WATER QUALITY, SANITATION, AND WASH SERVICE-LEVEL ASSESSMENT IN THREE ISLAMIC BOARDING SCHOOLS (DAYAH) IN ACEH: A MULTI-SITE COMPARATIVE STUDY

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Abstract

This study compared drinking-water quality, general-use water quality, sanitation conditions, and water, sanitation, and hygiene (WASH) service levels in three Islamic boarding schools (dayah) in Aceh Province, Indonesia. An exploratory multi-site mixed-methods design combined six point-of-use water samples, site observation, management interviews, and questionnaires administered to 10 students at each site. Water quality was assessed using pH, turbidity, total dissolved solids (TDS), and H_2S screening at all sites, while culture-based Escherichia coli and Total Coliform testing was conducted at only one site because of laboratory capacity constraints. Service performance was evaluated using an adapted WASHCost framework covering quality, quantity, accessibility, and reliability. Drinking water generally met the study reference ranges for pH and turbidity, but TDS exceeded the operational threshold of 300 mg/L at Al-Muslimun (400 mg/L) and Darul Aman (548 mg/L). General-use water showed the clearest cross-site weakness: H_2S screening was positive at 24 and 72 hours at all three dayah. Darul Aman recorded high turbidity (6.59 NTU) and TDS (1,051 mg/L), and Al-Muslimun showed a Total Coliform Count of 151 CFU/100 mL in general-use water, with E. coli non-detectable. Student perceptions were generally positive, indicating a perception-risk gap. Under the adapted WASHCost assessment, Al-Muslimun and Darul Ulum were classified as intermediate, whereas Darul Aman was classified as substandard. These findings suggest that dayah WASH improvement should prioritize the protection and routine monitoring of general-use water systems, not only treated drinking-water points.

Keywords: *dayah, eco-pesantren, Islamic boarding school, water quality, WASH service level*

Introduction

In Indonesia, Islamic boarding schools (*pesantren*/*dayah*) are some of the oldest residential educational institutions, educating over 1.4 million students nationwide. Because learners live, study, and worship on-site, water, sanitation, and hygiene (WASH) services are daily operational essentials rather than secondary infrastructure concerns. In boarding school environments, the adequacy of water quantity and quality, as well as sanitation management, directly impacts health protection, hygiene practices, and the quality of residential life (Kasanah et al., 2023; Kementerian Agama RI, 2023).

Discussions within the broader sustainability movement increasingly connect environmental stewardship, resource management, and religious education to pesantren sustainability. In Aceh, such eco-dayah or eco-pesantren

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initiatives place water, waste, and environmental care as elements of institutional responsibility rather than as isolated technical tasks (Hamdan et al., 2022; Herdiansyah et al., 2019; Maulida & Ali, 2023; Maulida et al., 2024). WASH conditions in dayah cannot be divorced from institutional variation in the same breath. The Qanun Aceh No. 9/2018 distinguishes between *salafiyah dayah* (whose instructional core remains rooted in classical Islamic texts) and more integrated dayah, which combine dayah learning with formal school or madrasah structures. The Aceh scholarship similarly accounts for ongoing diversification in curriculum, administration, and organizational modernization of dayah (Basri et al., 2023; Erawadi & Setiadi, 2023; Fakhrurrazi et al., 2021; Nur, 2019; Qanun Aceh Nomor 9 Tahun 2018 Tentang Penyelenggaraan Pendidikan Dayah, 2018; Ridha, 2020; Zuhri & Syamsi, 2023)

Previous studies have documented microbial contamination in bath or drinking water among Indonesian boarding school settings as well as discussed environmental management more generally in pesantren; however, they have predominantly focused on single institutions of limited sets of indicators (Auvaria et al., 2019; Hariyanto et al., 2020; Wikurendra et al., 2020). Comparative evidence for Aceh dayah remains scant, especially evidence that combines measured water quality with a service-level lens that integrates quantity, quality, accessibility, and reliability. We highlight this gap because a dayah could potentially have treated drinking water, but continues to provide inadequate overall service if non-drinking water systems remain at risk.

