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Research Article

Physicochemical Characterization and Water Quality Feasibility across Three Source Water Types in the Ciputat Area, South Tangerang

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Abstract

This study aims to characterize the physicochemical quality and assess the water quality feasibility across three source Water Source Type used in parallel within the Ciputat area, South Tangerang, namely tap water from public facilities and residential areas (Type I, n = 4), tap water from university buildings at Universitas Islam Negeri Syarif Hidayatullah Jakarta (Type II, n = 8), and drinking water from refill stations (Type III, n = 8), evaluated against the Ministry of Health Regulation (Permenkes) No. 2 of 2023. In situ parameters included pH, temperature, dissolved oxygen (DO), turbidity, total dissolved solids (TDS), and salinity. Laboratory analyses encompassed iron (Fe) and manganese (Mn) determination via atomic absorption spectrophotometry (AAS) across all three Water Source Types, as well as ammonia (N-NH_3) and phosphate (P-PO_4) analysis using UV-Vis spectrophotometry specifically for Water Source Types II and III. The results indicated that the turbidity of all samples (3.70–23.81 NTU) exceeded the maximum permissible limit of less than 3 NTU across all three water sources. Whereas, based on the WHO guideline, drinking water turbidity should not exceed 5 NTU [1]. The campus tap water was dominated by acidic pH levels (5.40–7.50), with six out of eight buildings falling below the minimum threshold of 6.5. Iron levels in all samples were below the method detection limit, whereas manganese levels exceeded the quality standard of 0.1 mg/L exclusively in Water Source Type I (0.336–0.853 mg/L), which is consistent with geogenic sources in shallow groundwater. The N-NH_3 and P-PO_4 concentrations in all samples complied with the specific parameter standards of Permenkes No. 2 of 2023. In conclusion, no matrix satisfied all parameters simultaneously. Hence, corrective interventions must be tailored to the dominant characteristics of each respective water source.

Keywords: physicochemical; tap water; water quality; water refill station

1. INTRODUCTION

Safe drinking water and clean water are fundamental prerequisites for public health and constitute a core target of Sustainable Development Goals (SDGs) Indicator 6.1, which aims to achieve universal access to safe drinking water by 2030 [1]. In Indonesia, daily water demands are generally met through public piping systems, private borewells, and water refill stations (DAMIU), which have rapidly expanded as an economical alternative for drinking water [2]. The quality across these three sources is not always equivalent, as it is influenced by aquifer characteristics, the condition of distribution pipelines, and the maintenance standards of treatment units at the provider level [3].

Water quality degradation can originate from both natural (geogenic) sources and human (anthropogenic) activities. The dissolution of iron and manganese oxide minerals from soil layers and bedrock constitutes the primary source of Fe and Mn in shallow groundwater within tropical regions [4,5]. Meanwhile, the discharge of domestic waste, detergents, nitrogen fertilizers, and fecal matter from inadequate sanitation systems increases the load of inorganic nitrogen compounds and orthophosphates in aquatic environments [6,7]. Iron and manganese concentrations that exceed the permissible thresholds can induce aesthetic issues, such as discoloration, unpleasant odors, and a metallic taste in water, as well as cause health impairments upon long-term exposure, particularly neurological disorders induced by Mn [8,9,10]. Ammonia serves as an indicator of recent organic waste contamination and may exhibit toxic effects at elevated concentrations, whereas excessive phosphate is closely associated with eutrophication and the depletion of dissolved oxygen [11,12].

In Indonesia, drinking water quality standards are regulated under the Regulation of the Minister

of Health of the Republic of Indonesia No. 2 of 2023 concerning the Implementation of Government Regulation No. 66 of 2014 on Environmental Health. This regulation establishes mandatory drinking water quality parameters, including turbidity (<3 NTU), total dissolved solids (TDS, <300 mg/L), pH (6.5–8.5), dissolved iron (0.2 mg/L), dissolved manganese (0.1 mg/L), phosphate (as P, 0.2 mg/L), and ammonia (1.5 mg/L) [13].

The Ciputat and South Tangerang areas are densely populated urban regions characterized by complex patterns of water use. As a major higher education hub, these areas support a large population that relies simultaneously on multiple water sources, including tap water from public facilities and residential areas, which is generally supplied by shallow groundwater, tap water distributed through the campus internal piping system, and refill drinking water produced by drinking water refill stations (DAMIU), which is consumed directly as drinking water. Previous studies conducted in similar urban settings have generally focused on a single type of water source, such as refill drinking water alone [14] or residential well water [15]. Consequently, a comparative assessment of the three water sources simultaneously used by the community remains unavailable, particularly with respect to variations in metal and nutrient profiles among different water sources.

