



Integrated Proximate and Contamination Analysis of Tofu Wastewater: A Case Study in Telaga Subdistrict, Gorontalo, Indonesia

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Abbreviation: Nat. Env. & Poll. Technol.

Website: www.neptjournal.com

Received: 17-09-2025

Revised: 25-11-2025

Accepted: 28-11-2025

Key Words:

Tofu wastewater
Proximate analysis
Contamination
COD
BOD
Circular economy

Citation for the Paper:

Taupik, M., Hutuba, A.H., Thomas, N.A., Makkulawu, A. and Suharmin, W.N., 2026. Integrated proximate and contamination analysis of tofu wastewater: A case study in Telaga Subdistrict, Gorontalo, Indonesia. *Nature Environment and Pollution Technology*, 25(3), D1870. <https://doi.org/10.46488/NEPT.2026.v25i03.D1870>

Note: From 2025, the journal has adopted the use of Article IDs in citations instead of traditional consecutive page numbers. Each article is now given individual page ranges starting from page 1.



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ABSTRACT

Tofu wastewater is a major contributor to organic pollution in many Asian rivers; however, household-scale tofu production in eastern Indonesia remains poorly documented. This study provides an integrated characterization of tofu and its wastewater in the Telaga Subdistrict, Gorontalo, as baseline information for local water management. The proximate composition of tofu and wastewater was determined following standard AOAC methods, and river water was sampled at three points: upstream (A), downstream (B), and the wastewater channel (C). Contamination parameters (COD, BOD, TSS, ammonia, and pH) were assessed and compared using one-way analysis of variance (ANOVA) with Tukey's test. Tofu retained high moisture and moderate protein levels, confirming its role as an affordable protein source, while the wastewater still contained soluble proteins and carbohydrates. At Point C, COD (7499 mg.L⁻¹), BOD (864 mg.L⁻¹), and TSS (147 mg.L⁻¹) substantially exceeded national and international thresholds, whereas ammonia (0.01–0.10 mg.L⁻¹) and pH (7.2–7.3) remained within regulatory limits and were lower than those commonly reported for tofu effluents elsewhere. Although wastewater flow was not measured, the very high organic concentrations indicate that even household-scale tofu industries can exert considerable local organic pollution pressure and should be included in water quality monitoring and low-cost treatment programs. At the same time, the presence of residual nutrients suggests potential for valorization pathways such as biogas generation or microbial biomass production, which should be explored in future studies to support context-appropriate circular economy initiatives in Gorontalo.

1. INTRODUCTION

Recent research has explored both the treatment and valorization pathways of tofu wastewater. For instance, phytoremediation using water lettuce and *Pistia stratiotes* achieved significant reductions in COD and BOD, highlighting the potential of aquatic plants as low-cost treatment systems (Nurpita & Temmy 2022, Kurniawan et al. 2024). Constructed wetlands with *Typha angustifolia* and *Ipomoea aquatica* also demonstrated a 68–70% reduction in organic loads (Rohmah et al. 2023). Physicochemical approaches such as coagulation-flocculation with polyaluminium chloride, multilevel filtration, and photocatalysis using TiO₂ have been applied to reduce turbidity, COD, and TSS (Prasetyo et al. 2021, Widyastuti et al. 2023). Advanced methods that combine adsorption, Fenton oxidation, and ultrafiltration membranes have further improved the removal efficiency (Liu et al. 2024). Beyond treatment, valorization studies have shown that tofu wastewater can support microalgal cultivation, producing biomass enriched in protein and valuable proximate components (Putri et al. 2024), while anaerobic digestion coupled with microbial consortia produces methane-rich biogas (Budiastuti et al. 2021).

Despite these advances, current research on tofu wastewater still has important blind spots. Many investigations have prioritized treatment efficiency and regulatory compliance, while the residual nutrient composition that could underpin value-added applications has received comparatively less emphasis (Chen et al.