This study, therefore, aimed to compare drinking-water quality, general-use water quality, sanitation conditions, and WASH service levels in three dayah in Aceh. In addition, the study used an adapted WASHCost framework to characterize and rank service bottlenecks and their implications for dayah WASH management (Moriarty et al., 2011).

Research Methodology

Study design

This study utilized a multi-site comparative design with an exploratory mixed-methods approach. The design incorporated water-quality testing, along with interviews, observations, and questionnaires, to produce a diagnostic comparison rather than a statistically generalizable estimate for all Aceh dayah. Published WASH evidence for Aceh dayah is limited, and triangulation between measured and reported service conditions was needed, making an exploratory mixed-methods approach appropriate (Creswell & Clark, 2017).

Study sites

Purposive sampling was used to select three dayah that represent different institutional and geographic contexts in Aceh. In Aceh Utara, Dayah Terpadu Al-Muslimun is a modern/integrated dayah serving 1,635 students, including about 1,400 residential students; its drinking water tap is connected to a PDAM reverse-osmosis system, and the general-use water supply comes via PDAM. Dayah Darul Aman Lubuk in Aceh Besar is a traditional/salafiyah dayah with around 200 students; it purchases drinking water from an external refill depot and collects general-use water directly from untreated boreholes. The modern/integrated dayah, Dayah Darul Ulum, located in Banda Aceh, has around 900 students; drinking water is provided by private reverse osmosis treatment, and general-use water is sourced from PDAM.

The sites (Figure 1, Figure 2 and Figure 3) were selected to capture variation in typology, scale, and water-service configuration, rather than to be statistically representative of all dayah.

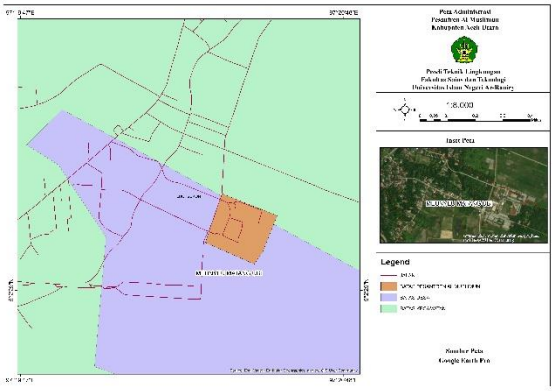

Figure 1. Map of Dayah Terpadu Al-Muslimun, Aceh Utara

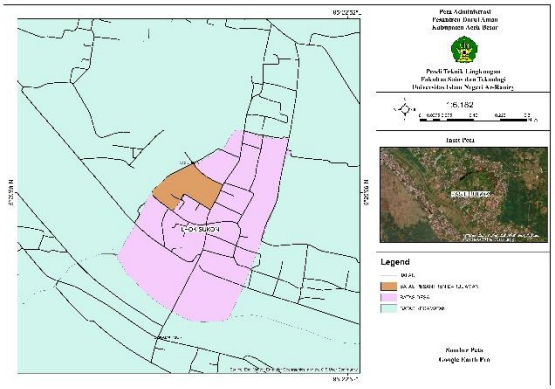

Figure 2. Map of Dayah Darul Aman Lubuk, Aceh Besar

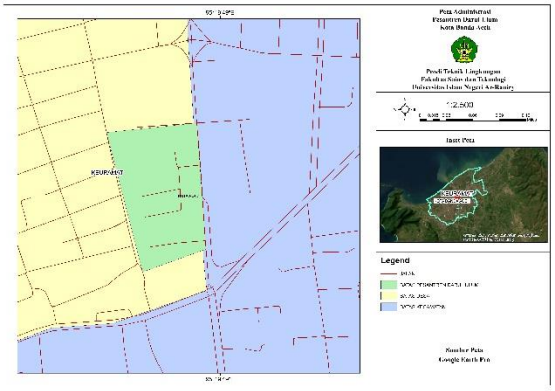

Figure 3. Map of Dayah Darul Ulum, Banda Aceh

Data collection

Fieldwork took place between February and September 2024. Preparatory work and instrument development occurred from February to May 2024; data collection from May to July 2024; and analysis and reporting from July to September 2024. The study involved four main types of data collection: water-quality data (water tests), service information at the site level, observation of sanitation and environmental conditions, and user perception.