This study aimed to characterize the physicochemical quality and assess the suitability of three water source types in the Ciputat-South Tangerang area: (1) tap water from public facilities and residential areas, (2) campus tap water distributed through buildings at Syarif Hidayatullah State Islamic University Jakarta, and (3) refill drinking water produced by drinking water refill stations located around the campus, using the Indonesian Minister of Health Regulation No. 2 of 2023 as the reference standard. The analysed parameters included pH, temperature, dissolved oxygen (DO), turbidity, total dissolved solids (TDS), and salinity, measured *in situ*. Iron (Fe) and manganese (Mn) were determined by atomic absorption spectrophotometry (AAS) for all three water source types. Ammonia ($N–NH_3$) and phosphate ($P–PO_4$) were determined by UV–Vis spectrophotometry for campus tap water and refill drinking water. The novelty of this study lies in the comparative assessment of three water source types simultaneously used by the same population, providing empirical evidence to support area-based water quality monitoring and management.

The physicochemical parameters analysed in this study were selected because they are directly regulated as mandatory or special parameters under the Indonesian Minister of Health Regulation No. 2 of 2023, are measurable with the available AAS and UV-Vis instrumentation, and correspond to the dominant contamination pathways anticipated in the study area, namely geogenic metals originating from shallow groundwater and nutrient loading from domestic sources. Other important drinking-water parameters, including nitrate, nitrite, residual chlorine, sulphate, total hardness, and microbiological indicators (*Escherichia coli* and total *coliforms*) were beyond the analytical scope of this study. Accordingly, the present assessment should be regarded as a physicochemical screening rather than a complete potability determination, and these parameters are identified as priorities for subsequent work.

2. MATERIALS AND METHODS

2.1. Materials

In situ parameters were measured using a pH meter, dissolved oxygen (DO) meter, and turbidimeter. Iron (Fe) and manganese (Mn) concentrations were determined using an Agilent 280FS AA Atomic Absorption Spectrophotometer (AAS). Ammonia ($N–NH_3$) and phosphate ($P–PO_4$) concentrations were analysed using a UV-Vis spectrophotometer. All chemicals were of analytical grade and included concentrated HNO_3, Fe and Mn standard stock

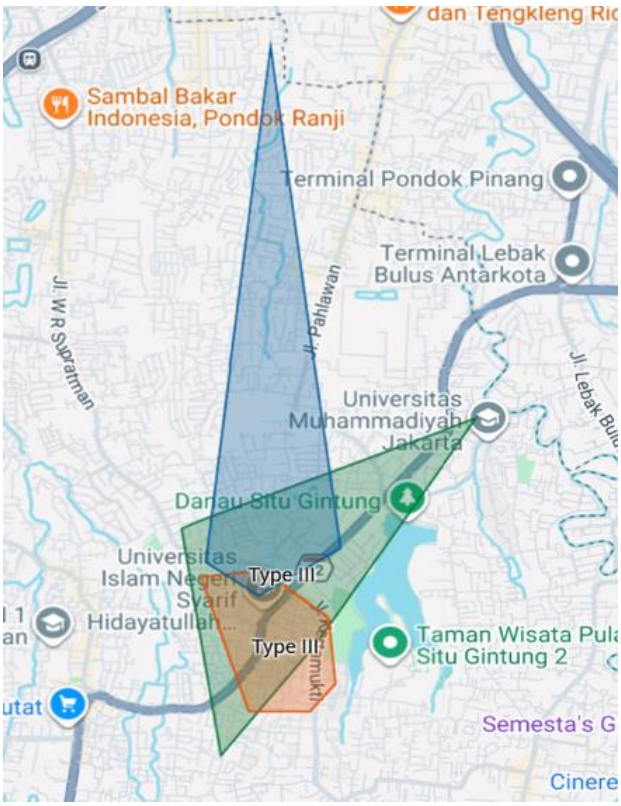

Figure 1. Sampling locations in the Ciputat-South Tangerang area. The sampling sites are presented as anonymized zones rather than their exact locations. Different colours represent the three water source types included in this study.