2022, Dewi et al. 2024). Nevertheless, previous studies have demonstrated that tofu effluent can retain appreciable amounts of protein, carbohydrates, and fat, indicating untapped potential for resource recovery (Chen et al. 2022, Dewi et al. 2024). Geographically, published studies are heavily concentrated in Java, with far fewer reports from Sumatra, Kalimantan, and Sulawesi (Pradana et al. 2023, Ridhuan et al. 2022). Localized household-scale industries in peripheral regions, such as Gorontalo, have received little attention; therefore, basic information on both contamination profiles and residual nutrient content remains scarce. While several authors have reported either contamination indicators or proximate composition, there is still limited baseline information that considers both dimensions together for household tofu wastewater in under-reported eastern Indonesian settings, which is needed to support circular-economy-oriented management.

This study provides an integrated baseline description of tofu, its wastewater, and receiving river water in household-scale tofu industries in the Telaga Subdistrict of Gorontalo, Indonesia. Specifically, we (i) determined the proximate composition of tofu and its wastewater, (ii) quantified key contamination parameters (BOD, COD, TSS, ammonia, and pH) at upstream, downstream, and wastewater discharge points relative to regulatory thresholds, and (iii) discussed the implications of these concentration profiles for local water quality management and potential valorization options. In doing so, this study offers empirical baseline data from an underrepresented region and highlights that tofu wastewater in Gorontalo is not only an environmental concern but also a potential resource for future circular-economy initiatives.

2. MATERIALS AND METHODS

2.1. Study Area and Sampling Strategy

This study was conducted in the Telaga Subdistrict, Gorontalo, Indonesia, where tofu production is operated at a household scale and liquid effluents are discharged directly into nearby rivers. Sampling was conducted at three points (Fig. 1): Point A ($0^{\circ}34'43.13''$ N, $123^{\circ}02'48.92''$ E) representing the upstream river section before contact with the tofu effluent, Point B ($0^{\circ}34'42.61''$ N, $123^{\circ}02'48.33''$ E) representing the downstream river section after effluent discharge, and Point C ($0^{\circ}34'42.23''$ N, $123^{\circ}02'48.16''$ E) representing the drainage channel directly releasing tofu wastewater.

To capture short-term temporal variability, a composite water sample was collected at each point (A, B, and C) weekly for three consecutive weeks, resulting in three independent temporal replicates ($n = 3$) per point. Each weekly composite sample was prepared by combining several grab subsamples taken at approximately equal time intervals during active tofu production. In the laboratory, all physicochemical parameters (COD, BOD, TSS, pH, and ammonia) were measured in triplicate for each weekly sample, and the mean of the three analytical replicates was used as a single observation in subsequent statistical analyses. Water collection and handling followed the Indonesian National Standard for water sampling (SNI 6989.57:2008), which provides guidelines for representative and contamination-free sampling, and the upstream–downstream design was consistent with recent tofu wastewater studies (Rahman & Fajriati 2021, Pradana et al. 2023).

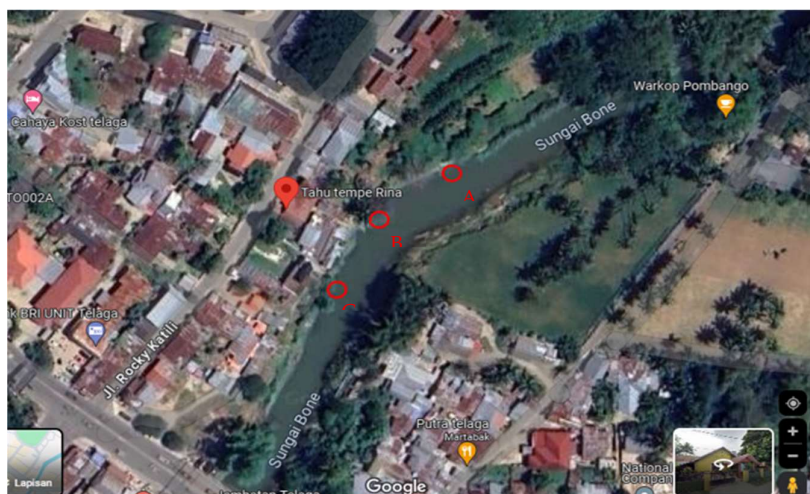


Fig. 1: Sampling locations (Points A, B, and C) in Telaga Subdistrict, Gorontalo, Indonesia.

