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Assessment of Domestic Wastewater Treatment Capacity at a Boarding School in North Toraja, Indonesia

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ABSTRACT

In boarding schools with separate wastewater treatment units, total bed capacity alone does not indicate which unit will experience the highest hydraulic load. This study evaluated whether each unit's reported treatment capacity at a boarding school in North Toraja, Indonesia, could accommodate the average daily inflow at full occupancy. The analysis considered the school's 720 residential places, including 400 in the girls' dormitory and 320 in the boys' dormitory. A water balance approach allocated wastewater from each activity to its respective unit using activity-specific water allowances and wastewater return fractions. Estimated wastewater generation was 45.504 m^3/day, exceeding the combined reported capacity of 35 m^3/day by 10.504 m^3/day. Both the girls' and boys' dormitory units had a reported capacity of 15 m^3/day, but their estimated inflows were 22.400 and 17.920 m^3/day, respectively. The girls' unit represented 70.4% of the total projected shortfall. At the shared laundry and kitchen unit, the estimated inflow exceeded capacity by only 0.184 m^3/day, and the assessment outcome changed when the assumed return fraction decreased from 80.0% to approximately 77.2%. Linking occupancy and water use to individual units identified the girls' dormitory as the priority for verifying treatment capacity and measuring inflow.

Keywords: *Boarding School, Domestic Wastewater, Treatment Capacity, Water Balance, Hydraulic Loading*

1. INTRODUCTION

Water demand at a boarding school extends beyond classroom hours. Residents require water for bathing and toilet flushing, while shared kitchens and laundries use water for meal preparation, dishwashing, and laundry. Each activity serves a distinct user group. Dormitory bathrooms typically serve residents of a single building, whereas a central kitchen may prepare meals for multiple dormitories. A study of two student residences combined resident surveys with measurements at taps, showers, and toilet cisterns to characterize water use by activity [1]. For wastewater assessment, this distinction also applies to the resulting discharge: toilets generate blackwater, while bathing, kitchen activities, and laundry generate greywater [2].

The relative volumes of these wastewater streams are particularly significant in Indonesia. A review of domestic wastewater generation and treatment found that, across Indonesian cases, greywater generation ranged from one to four times the volume of blackwater. Untreated greywater volume was three to six times that of untreated blackwater [3]. In boarding schools, greywater may enter multiple collection systems because bathing occurs in individual dormitories, while cooking and laundry are often centralized. Estimating discharge from each source therefore requires data on

the number of residents served, water use for each activity, and the proportion of water entering the wastewater collection system.

A water balance integrates these quantities to estimate daily wastewater flow [4]. In a design study of a male dormitory in Banyuwangi, Indonesia, a water demand of 22.20 m^3/day resulted in an estimated wastewater flow of 17.76 m^3/day. This estimate informed the sizing of a proposed treatment installation [5]. At an operational healthcare facility in Surabaya, estimates based on water use and population served were used to evaluate the capacity of existing treatment units [6]. Applying this methodology to a boarding school with separate treatment units requires tracing the estimated discharge from each activity to the corresponding unit [7].

This allocation is important because the combined capacity of multiple units can obscure a shortfall within a specific service area. For instance, surplus capacity at a laundry treatment unit cannot address excess dormitory flow unless the collection network permits diversion. As a result, nominal capacity may be sufficient for the entire facility but inadequate for individual units [5]. For a dormitory unit, the relevant comparison is between its daily capacity and the estimated discharge from the residents it serves. For a unit serving both a shared kitchen and laundry, the comparison must include both activities. In the boarding school examined in North Toraja, the key question is whether each unit's reported daily capacity can accommodate the expected flow from its service area under full occupancy.

This study evaluates domestic wastewater treatment capacity at a boarding school in North Toraja by constructing a water balance for each treatment service area. It estimates average daily wastewater generation from dormitory sanitation, kitchen activities, and laundry, and compares the estimated flow entering each unit with its reported daily treatment capacity. This unit-level assessment identifies potential capacity shortfalls, the activities driving the estimated flow, and the locations where influent measurements would be most informative before decisions on wastewater rerouting or treatment capacity expansion.