solutions, phenol, sodium nitroprusside ($Na_2[Fe(CN)_5NO]\cdot 2H_2O$), alkaline citrate solution, sodium hypochlorite, NH_4Cl standard stock solution, KH_2PO_4 standard stock solution, ammonium molybdate, potassium antimony tartrate, ascorbic acid, concentrated H_2SO_4, and deionized water

2.2. Methods

The study was conducted from March to May 2026 at the Integrated Laboratory Center, Faculty of Science and Technology, Syarif Hidayatullah State Islamic University Jakarta. Water samples were collected from three water source types in the Ciputat-South Tangerang area, comprising a total of 20 sampling sites (Figure 1). Iron (Fe) and manganese (Mn) were analyzed in all three water source types, whereas ammonia ($N–NH_3$) and phosphate ($P–PO_4$) were analyzed only in Water Source Types II and III (n = 16).

Water Source Type I consisted of tap water from public facilities and residential areas (n = 4), including taps located in educational building restrooms, a police post, a mosque, and one residential area in the Pesanggrahan area. The identity and exact location of the residential sampling site were withheld to protect privacy. Water Source Type II comprised campus tap water (n = 8) collected from eight university buildings: the Faculty I, Faculty II, Faculty III, Building I, Faculty III, Faculty IV, Faculty VI, and Building II. Water Source Type III consisted of refill drinking water (n = 8) collected from eight different drinking water refill stations (DAMIU) located around the campus. The refill stations were anonymized and labeled A–H to protect the identities of the service providers.

2.2.1. Sample Collection, Preservation, and In Situ Measurements

Water samples were collected in accordance with the Indonesian National Standard (SNI 6989.57:2008 [16]. During transportation, samples were stored at approximately 4 °C. Samples intended for iron (Fe) and manganese (Mn) analysis were preserved by acidification with concentrated HNO_3 to pH < 2, whereas samples for ammonia ($N–NH_3$) and phosphate ($P–PO_4$) analysis were kept refrigerated and analysed as soon as possible. The *in-situ*

parameters, including pH, temperature, dissolved oxygen (DO), turbidity, total dissolved solids (TDS), and salinity, were measured on site using calibrated instruments.

2.2.2. Determination of Iron, Manganese, Ammonia, and Phosphate

Iron (Fe) and manganese (Mn) concentrations were determined by flame atomic absorption spectrophotometry (AAS) using an air-acetylene flame at wavelengths of 248.3 nm for Fe and 279.5 nm for Mn [17,18]. Calibration curves were prepared over concentration ranges of 0–4 mg/L for Fe and 0–2 mg/L for Mn, and sample concentrations were calculated from the corresponding linear regression equations.

Ammonia ($N–NH_3$) concentrations in Water Source Types II and III were determined by UV-Vis spectrophotometry using the phenate method in accordance with SNI 06-6989.30-2005. The method is based on the Berthelot reaction, which produces a blue indophenol complex [19]. Calibration standards ranging from 0 to 0.6 mg/L were prepared, and absorbance was measured at 640 nm.

Orthophosphate ($P–PO_4$) concentrations in Water Source Types II and III were determined by UV-Vis spectrophotometry using the ascorbic acid method according to SNI 06-6989.31-2005 [20]. The method is based on the formation of a molybdenum blue complex with maximum absorbance at 880 nm. Calibration standards were prepared over the concentration range of 0–1.0 mg/L.

2.2.3. Data Processing and Water Quality Assessment

Method linearity was evaluated using the coefficient of determination ($R^2 \geq 0.99$). The limit of detection (LOD) and limit of quantification (LOQ) were calculated according to the IUPAC approach, where LOD = 3.3σ/b and LOQ = 10σ/b, with σ representing the standard deviation of the regression residuals and *b* the slope of the calibration curve. Sample concentrations were quantified using the calibration curve corresponding to the analytical session or instrument used, whereas comparisons among water source types were performed using concentration values (mg/L). Results below the LOD were reported as <LOD. Water quality suitability was evaluated based on the Indonesian Minister of Health Regulation No. 2 of 202 [13]. The absence of nutrient analyses for Water Source Type I is acknowledged as a limitation of this study.

3. RESULTS AND DISCUSSIONS

3.1. In-situ Physicochemical Parameters

The results of the *in-situ* measurements for six physicochemical parameters at 20 sampling sites representing the three water source types are summarized in Table 1. Overall, pH, total dissolved solids (TDS), and turbidity exhibited distinct characteristics among the different water source types, whereas salinity was consistently recorded as zero in all samples, indicating that all water sources were classified as freshwater.