2.2. Instruments and Analytical Conditions

The pH was measured using a calibrated benchtop pH meter (Thermo Scientific Orion Star A211) with daily three-point calibration at pH 4.01, 7.00, and 10.01 (NIST-traceable buffers). Total suspended solids (TSS) were measured following APHA 2540 D using Whatman GF/C 1.2 μm glass-fiber filters and an analytical balance (Sartorius Entris II, readability 0.1 mg). The samples were dried at 103–105 $^{\circ}\text{C}$ in a laboratory oven (Mettler UF55). The biochemical oxygen demand (BOD) was determined by 5-day incubation at 20 ± 1 $^{\circ}\text{C}$ in a BOD incubator (VELP FOC 120E). Dissolved oxygen was measured using an optical DO meter (Hach HQ40d with an Intellical LDO101 probe). Ammonia was analyzed using a Merck Pharo 300 photometer with the appropriate colorimetric method. All instruments were calibrated according to the manufacturer's recommendations, and quality control included blanks, duplicates, and linearity verification ($R^2 \geq 0.997$).

2.3. Materials and Reagents

All chemicals were of analytical grade, including concentrated sulfuric acid (H_2SO_4), sodium hydroxide (NaOH), boric acid (H_3BO_3), chloroform, catalyst tablets, hydrochloric acid (HCl), potassium hydroxide (KOH), chemical oxygen demand (COD) reagent kits, nutrient buffer pillows, and distilled water. Tofu products and wastewater samples were collected from local household tofu industries in the Telaga Subdistrict. Analytical procedures were conducted at accredited laboratories following the Indonesian National Standards (SNI) and APHA protocols (APHA 2017).

2.4. Proximate Analysis

Proximate composition was analyzed following SNI protocols: protein content via the Kjeldahl method (SNI 01-2354.4:2006), fat content through Soxhlet extraction (SNI 01-2354.3:2006), moisture determined by oven drying at 100 $^{\circ}\text{C}$ (SNI 01-2354.2:2006), and ash by incineration in a muffle furnace (SNI 01-2354.1:2006). Carbohydrate content was calculated by difference. All measurements were conducted in triplicate. These standardized methods are commonly used for characterizing soybean by-products (Chen et al. 2022, Dewi et al. 2024).

2.5. Contamination Analysis

Wastewater contamination was evaluated through measurements of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), pH, and ammonia levels. BOD_5 was determined following the APHA 5210 method (APHA 2017), while COD was measured using closed reflux spectrophotometry

in accordance with SNI 6989.2:2009. TSS was quantified via the gravimetric method per SNI 06-6989.25-2005. For samples with undiluted COD values exceeding the calibration range, serial dilutions with distilled water (up to 20-fold) were prepared to ensure absorbance readings fell within the 0–10,000 $\text{mg}\cdot\text{L}^{-1}$ calibration curve. Final COD concentrations were calculated by multiplying the instrument readings by the appropriate dilution factors. Ammonia and pH were measured with a Pharo 300 spectrophotometer (Merck). These parameters serve as indicators of organic pollution in tofu wastewater (Kurniawan et al. 2024, Liu et al. 2024).

2.6. Quality Control and Data Validation

All analyses were conducted in triplicate, and method blanks were included in every batch. Calibration for spectrophotometric analyses (COD and ammonia) employed at least five concentration levels, with linearity accepted at $R^2 \geq 0.995$. Precision was evaluated using the relative standard deviation (%RSD) of triplicate measurements, with acceptance limits of ≤ 5 –7% for proximate assays and $\leq 10\%$ for wastewater parameters. For spectrophotometric contamination measurements, spike recovery acceptance limits were set at 90–110%, and recoveries within this range were considered analytically acceptable, as summarized in Table 4. The method detection limits (LOD) and limits of quantitation (LOQ) were estimated using the standard deviation of the blanks and the slope of the calibration curves ($\text{LOD} = 3.3 \sigma\cdot\text{m}^{-1}$, $\text{LOQ} = 10 \sigma\cdot\text{m}^{-1}$). Laboratory control materials were included for proximate tests, and duplicate gravimetric runs were performed to verify the precision of the total suspended solids (TSS). Results failing the QC criteria were re-analyzed.