Water sampling and laboratory or field parameters

The point-of-use design of water sampling was meant to capture exposure-relevant conditions. Two grab samples were taken during the study at each dayah: one drinking-water sample was obtained from the primary point of student consumption, and one general-use water sample was collected from a high-frequency-use point (e.g., an ablution or washing facility). From this, we obtained six samples over the three sites. At each sampling point, two bottles of approximately 600 mL were produced. One bottle was used for immediate field measurement, while the other was transported to Laboratorium Multifungsi UIN Ar-Raniry Banda Aceh in a cooling container and analyzed within 24 hours.

Table 1. Water-quality parameters and reference criteria used in the study

Parameter	Method	Limit
pH	Multiparameter probe	6.5-8.5
Turbidity	Turbidimeter	<3 NTU
TDS	Multiparameter probe	<300 mg/L*
Total Coliform	Culture-based test	0 CFU/100 mL
E. coli	Culture-based test	0 CFU/100 mL
H_2S screening	Strip test	Negative at 24 and 72 h

Note. *Operational threshold used in the manuscript. EC, TSS, and COD were also measured as supporting indicators, but no decision threshold was applied to them in the service-level classification. Culture-based microbiology was performed only at Al-Muslimun due to laboratory and resource constraints.

The parameters measured were pH, turbidity, total dissolved solids (TDS), electrical conductivity (EC), total suspended solids (TSS), chemical oxygen demand (COD), and H_2S screening. H_2S screening was performed at 24 and 72 hours. Enumeration of Total Coliforms and Escherichia coli was performed as culture-based testing only for samples from Dayah Terpadu Al-Muslimun, as microbiological capacity was not equally available across sites. Here, "general-use water" means water for bathing, washing, ablution, and other daily nondrinking uses.

Interviews, observation, and questionnaires

A semi-structured guide was used to interview at least one administrator or management representative from each dayah, covering water sources, treatment arrangements, storage, and continuity of water supply, as well as constraints on maintenance and operation. Direct observation used a checklist to assess toilet status, drainage conditions, solid waste handling, and visible contamination routes near the water points. Questionnaires were administered to residential respondents (n = 30) across all three sites using a simple random sampling method within strata defined by academic level and, where applicable, gender to collect student perception data. The questionnaire was designed to provide context for the measured conditions rather than estimate population prevalence.

Data analysis

Water-quality data were compiled and descriptively compared among sites and water types. Responses to the questionnaire were entered in Microsoft Excel and summarized by frequencies and percentages. Data from interviews and observations were used to interpret water-service quantity, accessibility, and reliability, and to cross-check perception data against measured conditions. The analysis focused on comparative interpretation across the three sites rather than separate site-by-site reporting.

Water-quality assessment against standards

Water-quality interpretation was based on pH, turbidity, TDS, E. coli, and total coliform, together with H_2S screening as an indicative signal of contamination. Permenkes No. 2/2023 and the study screening protocol served as a reference for threshold-based interpretation (Menteri Kesehatan, 2023) . Because the H_2S test is only a screening method and does not provide confirmatory microbiological identification, positive results were interpreted cautiously as an indication of contamination risk rather than definitive evidence of specific microbial contamination.

WASHCost service-level classification

The service-level classification was adapted from the WASHCost water service framework, which defines service in terms of the quantity, quality, accessibility, and reliability of services provided to consumers, and establishes a minimum principle in which the lowest score determines the overall level of service achieved (Moriarty et al., 2011).

Table 2. Adapted WASHCost criteria used for service-level classification

Indicator	**Classification rule used in this study**
Quantity	High ≥60; Intermediate >40; Basic >20; Substandard >5 lpcd
Quality	High: good; intermediate: minor issues; Basic: some issues; Substandard: problematic
Accessibility	High <10; Intermediate/Basic <30; Substandard <60 min/cap/day
Reliability	High >95%; Intermediate 75-95%; Basic 50-75%; Substandard <50%
Overall service	The lowest indicator determines the final class.