The pH values exhibited clear differences among the three water source types (Figure 2a). All refill drinking water samples (Water Source Type III) fell within the acceptable range (7.55–8.50), while tap water from public facilities and residential areas (Water Source Type I) generally complied with the standard, except for the police post, which slightly exceeded the upper limit (pH 8.60). In contrast, campus tap water (Water Source Type II) was predominantly acidic, with six of the eight sampling locations exhibiting pH values ranging from 5.40 to 6.20, below the minimum permissible value of 6.5 specified in the Indonesian Minister of Health Regulation No. 2 of 2023 [13]. The lowest pH values were observed at Faculty II and Building II (pH 5.40). Acidic water may promote corrosion of distribution pipes and theoretically enhance the dissolution of metals from the distribution system [21]. However, as discussed in Section 3.3, iron concentrations in all campus tap water samples were below the limit of detection, indicating no evidence of significant metal leaching despite the acidic conditions.

Table 1. *In situ* physicochemical parameters of water from the three water source types.

Location	pH	Temperature (°C)	DO (mg/L)	Turbidity (NTU)	TDS (mg/L)	Salinity (%)
Water Source Type I (Public Facilities and Residential Areas)						
Educational building	7.60	27.0	6.3	7.94	36.5	0
Police post	8.60	27.3	8.6	23.81	35.5	0
Residential area	7.30	27.0	5.1	4.91	16	0
Mosque	7.15	27.1	6.0	5.36	136	0
Water Source Type II (Campus Tap Water)						
Faculty I	5.76	24.6	5.8	4.11	20	0
Faculty II	5.40	28.0	5.4	5.60	30	0
Faculty III	6.10	28.0	4.7	3.70	15	0
Building I	7.50	26.1	11.8	4.75	16	0
Faculty IV	5.50	27.0	6.4	5.08	15	0
Faculty V	6.20	27.4	5.4	5.19	11	0
Faculty VI	6.90	27.0	9.6	5.76	210	0
Building II	5.40	27.2	7.2	4.61	40	0
Water Source Type III (DAMIU)						
Depot A	8.00	28.0	8.5	5.19	10	0
Depot B	8.10	28.0	6.3	5.21	7	0
Depot C	8.50	26.6	8.3	4.92	92	0
Depot D	8.43	28.7	6.7	4.81	112	0
Depot E	8.35	27.0	7.2	4.80	146	0
Depot F	7.55	27.5	7.1	4.80	66	0
Depot G	8.17	27.5	6.6	4.19	80	0
Depot H	8.15	30.0	6.1	4.44	136	0
Regulatory standard [13]	6.5–8.5	±3	–	<3	<300	–

From a source-based perspective, the acidic character of campus tap water is more plausibly attributed to anthropogenic factors associated with the internal distribution network, such as aging pipes and storage tanks, than to the source water itself, since refill drinking water and public-facility water drawn from the same regional supply did not exhibit comparable acidity. In contrast, the near-neutral to slightly alkaline pH of refill drinking water reflects the standardizing effect of treatment.

All samples complied with the regulatory standard for total dissolved solids (TDS) (<300 mg/L), with concentrations ranging from 7 to 210 mg/L. The highest TDS value was observed at the faculty VI (210 mg/L), which was noticeably higher than those of the other campus buildings. However, this was not accompanied by elevated metal concentrations (Section 3.3), suggesting that the dissolved solids were predominantly composed of non-metallic minerals. Dissolved oxygen (DO) concentrations ranged from 4.7 to 11.8 mg/L, with the relatively high values observed in most samples indicating adequate aeration. Water temperatures ranged from 24.6 to 30.0 °C, remaining within the allowable deviation of ±3 °C from the ambient air temperature.

3.2. Method Validation

The validation parameters for all calibration curves are summarized in Table 2 and Table 3.

Table 2. Validation parameters of the calibration curves for iron (Fe) and manganese (Mn) determined by atomic absorption spectrophotometry (AAS).

Analyte	λ (nm)	Water Source Type	Regression Equation	R^2	LOD (mg/L)	LOQ (mg/L)
Fe	248.3	I	y = 0.1064x + 0.0101	0.9980	0.2471	0.7488
Fe	248.3	II	y = 0.1034x + 0.0028	0.9985	0.2100	0.6364
Fe	248.3	III	y = 0.1068x + 0.0034	0.9986	0.1999	0.6058
Mn	279.5	I	y = 0.2551x + 0.0121	0.9974	0.1262	0.3823
Mn	279.5	II	y = 0.2559x + 0.0054	0.9986	0.1093	0.3312
Mn	279.5	III	y = 0.2417x + 0.0361	0.9827	0.3634	1.1012

Table 3. Validation parameters of the calibration curves for ammonia ($N–NH_3$) and orthophosphate ($P–PO_4$) determined by UV-Vis spectrophotometry.