2.7. Data Analysis

Descriptive statistics, including mean, standard deviation, and %RSD, were calculated for all parameters. For each sampling point (A, B, and C), three weekly mean values—obtained from analytical triplicates—were averaged over the three-week sampling period. These weekly means ($n=3$ per point) served as independent observations in the statistical analysis. One-way ANOVA tested for differences among sampling points for each water quality parameter (BOD , COD , TSS , ammonia, and pH), followed by Tukey's post hoc test when ANOVA results were significant ($\alpha=0.05$). Before ANOVA, data were assessed for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test. Results are reported as the mean \pm standard deviation of the three weekly observations. Different superscript letters in the tables denote significant differences between sampling points based on the ANOVA–Tukey

procedure. Statistical analyses were conducted using SPSS version 26 (IBM Corp., USA), with a significance level set at $\alpha=0.05$. Findings were compared to Indonesian wastewater quality standards (Government Regulation of the Republic of Indonesia No. 22/2021) and international benchmarks (WHO 2017, USEPA 2020).

3. RESULTS

3.1. Proximate Composition of Tofu

The proximate composition of tofu produced in household-scale industries within the Telaga Subdistrict is summarized in Table 1. Moisture was the predominant component, ranging from $81.72 \pm 1.63\%$ to $82.06 \pm 1.65\%$ (%RSD 1.99–2.01%), followed by protein ($6.10 \pm 0.12\%$ to $7.08 \pm 0.14\%$, %RSD 1.97–2.07%), carbohydrates ($7.50 \pm 0.19\%$ to $9.47 \pm 0.12\%$, %RSD 1.22–2.53%), fat ($1.36 \pm 0.07\%$ to $2.72 \pm 0.11\%$, %RSD 4.04–5.15%), and ash ($0.79 \pm 0.04\%$ to $1.32 \pm 0.05\%$, %RSD 3.79–5.06%). These findings indicate that the proximate composition remained relatively consistent across three consecutive weeks, implying that weekly variations in soybean raw materials or household processing practices had minimal impact on the nutritional quality of the tofu.

The protein content (6.10–7.08%) confirmed the role of tofu as an affordable plant-based protein source. This finding aligns with earlier reports that fresh tofu generally contains 6–9% protein (Chen et al. 2022, Feng et al. 2021). Fat levels were consistently low (1.36–2.72%), supporting

the classification of tofu as a low-fat food that is beneficial for cardiovascular health (Li et al. 2020). Carbohydrate variation (7.50–9.47%) may be explained by soluble sugars and oligosaccharides that remain in the curd matrix, consistent with previous soybean product studies (Wang et al. 2021).

Moisture levels consistently above 81% are typical for fresh tofu and are essential for preserving its soft texture. However, such high moisture content also increases the risk of microbial spoilage, as noted by Zhang et al. (2023). The ash content, ranging from 0.79% to 1.32%, indicates stable mineral levels, aligning with measurements from other Southeast Asian tofu studies (Utami et al. 2012). Precision testing confirmed that all parameters met the acceptable standards, with %RSD values significantly below the 5–7% threshold, demonstrating the reproducibility of the analyses. Overall, the proximate composition of tofu from the Telaga Subdistrict aligns with both national and international data, reaffirming its nutritional value. These results also serve as a baseline for assessing nutrient residues in tofu wastewater, discussed further in the next section.

3.2. Proximate Composition of Tofu Wastewater

To assess the nutrient residues released during tofu processing, the proximate composition of tofu wastewater was analyzed, with results shown in Table 2. Moisture was the predominant component, ranging from $97.61 \pm 1.95\%$ to $99.18 \pm 1.98\%$ (%RSD 1.95–2.03%), while protein, fat, carbohydrates, and ash were present in smaller proportions. Protein levels varied from $0.21 \pm 0.01\%$ to $0.47 \pm 0.01\%$

Table 1: Proximate composition of tofu samples collected over three weeks (mean \pm SD, %RSD, n = 3).