Note. The ladder was adapted from Moriarty et al. (2011). The original framework includes a no-service rung, but that category was not applicable because all three sites had some level of water service.

In this study, quantity was described as liters per capita per day (lpcd), accessibility as minutes per capita per day to obtain water, and reliability as the proportion of time water service was reported available. Since all three facilities had at least some water service, the no-service rung was eliminated for the current adaptation. Quality was operationalized using measured drinking-water and general-use water results, with an explicit caveat regarding unequal microbiological testing across sites.

Validity, limitations, and ethics

Field instruments were calibrated prior to use according to the manufacturer's specifications. Multiple triangulations were applied across surveys, interviews, and observations to eliminate single-source bias in data collection, while questionnaire entries were monitored for duplication or transcription errors. The main limitations of the study were snapshot sampling, the use of H_2S as a screening indicator, and culture-based microbiological analysis limited to one site. Quantity, accessibility, and reliability were derived from estimates based on interviews rather than direct metering or continuous monitoring, so they should be considered threshold-based estimates rather than precision measurements.

The study was conducted with ethical approval from the UIN Ar-Raniry institutional research ethics committee. Participation was voluntary; written institutional permission was secured from each dayah, and, where appropriate, informed consent or assent was obtained. Where relevant, guardian consent was sought for respondents aged <18 years. All data were anonymized and reported as aggregate.

Results and Discussion

Comparative profile of the three dayah

The three dayah were significantly different in scale, typology, and water-service configuration. Al-Muslimun and Darul Ulum, both considered to be integrated dayah here, applied the dual-arrangement system in which treated drinking water is separated from general-use water. Darul Aman, in contrast, relied on untreated borehole water for daily use and externally sourced drinking water from a refill depot. This finding is important because it indicates that WASH performance in dayah is attributable not only to source type but also to the organization, protection, and maintenance of the service chain.

Population size did not correlate directly with service quality. Despite operating in an urban context serving over 900 individual students, Darul Ulum reported the best overall continuity. Al-Muslimun serves the largest population and has still maintained a relatively stable service profile. Darul Aman, the smallest site, had the most apparent constraints on quantity and access to hand or general-use water. Put together, these patterns indicate that management arrangements and operational safeguards are as important as scale.

Comparative water quality results

Water-quality results are presented separately for drinking water and general-use water (Table 3 and Table 4).

Table 3. Drinking-water quality across the three dayah

Parameters	Al-Muslimun	Darul Aman	Darul Ulum
pH	7.4	8.2	7.0
Turbidity (NTU)	1.25	0.00	0.07
TDS (mg/L)	400	548	250
H_2S, 24 h	Neg.	Neg.	Pos.
H_2S, 72 h	Pos.	Pos.	Pos.
TC	0	NT	NT
E. coli	0	NT	NT
EC (mS/cm)	0.64	0.77	0.71
TSS (mg/L)	1	0	1
COD (mg/L)	141	55	107

Note. NT = not tested; TC = total coliform. Culture-based microbiological testing was conducted only at Al-Muslimun. EC, TSS, and COD are reported as supporting indicators.

Table 4. General-use water quality across the three dayah

Parameters	Al-Muslimun	Darul Aman	Darul Ulum
pH	7.6	7.9	7.6
Turbidity (NTU)	2.37	6.59	2.51
TDS (mg/L)	251	1,051	291
H_2S, 24 h	Pos.	Pos.	Pos.
H_2S, 72 h	Pos.	Pos.	Pos.
TC	151	NT	NT
E. coli	0	NT	NT
EC (mS/cm)	0.35	1.46	0.41
TSS (mg/L)	1	3	5
COD (mg/L)	119	15	97

Note. NT = not tested; TC = total coliform. H_2S results are screening-based and should be interpreted conservatively. EC, TSS, and COD are reported as supporting indicators.