2. LITERATURE REVIEW

2.1 Water Use and Wastewater Sources in Residential Education Facilities

Water use in student housing is influenced by both occupancy levels and the specific activities supported by each building. A study of two university residences in Portugal reported that showers accounted for 46.0% of water consumption in one residence and 61.4% in the other, while kitchen taps accounted for 31.5% and 11.5%, respectively [1]. Similarly, a study of six student housing buildings in Belgium identified substantial variation between residences. Meter records and short-term measurements indicated that four buildings used less water per resident than the national residential average, whereas the reasons for higher consumption in the remaining two buildings were not determined [8]. These findings are directly relevant to applying per-capita allowances in boarding schools. In the context of a dormitory bathroom, the relevant population comprises the residents who use that facility. For a central kitchen, the population may include residents from multiple dormitories. Therefore, population selection depends on the activity generating the flow and the location where the flow is discharged.

The distinction between greywater and blackwater categorizes wastewater by its source but does not indicate which treatment unit receives each stream. An Indonesian

review documented significant variation in how these two wastewater streams are generated, collected, and treated. In boarding schools, shower and laundry discharges may both be classified as greywater, even if they are directed to separate treatment units. Conversely, wastewater from showers and toilets may be combined in the same dormitory treatment unit, despite originating from different source categories. Therefore, a water balance for treatment assessment must consider both the activity that consumes the water and the collection route that determines its final destination. This process requires defining each treatment unit's service area before estimating its daily inflow [3].

2.2 Water Balance and Estimation of Daily Wastewater Flow

A service-area water balance connects the number of users to the water consumed by each activity and the proportion expected to enter the collection system. This proportion, known as the wastewater return fraction, is particularly important when water-supply records are available, but wastewater flow is not metered. In a boarding-school design study in Banyuwangi, estimated wastewater generation was 17.76 m^3/day from a water demand of 22.20 m^3/day, resulting in a return fraction of 0.80 [5]. This value serves as a documented assumption for the residence studied. Applying this value to another facility requires verification that the water-use estimate encompasses the same activities. For instance, adding separate kitchen and laundry allowances to a residential allowance that already includes these services would double-count part of the demand.

The choice of occupancy basis similarly influences how you interpret estimated flow. Calculations based on occupied beds estimate demand for the population present during a specific period, while calculations based on all available beds represent a full-occupancy scenario, assuming the per-capita demand and return fractions remain valid. This distinction is significant when evaluating existing installations. For example, a hospital capacity study in Surabaya found that water demand calculated from user numbers and literature allowances differed from the facility's reported water use [6]. In boarding schools, a similar discrepancy could affect assessments of whether a unit has sufficient capacity. Therefore, comparisons must retain the basis of the flow estimate when matching it to the unit's reported rating.

2.3 Interpretation of Treatment Capacity at the Unit Level

A capacity assessment requires directly comparable quantities. Estimated daily inflow and rated daily throughput can be compared when both are expressed in m^3/day. Tank volume, also expressed in m^3, represents storage or working volume and does not alone determine a unit's daily treatment capacity. The relationship between volume and flow is influenced by hydraulic retention time. A field evaluation of decentralized treatment systems in Malang highlighted this distinction: reported retention times in anaerobic baffled reactors ranged from 52 to 138 hours, compared to the 6–20-hour design range cited in the study [9]. The evaluation considered reactor conditions alongside treatment performance, demonstrating that nominal tank dimensions alone are insufficient for assessing an operating unit.

For treatment units serving separate areas, the key indicator is the ratio of estimated daily inflow to reported daily capacity. A ratio greater than one indicates that estimated

demand exceeds the stated capacity under the given assumptions. A ratio less than one suggests a margin at the daily scale, though short-term peaks may still occur. However, this ratio does not determine pollutant removal efficiency, which requires water-quality data from the treatment process. For the boarding school in North Toraja, the main value of a unit-level water balance is identifying which installations need flow verification and why. This approach maintains the connection between occupancy, contributing activities, and the receiving unit, enabling potential capacity shortfalls to be investigated before making decisions about treatment expansion.