Parameter	Week 1 [Mean \pm SD]	%RSD	Week 2 [Mean \pm SD]	%RSD	Week 3 [Mean \pm SD]	%RSD
Protein [%]	7.08 \pm 0.14	1.97	6.27 \pm 0.13	2.07	6.10 \pm 0.12	1.97
Fat [%]	2.72 \pm 0.11	4.04	1.41 \pm 0.07	4.96	1.36 \pm 0.07	5.15
Carbohydrate [%]	7.50 \pm 0.19	2.53	9.40 \pm 0.23	2.45	9.47 \pm 0.12	1.22
Moisture [%]	81.78 \pm 1.64	2.01	82.06 \pm 1.65	2.01	81.72 \pm 1.63	1.99
Ash [%]	0.91 \pm 0.04	4.40	0.79 \pm 0.04	5.06	1.32 \pm 0.05	3.79

Note: Values represent mean \pm SD of triplicate determinations, %RSD calculated as (SD/mean) \times 100. All %RSD values met acceptance limits (≤ 5 –7%) for proximate analysis (Chen et al. 2022, Feng et al. 2021).

Table 2: Proximate composition of tofu wastewater samples collected over three weeks (mean \pm SD, %RSD, n = 3).

Parameter	Week 1 [Mean \pm SD]	%RSD	Week 2 [Mean \pm SD]	%RSD	Week 3 [Mean \pm SD]	%RSD
Protein [%]	0.42 \pm 0.01	2.38	0.47 \pm 0.01	2.13	0.21 \pm 0.01	4.76
Fat [%]	0.60 \pm 0.02	3.33	0.45 \pm 0.02	4.44	0.30 \pm 0.02	6.67
Carbohydrate [%]	0.90 \pm 0.02	2.22	0.20 \pm 0.01	5.00	0.30 \pm 0.01	3.33
Moisture [%]	97.61 \pm 1.95	2.00	99.18 \pm 1.98	2.00	98.74 \pm 1.97	1.99
Ash [%]	0.36 \pm 0.01	2.78	0.46 \pm 0.02	4.35	0.37 \pm 0.01	2.70

Note: Values represent mean \pm SD of triplicate determinations, %RSD calculated as (SD/mean) \times 100. All %RSD values were within the acceptance limits (≤ 5 –7%) for proximate analysis (Dewi et al. 2024, Wang et al. 2021).

Table 3: Contamination parameters of river water and tofu wastewater at three sampling points (mean \pm SD, n = 3).

Parameter	Point A (Upstream)	Point B (Downstream)	Point C (Wastewater Channel)	Quality Standard*
TSS [mg.L ⁻¹]	65.65 \pm 2.01 ^a	78.45 \pm 2.35 ^a	147.00 \pm 3.21 ^b	50
COD [mg.L ⁻¹]	62.00 \pm 1.88 ^a	72.00 \pm 2.14 ^a	7499.00 \pm 22.35 ^b	25
BOD [mg.L ⁻¹]	64.00 \pm 1.92 ^a	59.00 \pm 1.77 ^a	864.00 \pm 8.65 ^b	3
Ammonia [mg.L ⁻¹]	0.10 \pm 0.01 ^a	0.01 \pm 0.00 ^a	0.05 \pm 0.01 ^a	0.2
pH	7.3 \pm 0.1 ^a	7.2 \pm 0.1 ^a	7.2 \pm 0.1 ^a	6–9

Note: Values represent mean \pm SD of three weekly observations per sampling point, each derived from analytical triplicates. Different superscript letters within a row indicate significant differences among sampling points ($p < 0.05$, one-way ANOVA with Tukey's post hoc test). Standards based on Government Regulation of the Republic of Indonesia No. 22/2021, WHO (2017), USEPA (2020).

(%RSD 2.13–4.76%), fat from 0.30 \pm 0.02% to 0.60 \pm 0.02% (%RSD 3.33–6.67%), carbohydrates from 0.20 \pm 0.01% to 0.90 \pm 0.02% (%RSD 2.22–5.00%), and ash from 0.36 \pm 0.01% to 0.46 \pm 0.02% (%RSD 2.70–4.35%). These findings confirm that although most nutrients are retained within the tofu curds, measurable quantities are still released into the liquid effluent.