Drinking water generally fared better than general-use water across the three sites. Drinking-water pH ranged from 7.0 to 8.2, and turbidity from 0.00 to 1.25 NTU, within the limits of the reference values for these parameters in this study agent. At Al-Muslimun (400 mg/L) and Darul Aman (548 mg/L), however, TDS exceeded the critical threshold of 300 mg/L. As such, only the third point—Darul Ulum—which remained within this threshold with a reading of 250 mg/L, had the best drinking-water physicochemical profile of all three sites.

The more important cross-site signal came from contamination screening. Whereas for drinking water, H_2S screening at 72 hours was positive at all dayah, but already positive at Darul Ulum at 24 hours. Given that H_2S is a screening tool for indicating presence only, not a confirmatory microbiological assay, these results should not be considered direct counts. However, the repeated detection of positive results indicates that the risk of contamination is likely to remain high post-treatment or at the source, persisting during storage and throughout handling and distribution prior to use.

General-use water was the most visible system-wide weakness. As for dayah's general-use water samples, they were H_2S-positive at 24 and 72 h, respectively. The most affected site was Darul Aman, where turbidity and TDS of general-use water were 6.59 NTU and 1,051 mg/L, respectively. In the general-use water, al-Muslimun results for Total Coliform were 151 CFU/100 mL, and E. coli was not detected. The general-use water from Darul Ulum met the study's reference ranges for pH, turbidity, and TDS; however, it remained H2S-positive at both time points. Direct cross-site microbiological comparison is limited, as culture-based testing was performed only at Al-Muslimun. Similar boarding-school investigations in Indonesia have reported microbial contamination of bath or drinking water, although a standard-of-service approach was not provided here (Hariyanto et al., 2020; Wikurendra et al., 2020).

Comparative WASH service-level assessment

The comparative WASH service-level assessment for the three dayah is presented in Table 5. The table summarizes site performance across the quantity, quality, accessibility, and reliability indicators used in the adapted WASHCost framework and provides the basis for the overall classification. Based on these results, the service profile of each dayah can be interpreted comparatively rather than as isolated water-quality findings.

Interpreting the findings through the WASHCost minimum principle clarifies why drinking-water improvements alone did not result in high service at any site (Moriarty et al., 2011). Overall, Al-Muslimun and Darul Ulum were classified as intermediate, while Darul Aman was classified as substandard. The two integrated dayah performed better overall, but neither reached a high service level because contamination signals remained, and water quantity did not meet the highest benchmark. At Al-Muslimun, the main constraints were

contamination risk in general-use water and the elevated TDS value in drinking water, despite relatively stable quantity, access, and continuity. Darul Ulum demonstrated the strongest continuity, as its storage capacity and source arrangement supported a virtually continuous supply, yet repeated H_2S positivity still precluded interpretation as high service. Darul Aman, by contrast, was disadvantaged not only by poorer water quality but also by a heavier service burden, since a reported quantity of approximately 15 lpcd and an access time of approximately 45 minutes per capita per day indicate lower daily adequacy even before water-quality limitations are taken into account.

Table 5. Comparative WASH service-level assessment

Dayah	Service-level summary
Al-Muslimun	Quantity ≥50 lpcd (Intermediate) Quality: Intermediate; general use contamination risk Accessibility <30 min (Intermediate) Reliability ≈90% (Intermediate) Overall: **Intermediate**
Darul Aman	Quantity ≈15 lpcd (Substandard) Quality: Substandard; drink + general use issues Accessibility ≈45 min (Substandard) Reliability ≈85% (Intermediate) Overall: **Substandard**
Darul Ulum	Quantity ≈55 lpcd (Intermediate) Quality: Intermediate; H_2S screening risk Accessibility ≈20 min (Intermediate) Reliability ≈100% (High) Overall: **Intermediate**

Note. The final class follows the minimum principle, and the bottleneck for each site is embedded in the summary cell.

Sanitation, management, and perception findings

The observation data revealed that sanitation and environmental management were operational but uneven. Municipal waste in Al-Muslimun was either collected or basic rubbish bins were provided; however, it was not necessarily separated and composted, and some toilet blocks exhibited minor structural damage and drainage problems. Darul Aman possessed the least mature environmental management profile: there was reported burning of combustible waste outside the dayah, and bin availability was the weakest among the mapped sites. Darul Ulum was generally cleaner and more orderly, with staff-based collection (and later municipal pickup). However, the temporary storage area was still open, and blackwater management relied on semi-planned rather than formally scheduled desludging. These also align with pesantren environmental management studies that link water, waste, and stewardship to institutions rather than conceptually separating them (Auvaria et al., 2019; Hamdan et al., 2022; Kasanah et al., 2023).