3. METHODS

3.1 Study Design and Scope

A descriptive quantitative case study was conducted to assess the adequacy of domestic wastewater treatment capacity at a boarding school in North Toraja Regency, Indonesia. Each treatment unit was evaluated by comparing its estimated average daily inflow under full occupancy with its reported daily treatment capacity.

The service area of each unit was defined by tracing wastewater from dormitory sanitation, laundry, and kitchen activities to the corresponding receiving unit. This process established which activities and users were included in each unit's water balance.

3.2 Water Balance Estimation

The water balance was constructed by estimating daily water demand for each activity and applying a return fraction to determine how much water entered the wastewater collection system. For dormitory sanitation, the number of users corresponded to the residential capacity of the dormitory served. For shared activities, the calculation included all residents served by that activity. We assigned water allowances to individual activities to avoid counting laundry or kitchen water use twice.

The average daily wastewater flow from each activity was estimated using Equation (1).

$$Q_i = \frac{N_i w_i r_i}{1000} \qquad (1)$$

Here, (Q_i) is the estimated wastewater flow from activity (i) (m^3/day), (N_i) is the number of users served under full occupancy, (w_i) is the activity-specific water allowance (L/person/day), and (r_i) is the fraction of water use expected to enter the wastewater collection system. The divisor converts liters to cubic meters.

We estimated the inflow to each treatment unit by summing the flows from all activities connected to that unit. When several activities shared a unit, we calculated their contributions separately and then combined them for the capacity assessment.

3.3 Assessment of Treatment Capacity

Two indicators were used to assess each unit: the difference between estimated inflow and reported daily capacity, and the percentage of capacity utilized under the full-occupancy scenario. Both inflow and capacity were expressed in m^3/day. The indicators were calculated using Equations (2) and (3).

$$\Delta Q_j = Q_j - C_j \qquad (2)$$

$$U_j = \frac{Q_j}{C_j} \times 100\% \qquad (3)$$

Here, (Q_j) is the estimated average daily inflow to treatment unit (j) (m^3/day), (C_j) is its reported daily treatment capacity (m^3/day), and (U_j) is its estimated capacity utilization (%).

A positive (ΔQ_j) indicates how much estimated inflow exceeds the unit's reported capacity. A negative value indicates spare capacity under the same assumptions. Capacity utilization provides a common basis for comparing units of different sizes. For the facility as a whole, utilization was calculated by dividing the combined estimated inflow by the combined reported capacity and multiplying by 100. Capacity adequacy was also assessed separately for each unit to account for its designated service area.

3.4 Estimation of the Occupancy Threshold

An additional analysis estimated the number of users at which the average daily wastewater inflow would reach each unit's reported capacity. Wastewater generation per user was calculated by multiplying the activity-specific water allowance by its return fraction. When several activities served the same residents and discharged to the same unit, their per-user contributions were summed. The occupancy threshold was calculated using Equation (4).

$$N_j^* = \frac{1000\ C_j}{g_j} \quad (4)$$

Here, N_j^* is the number of users at which the estimated inflow equals the daily capacity of unit (j), and g_j is the daily wastewater generation per user routed to that unit (L/person/day). The result was rounded down to obtain the largest whole number of users whose estimated daily discharge remained within the reported capacity. This threshold applies to average daily flow under the water-use assumptions specified in the water balance.

4. RESULTS AND DISCUSSION

4.1 Distribution of Capacity Shortfalls Across Treatment Units

At full occupancy, the dormitories generate 40.320 m³/day, representing 88.6% of the facility's estimated wastewater. The two associated treatment units have a combined reported capacity of 30 m³/day. This results in a difference of 10.320 m³/day, which constitutes 98.2% of the facility-wide shortfall of 10.504 m³/day. The distinction between these percentages is significant. While the dormitories contribute the majority of the estimated flow, their impact on the potential shortfall is even greater because the shared laundry and kitchen unit is sized much closer to its estimated daily inflow. Variations in laundry or kitchen water use could affect the shared unit assessment but would have minimal impact on the primary capacity constraint.