The protein content, ranging from 0.21% to 0.47%, indicates the leaching of soluble nitrogen compounds into the wastewater. Dewi et al. (2024) reported similar patterns, demonstrating that tofu wastewater can support microalgae growth due to its residual nitrogen. Although fat concentrations were low (0.30% to 0.60%), their presence points to inefficiencies in coagulation and pressing processes. Carbohydrate levels (0.20% to 0.90%) likely reflect soluble sugars and oligosaccharides not incorporated into the tofu, aligning with reports on soybean-based foods (Wang et al. 2021). Moisture content above 97% is typical, as the wastewater is predominantly liquid.

The ash fraction (0.36% to 0.46%) confirms that minerals from soybeans and coagulants also enter the effluent. Precision testing showed %RSD values below 7% for all parameters, indicating good reproducibility and meeting acceptance criteria. Overall, these results reveal that tofu wastewater contains organic pollutants and measurable nutrient residues.

Consistent with previous research, such nutrient-rich effluents could be suitable for valorization pathways such as biogas production or microbial biomass generation, though further targeted studies are necessary to evaluate key parameters like C:N ratio, biodegradability, and volatile solids, which were not assessed in this work.

3.3. Contamination Parameters and Method Validation

The contamination parameters of the river water and tofu wastewater are summarized in Table 3. Of the five parameters evaluated, COD, BOD, and TSS at Point C (the wastewater channel) were significantly higher than those at Points A and B. One-way ANOVA of the three weekly mean values per

point revealed that COD, BOD, and TSS differed statistically among sampling locations ($p < 0.05$), while ammonia and pH showed no significant differences ($p > 0.05$). Tukey's post-hoc test indicated that Point C had higher levels than Points A and B for COD, BOD, and TSS, with no notable differences between Points A and B.

Notably, COD and BOD at Point A (upstream) already surpassed the Indonesian river water quality standards (25 mg.L⁻¹ for COD and 3 mg.L⁻¹ for BOD), suggesting the influence of other upstream pollution sources unrelated to the studied tofu factory outlet. The slight differences between Points A and B for COD (62 vs. 72 mg.L⁻¹) and BOD (64 vs. 59 mg.L⁻¹) imply that, over the sampled short downstream reach, the additional impact of household tofu discharge on overall river quality is modest compared to existing background pollution.

To better illustrate these statistical differences, the data are visualized in Fig. 2. COD, BOD, and TSS at Point C were significantly higher than at the upstream and downstream river points, whereas ammonia and pH values showed no significant differences.

The high COD and BOD levels observed at Point C indicate significant organic pollution that exceeds regulatory standards and past tofu wastewater research, although the overall pollution load could not be determined due to the lack of flow rate measurements. These results align with reports from Central Java (Pradana et al. 2023), Bengkulu (Mualim et al. 2025), and international studies indicating that tofu wastewater is among the most concentrated soybean-based effluents (Liu et al. 2024). Ecological concerns include oxygen depletion caused by elevated organic matter and decreased light penetration from high TSS levels (Nurpita & Temmy 2022). In contrast, ammonia and pH values staying within permissible limits imply that organic material, rather than inorganic nitrogen or acidity, predominantly contaminates the water.

Reproducibility across replicate measurements was satisfactory, with %RSD less than 5% for COD and BOD, under 10% for TSS, and below 2% for pH, confirming

