national regulations (Permenkes 43/2014 and 2/2023) mandate compliance, several municipalities lacked explicit local bylaws (*Peraturan Daerah* / *Perda*) or mayoral decrees (*Perwali*) establishing administrative sanctions, fines, or operational closure mechanisms for non-compliant depots. Consequently, unlicensed depots operated indefinitely without penalty.

3.5. Discussion

1. Interpretation of Findings

The results of this multi-regional evaluation demonstrate that drinking water safety risks in Indonesian DAMIU are twofold and spatially structured:

- Hydrogeology-Driven Chemical Risks:** In regions like Dumai and Jambi, water safety is compromised by regional raw water chemistry (high Fe and Mn levels in peatland and alluvial groundwaters). Standard physical filtration systems used by typical depots are technically incapable of removing dissolved heavy metal ions, leading to persistent chemical non-compliance regardless of operator hygiene.
- Operational-Driven Microbiological Risks:** In urban areas like Makassar and Yogyakarta, raw water chemistry is benign, but water safety is severely undermined by biological contamination (*Coliform* and *E. coli*). This contamination stems from operational neglect—specifically failed UV lamp maintenance, dirty filter housings, and unhygienic container handling.

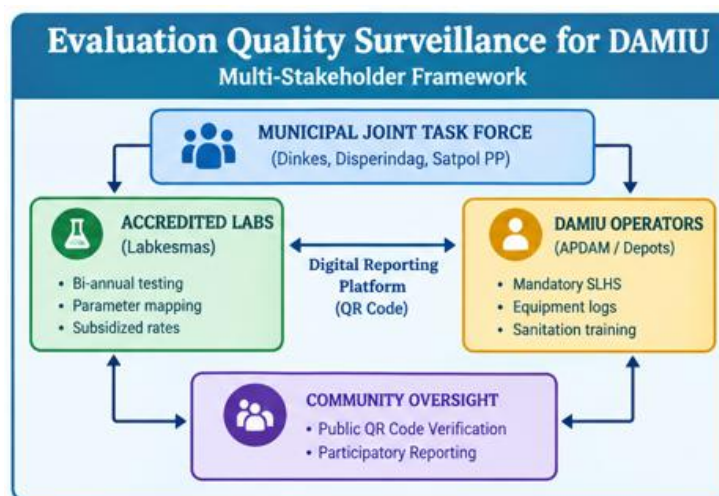
These findings align with prior research in other Indonesian cities. Sudarmi et al. (2020) observed that microbial contamination in refill depots is primarily a post-treatment phenomenon caused by contaminated filling nozzles and dirty storage tanks. Similarly, Effendi et al. (2021) emphasized that basic sand and micro-filtration media cannot remove dissolved iron without oxidation steps, explaining the elevated Fe levels seen in coastal and peatland regions.

2. Strategic Implications for SDG 6

Indonesia's progress toward SDG 6 (Target 6.1) is threatened if decentralized water systems like DAMIU remain unmonitored. While DAMIU successfully fulfill the *accessibility* and *affordability* criteria of SDG 6, they fail the *safety* criterion. Counting population access to DAMIU as "safely managed drinking water" without rigorous, laboratory-verified surveillance introduces significant public health risks, including waterborne gastrointestinal illnesses and chronic toxic metal exposure.

3. Proposed Evaluation Quality Surveillance

To bridge the gap between national regulations and local enforcement, this study proposes a practical, multi-stakeholder framework: the Evaluation Quality Surveillance for DAMIU.



Source: data processed by the authors (2026).

Figure 6. the Evaluation Quality Surveillance for DAMIU

The model operates across four Evaluation integrate pillars:

1. **Digital Surveillance Platform and Public Verification (QR Code System)**
Every registered DAMIU facility is issued a unique digital ID and a public QR code sticker displayed at the filling station. Laboratory results from *Labkesmas* are uploaded directly to a centralized web platform. Consumers scan the QR code using smartphones to view real-time compliance status, last inspection date, and water testing results. Depots failing testing protocols automatically display a "Warning/Non-Compliant" badge on the platform.
2. **Subsidized Public Health Laboratory (*Labkesmas*) Testing Framework**
To overcome financial barriers, municipal governments incorporate DAMIU testing into local public health budgets (*APBD*). By bundling testing into regional public health surveillance programs, testing costs per depot can be reduced through volume processing. *Labkesmas* performs bi-annual testing focusing on regionally specific risk parameters (e.g., Fe and Mn in peat areas; *E. coli* in dense urban centers).
3. **Inter-Agency Licensing and Enforcement Task Force**
Municipalities establish a permanent Joint Task Force (*Tim Terpadu*) comprising the Health Office, Trade Office, and Satpol PP. Business license renewals (*NIB*) issued by Disperindag are strictly conditional upon receiving a Sanitation Hygiene Certificate (SLHS) from Dinkes and valid lab test results from *Labkesmas*. Satpol PP enforces administrative closures for non-compliant or uncooperative facilities.
4. **Mandatory Operator Certification and Technical Assistance**
Working in partnership with local depot associations (APDAM), Dinkes conducts standardized, low-cost sanitation and hygiene training modules. Certification covers technical skills including UV bulb maintenance, micro-filter replacement scheduling, chemical oxidation techniques for heavy metals, and container sanitation protocols.

4. Conclusion

4.1. Conclusion

Refill Drinking Water Depots (DAMIU) play an indispensable role in providing affordable drinking water across Indonesian communities. However, current operations fall far short of national safety standards and global SDG 6 targets. Water quality non-compliance is regionally distinct: chemical hazards (excessive Fe and Mn) predominate in peatland and lowland riverine geographies (Dumai and Jambi), whereas microbiological contamination (Total Coliform and *E. coli*) dominates in high-density urban areas (Makassar and Yogyakarta). Current surveillance mechanisms are severely weakened by institutional fragmentation, lack of local enforcement regulations, high laboratory costs, and inadequate operator knowledge.

Achieving SDG 6 requires transitioning from passive, ad-hoc inspections to an active, laboratory-anchored, and digitally transparent surveillance framework. The Evaluation Quality Surveillance proposed in this study offers a scalable solution for local governments in Indonesia and other developing nations facing similar decentralized water management challenges.

4.2. Recommendations

Based on these findings, the following actions are recommended:

1. For Municipal Governments (Pemerintah Daerah): Draft and enact local bylaws (Peraturan Daerah) that establish clear sanctions for unlicensed or non-compliant

- DAMIU, and allocate municipal budget lines (APBD) to subsidize routine water testing at Labkesmas.
2. For Health Offices (Dinas Kesehatan): Deploy the digital QR-code verification system to enable public transparency, and conduct mandatory, routine hygiene certification workshops for all depot handlers in collaboration with APDAM.
 3. For Depot Operators (Pengusaha DAMIU): Upgrade filtration technologies based on local raw water chemistry (e.g., installing manganese greensand or aeration units in high- Fe / Mn areas), strictly adhere to micro-filter and UV lamp replacement schedules, and implement routine hand hygiene.
 4. For Future Research: Expand quality evaluations to include emerging contaminants (microplastics, pesticides, and residual pharmaceuticals) in DAMIU supplies, and perform cost-benefit analyses on regional Labkesmas subsidy frameworks.

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