Analyte	λ (nm)	Water Source Type	Session	Regression Equation	R^2	LOD (mg/L)	LOQ (mg/L)
$N-NH_3$	640	II	1	y = 1.11424x + 0.07494	0.9403	0.185	0.560
$N-NH_3$	640	II	2	y = 1.0395x + 0.0086	0.9820	0.116	0.352
$N-NH_3$	640	III	1	y = 0.836x − 0.0262	0.9866	0.0994	0.3013
$N-NH_3$	640	III	2	y = 1.24015x − 0.01470	0.9872	0.0585	0.1772
$P-PO_4$	880	II	1	y = 0.50263x − 0.00593	0.9980	0.0753	0.2280
$P-PO_4$	880	II	2	y = 0.47613x − 0.00956	0.9980	0.0719	0.2178
$P-PO_4$	880	III	1	y = 0.4607x − 0.0049	0.9986	0.0596	0.1806
$P-PO_4$	880	III	2	y = 0.49520x − 0.00548	0.9978	0.0625	0.1892

As the atomic absorption spectrophotometry (AAS) measurements were performed on a single instrument in three consecutive analytical sessions, whereas the UV-Vis measurements were conducted using two spectrophotometers for different sample subgroups, separate calibration curves were established for each analytical session or instrument. The concentration of each sample was subsequently calculated using the corresponding calibration curve.

The Fe calibration curves obtained from the three AAS analytical runs exhibited highly consistent slopes (0.1034–0.1068), indicating stable instrumental responses across analytical runs. Most calibration curves satisfied the linearity criterion ($R^2 \geq 0.99$). Exceptions were observed for two ammonia calibration curves, namely Water Source Type II, session 1 (R^2 = 0.9403) and Water Source Type III, session 2 (R^2 = 0.9872), both of which fell below the recommended threshold. This limitation in linearity was acknowledged and taken into consideration during data interpretation. However, its impact was considered negligible because all samples quantified using these calibration curves were below the limit of detection (LOD) and therefore did not require quantitative determination.

Particular attention should be given to the relatively high LOD values for the metal analyses. The LOD for Fe ranged from 0.1999 to 0.2471 mg/L, while the LODs for Mn in Water Source Types I and III were 0.1262 and 0.3634 mg/L, respectively. These values approached or exceeded the regulatory limits for Fe (0.2 mg/L) and Mn (0.1 mg/L). Consequently, for samples reported as below the LOD, compliance with the regulatory standards could not be quantitatively confirmed at the corresponding regulatory thresholds but could only be stated as not detected above the method detection limit.

3.3. Iron (Fe) and Manganese (Mn)

The Fe and Mn concentrations measured at the 20 sampling sites are presented in Table 4. Iron

Table 4. Iron (Fe) and manganese (Mn) concentrations in the three water source types.

Location	Fe (mg/L)	Mn (mg/L)	Remarks
Water Source Type I (Public Facilities and Residential Areas)			
Educational Buliding	<LOD	0.853	Mn exceeded the regulatory limit
Police Post	<LOD	0.336	Mn exceeded the regulatory limit
Residental Area	<LOD	<LOD	Compliant
Mosque	<LOD	<LOD	Compliant
Water Source Type II (Campus Tap Water)			
Faculty I	<LOD	<LOD	Compliant
Faculty II	<LOD	<LOD	Compliant
Faculty III	<LOD	<LOD	Compliant
Building I	<LOD	<LOD	Compliant
Faculty IV	<LOD	<LOD	Compliant
Faculty V	<LOD	<LOD	Compliant
Faculty VI	<LOD	<LOD	Compliant
Building II	<LOD	<LOD	Compliant
Water Source Type III (DAMIU)			
Depot A	<LOD	<LOD	Compliant
Depot B	<LOD	<LOD	Compliant
Depot C	<LOD	<LOD	Compliant
Depot D	<LOD	<LOD	Compliant
Depot E	<LOD	<LOD	Compliant
Depot F	<LOD	<LOD	Compliant
Depot G	<LOD	<LOD	Compliant
Depot H	<LOD	<LOD	Compliant
Regulatory Standard [13]	≤0.2	≤0.1	–

concentrations in all samples from the three water source types were below the method limit of detection (LOD). Given that the Fe LOD (0.1999–0.2471 mg/L) was comparable to the regulatory limit of 0.2 mg/L, these results indicate no evidence of excessive iron concentrations. However, the method was not sufficiently sensitive to quantitatively confirm compliance at the regulatory threshold. The absence of detectable Fe is consistent with a low potential for iron dissolution at the time of sampling, including in the acidic campus tap water.