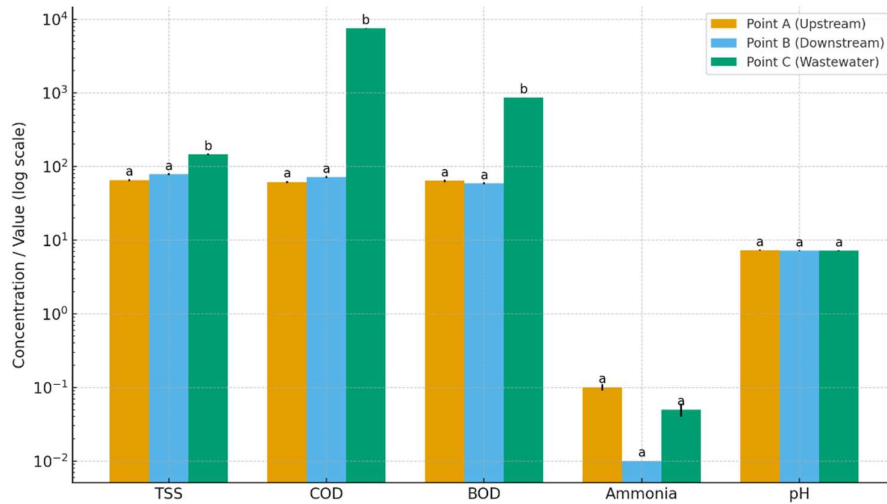


Fig. 2: Contamination parameters (TSS, COD, BOD, ammonia, and pH) of river water and tofu wastewater at three sampling points (Point A = upstream, Point B = downstream, Point C = wastewater channel). Values represent mean \pm SD ($n = 3$). Bars with different superscript letters indicate significant differences among sampling points ($p < 0.05$, ANOVA with Tukey's test).

Table 4: Method validation summary for contamination analysis.

Parameter	Calibration range	R ²	LOD	LOQ	%Recovery	%RSD [n=3]	QC Status
COD	0–10,000 mg.L ⁻¹	0.998	2.1 mg.L ⁻¹	6.4 mg.L ⁻¹	94–103%	<5%	Accepted
BOD	0–1,000 mg.L ⁻¹	–	–	–	–	<7%	Accepted
TSS	0–1,000 mg.L ⁻¹	–	–	–	–	<10%	Accepted
Ammonia	0–1,000 mg.L ⁻¹	0.997	0.02 mg.L ⁻¹	0.06 mg.L ⁻¹	92–105%	<5%	Accepted
pH	4–10 (pH buffer solutions)	0.999	–	–	–	<2%	Accepted

Note: COD and ammonia validated using calibration curves and matrix spike recoveries, BOD and TSS verified by replicate precision, and pH validated by buffer calibration.

consistent results. Method validation for each parameter, summarized in Table 4, further verified the reliability of the results. COD and ammonia analyses demonstrated excellent linearity ($R^2 \geq 0.997$) with detection limits of 2.1 mg.L⁻¹ and 0.02 mg.L⁻¹, respectively. Spike recoveries ranged from 92% to 105%, falling within acceptable limits (90–110%). Precision for BOD and TSS replicate measurements had %RSD under 10%, and pH calibration against standard buffers validated measurement accuracy.

The contamination data (Table 3) and the method validation results (Table 4) collectively highlight the extent of pollution in tofu wastewater and confirm the reliability of the analytical approach. These findings form a strong foundation for future discussions on mitigation measures and potential valorization strategies.

4. DISCUSSION

4.1. Comparative Analysis with Previous Studies

The findings of this study indicate that household-scale tofu industries in the Telaga Subdistrict discharge wastewater

with contamination levels that fall within the range reported in other regions of Indonesia and internationally. COD values at Point C (7499 mg.L⁻¹) and BOD (864 mg.L⁻¹) substantially exceeded Indonesian regulatory standards and were consistent with reports from Central Java, where COD concentrations in tofu effluents can exceed 7000 mg.L⁻¹ (Pradana et al. 2023) and from Bengkulu Province, where tofu-industry discharges have also been reported to surpass national discharge limits (Mualim et al. 2025). Liu et al. (2024) further emphasized that untreated tofu wastewater can reach COD levels exceeding 8000 mg.L⁻¹, confirming that the pollutant concentrations observed in this study fall within the upper range of values reported for soybean-based effluents globally.

Compared to studies employing remediation strategies, the results highlight both the risks and opportunities. Rohmah et al. (2023) demonstrated that constructed wetlands using *Typha angustifolia* and *Ipomoea aquatica* could reduce COD by up to 70%, whereas Kurniawan et al. (2024) reported successful phytoremediation of tofu wastewater with *Pistia stratiotes*. These interventions show promise for small-scale

industries, suggesting that similar low-cost and eco-friendly technologies could be adapted to the Telaga context.