Within the residential system, treatment capacity allocation is uneven on a per-bed basis. The girls' dormitory houses 400 of the 720 residents, or 55.6% of total residential capacity, but receives only 50% of the treatment capacity designated for dormitory sanitation. The boys' dormitory accommodates the remaining 44.4% of residents and also receives 50% of the treatment capacity. Assuming a discharge of 56 L/person/day, both dormitories reach their reported daily capacity at the same absolute number of residents. However, the larger dormitory reaches this threshold at a much lower proportion of its available beds. This disparity explains why the girls' dormitory accounts for 70.4% of the estimated facility-wide shortfall, without requiring any assumption of higher per capita water use.

The distinction between occupancy and individual water use is particularly important when comparing the two dormitories with published studies. Measurements from two student residences in Portugal attributed 46.0% and 61.4% of total consumption to showers, while kitchen taps accounted for between 11.5% and 31.5% [1]. In Belgium, meter records from six student residences indicated that per-capita consumption in four buildings was below the national household average, but the available evidence did not clarify why consumption was higher in the other two [5]. These findings demonstrate that observed differences between buildings require supporting evidence on fixtures, activities, and occupancy before attributing them to resident behavior. In the current water balance, the 4.480 m³/day difference between the dormitories is entirely explained by the 80

additional residential places multiplied by the standard allowance of 56 L/person/day. Whether this difference persists during operation depends on actual bed occupancy and the volume of water reaching each inlet [1].

4.2 Sensitivity of Estimated Inflow to the Wastewater Return Fraction

Classifying a unit as potentially overloaded depends partly on the proportion of water use assumed to reach it. The boys' dormitory illustrates why similar discharge estimates from different studies do not establish that a particular return fraction is appropriate. A boarding-school study in Banyuwangi reported 17.76 m^3/day of wastewater from 22.20 m^3/day of water use, implying a return fraction of 80% [5]. The present estimate for the boys' dormitory is almost identical at 17.920 m^3/day, although it was calculated from a higher water demand of 25.600 m^3/day and a lower return fraction of 70%. If the 80% fraction were applied to the same North Toraja water demand, estimated flow would increase to 20.480 m^3/day, and the shortfall relative to the 15 m^3/day rating would rise from 2.920 to 5.480 m^3/day. The comparison with Banyuwangi therefore supports the order of magnitude while leaving considerable uncertainty about the size of the local shortfall.

A more informative approach is to calculate the return fraction at which each unit would precisely reach its reported rating [5]. This calculation holds full occupancy and the assumed water allowances constant. It divides each unit's reported capacity by the estimated water demand associated with its activities [10]. For the shared unit, it assumes a common return fraction for laundry and kitchen use, consistent with the original water balance.

Table 4. Sensitivity of the full-occupancy assessment to the wastewater return fraction

Treatment unit	Estimated water demand (m^3/day)	Reported capacity (m^3/day)	Return fraction used	Return fraction at capacity	Difference
Girls' dormitory	32.000	15.000	70.0%	15 ÷ 32 = 46.9%	23.1 percentage points
Boys' dormitory	25.600	15.000	70.0%	15 ÷ 25.6 = 58.6%	11.4 percentage points
Laundry and kitchen	6.480	5.000	80.0%	5 ÷ 6.48 = 77.2%	2.8 percentage points

The three margins have distinct implications. At full occupancy and with the stated water allowance, the girls' dormitory would remain above its reported capacity unless the return fraction decreased from 70.0% to approximately 46.9% or lower. For the shared unit, a reduction from 80.0% to approximately 77.2% would bring the estimated daily flow within its rated capacity [11]. Therefore, an uncertainty of only a few percentage points could alter the assessment of the shared unit, while the evaluation of the girls' dormitory would remain unaffected. These calculations do not determine which return fraction applies in practice; rather, they show where increased measurement precision could influence decision-making. For the shared unit, measuring actual discharge could clarify whether a daily shortfall exists. For the girls' dormitory, confirming actual occupancy and the reported treatment rating is at least as critical as refining the return fraction.