Students' views tended to be more positive than the survey results implied. At Al-Muslimun, 90% of respondents rated both drinking water and general-use water as good or very good. At Darul Aman, the best objective evidence of impairment was found in surface water samples. However, all interview respondents rated drinking water as good and general-use water as good or fairly good. At Darul Ulum, perceptions of drinking water were all positive, while perceptions of general-use water were more mixed, with 10% of respondents rating it as not good. This mismatch, seen in all three sites, indicates a perception-risk gap that could undermine demand for routine monitoring and preventive maintenance. The perception data also revealed that waste handling, toilet adequacy, and bin availability were more uneven than simple toilet-use behavior would indicate.

Cross-site synthesis and implications for dayah WASH management

In all three locations, the common weakness was not a lack of drinking-water provision. Rather, the key issue was that the full water chain, particularly the one providing general-use water

for washing and *wudu* (ablution before prayers), was not fully protected. It builds on previous single-site evidence from Indonesian boarding schools, where contamination was found in baths or drinking water but not analyzed through a comparative (and service agency) lens (Hariyanto et al., 2020; Wikurendra et al., 2020). It also validates the utility of the WASHCost logic in practice: poor overall performance was frequently limited by the weakest service dimension rather than by the mere presence of a treated drinking-water point (Moriarty et al., 2011).

Three practical priorities follow. The first, general-use water source-storage-distribution-point-of-use chain requires a stricter barrier of routine cleaning of the tanks, better physical protection of both storage and taps, and, if reasonable, measures for secondary disinfection. Second, dayah requires simple yet consistent monitoring and documenting systems. Periodic H_2S screening can be a low-cost early-warning tool, but you should also perform confirmatory E. coli testing if resources allow. Third, investments in infrastructure upgrades should be targeted toward the prevailing bottleneck at each location. Water quality is indeed a concern for Darul Aman, but not on its own. For Al-Muslimun as well as for Darul Ulum, the focus is on reducing the risk of contamination after treatment or procurement rather than simply increasing the number of drinking-water points.

Such implications parallel the broader eco-dayah and eco-pesantren literature, which theorizes environmental care, daily operation, and institutional culture as mutually reinforcing categories rather than separate domains (Hamdan et al., 2022; Herdiansyah et al., 2019; Maulida et al., 2024). Linking monitoring and preventive maintenance to stewardship and taharah in Islamic educational settings may therefore reinforce institutional ownership of WASH improvements. Interpretation of the results should remain cautious because this study was based on a one-off sampling, H_2S screening is indicative rather than confirmatory, and culture-based microbiology was not conducted consistently across all sites.

Conclusions

This study compared drinking-water quality, general-use water quality, sanitation conditions, and WASH service levels in three dayah in Aceh using point-of-use water testing, observation, interviews, and student questionnaires. Drinking water largely complied with the study's pH and turbidity reference ranges but had high total dissolved solids (TDS), exceeding the operational threshold at Al-Muslimun and Darul Aman. The most consistent weakness across the three sites was general-use water. H_2S screening was positive at 24 and 72 hours in all general-use samples. Darul Aman showed the most pronounced physicochemical impairment, and Al-Muslimun recorded Total Coliforms in general-use water despite E. coli being non-detectable.

Applying the adapted WASHCost framework, Al-Muslimun and Darul Ulum scored intermediate, while Darul Aman leaned more towards substandard. The main implication is that dayah WASH improvement should not focus solely on treated drinking-water points. It can include general-use water protection, routine monitoring, remedial maintenance, and on-site infrastructure improvements. As the study was exploratory and microbiological testing was not uniformly performed across all sites, the results should be interpreted as a comparative diagnostic tool to identify priorities for monitoring and intervention going forward.

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