Moreover, the presence of soluble proteins, carbohydrates, and minerals suggests that, consistent with previous reports, tofu wastewater could potentially serve as a feedstock for microalgae cultivation or anaerobic digestion (Dewi et al. 2024, Budiastuti et al. 2021). However, the present study did not evaluate nitrogen speciation, C:N ratio, biodegradability, or volatile solids; therefore, any valorization pathways should be regarded as hypothetical options derived from the literature rather than outcomes directly demonstrated by our data.

Taken together, this comparative analysis shows that although Telaga's tofu industries operate at a household scale, the concentrations of COD, BOD, and TSS in their wastewater fall within the upper range reported for tofu effluents in other regions. Therefore, this study provides empirical baseline evidence that small-scale tofu wastewater discharges can contribute to local water quality degradation and should be considered in river management strategies, even though the overall mass loading could not be quantified due to the absence of flow data.

This study had several limitations. First, sampling was restricted to a single subdistrict (Telaga) and covered only three weeks, which may not capture seasonal variations in wastewater characteristics and river hydrology. In addition, neither the discharge flow rate of the tofu effluent nor the river flow at the sampling reach was measured; therefore, the assessment was limited to concentration data, and mass loading ($\text{kg}\cdot\text{day}^{-1}$), dilution, and the total downstream pollution contribution of household tofu industries could not be quantified. Second, only a limited number of physicochemical parameters were assessed, focusing on proximate composition, COD, BOD, TSS, ammonia, and pH, without including microbiological indicators or heavy metals that would allow a more direct evaluation of human health and ecotoxicological risks. Third, although statistical analysis (ANOVA with Tukey's test) confirmed significant differences among sampling points, the relatively small sample size ($n = 3$ per parameter) limited the statistical power and generalizability of the results; therefore, these significance patterns should be interpreted as exploratory rather than definitive. Finally, this study focused on wastewater characterization without evaluating treatment or valorization technologies, which are necessary for developing practical mitigation strategies. Future studies should expand sampling coverage, incorporate flow rate measurements and broader environmental parameters (including microbial indicators), and test low-cost remediation and resource recovery approaches under local conditions to provide a more comprehensive assessment.

5. CONCLUSIONS

This study offers a comprehensive baseline assessment of tofu, its wastewater, and the receiving river water in household-scale tofu operations within the Telaga Subdistrict of Gorontalo, Indonesia. Proximate analysis revealed that although tofu retains most of its nutrients, residual proteins, carbohydrates, and minerals remain in the wastewater, which exhibits high levels of COD, BOD, and TSS at the discharge point—values that are within or near the upper limits reported for tofu effluents elsewhere. Statistical analysis of three weekly mean samples from each site demonstrated that contamination levels in the direct wastewater channel (Point C) consistently exceeded those at upstream and downstream river points, highlighting the household tofu outlet as a significant local source of organic pollution. However, the overall contribution by flow volume could not be assessed due to a lack of flow rate measurements.

The findings emphasize two key points: first, even small-scale tofu industries can impose substantial local organic pollution, with wastewater characteristics at the discharge point approaching those observed in larger operations elsewhere, despite the total pollution load remaining unquantified due to absent flow data; second, tofu wastewater is nutrient-rich and could be valorized, potentially for biogas production or microbial biomass generation. Nonetheless, such applications were not experimentally explored here and warrant further study tailored to local conditions. Collectively, these results provide valuable baseline data for policymakers and stakeholders to implement routine monitoring of tofu effluents and adjacent river sections, promote low-cost decentralized treatment methods like settling tanks, anaerobic ponds, or small constructed wetlands suited for household-scale systems, and incorporate wastewater management into local environmental policies and community awareness programs. Future research should include flow and dilution assessments, microbiological water quality testing, and pilot-scale treatment or valorization trials to better quantify pollutant loads, health risks, and the potential for circular economy solutions in household tofu production.

6. ACKNOWLEDGMENTS

The authors gratefully acknowledge the technical and laboratory support provided by the Faculty of Sports and Health, Gorontalo State University.

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