4.3 Impact of Dormitory Occupancy Distribution on Treatment Unit Loading

A facility-wide occupancy figure conceals the effect of separate drainage routes. Consider two illustrative arrangements with the same total of 500 residents. If each dormitory houses 250 residents, the estimated sanitation flow is 14.000 m^3/day per unit, within each reported rating of 15 m^3/day. If 300 residents occupy the girls' dormitory and 200 occupy the boys' dormitory, their estimated flows become 16.800 and 11.200 m^3/day, respectively. The girls' unit would exceed its rating by 1.800 m^3/day, even though the boys' unit would have 3.800 m^3/day of unused capacity. In

both arrangements, the shared unit would receive the same estimated 3.600 m^3/day, and total facility flow would remain 31.600 m^3/day, below the combined 35 m^3/day rating. These scenarios use the study allowances, not observed occupancy records.

This comparison illustrates that total enrollment, total occupied beds, or a single campus water meter provide an incomplete basis for evaluating the current installation. Each metric could yield the same facility-wide estimate under different occupancy distributions, yet produce different outcomes for the girls' unit. Spare capacity in other units matters only if the drainage system permits flow redistribution. At full occupancy, an additional constraint arises: all three units exceed their reported ratings under the model assumptions. In this scenario, redirecting flow may alter the location of the estimated shortfall, but the combined deficit of 10.504 m^3/day would persist [11]. This distinction is critical when determining whether issues can be resolved by rerouting flows or if additional treatment capacity is necessary.

4.4 Implications of Estimated Hydraulic Loading on Treatment Performance

The water balance quantifies the volume each unit is expected to receive but does not determine the resulting effluent quality. Hydraulic loading is measured in m^3/day, while the pollutant mass entering a unit depends on both flow and influent concentration. Therefore, the observation that dormitory sanitation constitutes 88.6% of estimated wastewater volume should not be interpreted as indicating it also contributes 88.6% of the organic or suspended-solids load. An Indonesian review underscores this distinction: among nine decentralized treatment units in Yogyakarta, biochemical oxygen demand removal ranged from 23% to 97%, and effluent concentrations varied from 12 to 105 mg/L. This wide variation highlights the need to evaluate effluent quality using unit-specific data rather than inferring it from daily flow estimates [3].

Differences between the units also determine which operational measurements are most informative. For the girls' dormitory, simultaneous records of occupied beds and daily inlet volume would enable direct testing of the assumed sanitation discharge of 56 L/person/day [11]. In the shared unit, the estimated excess is only 184 L/day across 720 users [12]. While a daily total could indicate whether this small average difference persists, targeted measurements during laundry discharge and kitchen cleaning would clarify whether these activities generate coincident peaks. A unit may have sufficient daily capacity yet still experience brief periods of high inflow. Conversely, an estimated daily exceedance does not provide evidence that overflow, bypass, or deterioration in effluent quality has occurred.

The primary inference from this assessment is to prioritize capacity verification. The girls' dormitory shows the largest estimated shortfall, reaches its reported rating at the lowest residential occupancy, and remains above that rating across a broader range of return fractions than other units. The shared unit poses a narrower issue, as its classification shifts with minor adjustments to the assumed discharge. Prior to using these findings to inform expansion decisions, the reported daily ratings must be confirmed: the operating description presents them in m^3/day, while the dimensional specifications list the same values in m^3. Confirming the girls' unit's rated throughput and measuring inflow alongside occupied-bed counts would most directly assess whether the principal shortfall identified by the water balance persists under actual operating conditions.

5. CONCLUSION

In the full-occupancy scenario, the reported treatment capacities are insufficient to meet the estimated average daily inflow for any of the three units. The principal constraint is the girls' dormitory, which possesses the same treatment capacity as the boys' dormitory but serves a larger residential population. The projected shortfall at the shared laundry and kitchen unit is highly sensitive to the proportion of water assumed to be discharged as wastewater. These results highlight the need to account for both resident distribution and the drainage route associated with each

activity during capacity planning. At full occupancy, rerouting wastewater among the units would redistribute the projected shortfall without changing the overall capacity requirement.

Prior to determining the need for expanded treatment capacity, the school should verify each unit's rated daily throughput. The operating description specifies ratings in m^3/day, while the dimensional specifications present the same values in m^3. At the start of operations, record daily inlet volumes alongside occupied-bed counts, beginning with the girls' dormitory. At the shared unit, collecting measurements during laundry discharge and kitchen cleaning will clarify whether peak flows coincide and whether the minor projected daily shortfall persists.

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