In contrast to Fe, Mn exceeded the regulatory limit only in Water Source Type I (Figure 2c). The highest Mn concentration was measured in the educational building sample (0.853 mg/L). As this value exceeded the limit of quantification (LOQ: 0.3823 mg/L), it represents a valid quantitative result. The Mn concentration at the police post was 0.336 mg/L, which fell between the LOD and LOQ. Although this value should be regarded as semiquantitative, it nevertheless clearly exceeded the regulatory limit of 0.1 mg/L. These concentrations were approximately 8.5 and 3.4 times higher than the regulatory threshold, respectively. In contrast, Mn concentrations in all campus tap water and refill drinking water samples were below the method LOD.

This distribution pattern is consistent with the geogenic origin of Fe and Mn, which are released through the dissolution of minerals in shallow groundwater aquifers [5,14]. Tap water from public facilities and residential areas, which is generally supplied directly from shallow groundwater, is therefore more likely to contain elevated Mn concentrations than campus tap water distributed through the campus piping

network or refill drinking water that has undergone treatment. Elevated Mn concentrations warrant particular attention because chronic exposure through drinking water has been associated with adverse neurological effects, especially in children [10,22], in addition to aesthetic problems such as discoloration and metallic taste.

Taken together, the observed differences can be interpreted along a geogenic–anthropogenic axis: the manganese exceedance confined to Water Source Type I is most consistent with a geogenic origin (dissolution of Mn-bearing minerals in shallow aquifers), whereas the acidic pH of campus tap water and the elevated turbidity across all sources are more consistent with anthropogenic influences related to pipe condition, storage, and treatment efficiency. It should be noted, however, that the condition of the distribution infrastructure and the surrounding land use were not directly measured. These source attributions therefore remain inferential and require targeted infrastructure and land-use surveys for confirmation.

3.4. Ammonia (N-NH_3) and Phosphate (P-PO_4)

Ammonia (N–NH_3) and phosphate (P–PO_4) analyses were performed only for Water Source Types II and III (16 sampling sites). Water Source Type I was excluded from these analyses, as described in the Materials and Methods section. The results are presented in Table 5. All samples complied with the regulatory limits for ammonia (≤1.5 mg/L) and phosphate (≤0.2 mg/L) [10].

Ammonia concentrations in campus tap water were below the method limit of detection (LOD) at all sampling sites, except for a single sample from the Faculty V, which exhibited a duplicate mean concentration of approximately 1.03 mg/L, exceeding the limit of quantification (LOQ). Because this anomaly was confined to a single sampling site, was not accompanied by elevated phosphate concentrations (F.V: <LOD), and was inconsistent with the other water quality parameters measured at the same location, the elevated ammonia concentration is more likely attributable to localized contamination or sample heterogeneity than to widespread nutrient

Table 5. Ammonia (N–NH_3) and orthophosphate (P–PO_4) concentrations in Water Source Types II and III.

Location	N-NH_3 (mg/L)	P-PO_4 (mg/L)
Water Source Type II (Campus Tap Water)		
Faculty I	<LOD	<LOD
Faculty II	<LOD	<LOD
Faculty III	<LOD	<LOD
Building I	<LOD	<LOD
Faculty IV	<LOD	<LOD
Faculty V	1.03	<LOD
Faculty VI	<LOD	<LOD
Building II	<LOD	<LOD
Water Source Type III (DAMIU)		
Depot A	0.109	0.109
Depot B	<LOD	0.122
Depot C	<LOD	0.134
Depot D	0.075	0.118
Depot E	<LOD	0.122
Depot F	0.192	0.074
Depot G	<LOD	0.133
Depot H	<LOD	0.111
Regulatory Standard [13]	≤1.5	≤0.2

contamination. In refill drinking water, ammonia was detected at three refill stations: A (0.109 mg/L) and D (0.075 mg/L), both of which fell between the LOD and LOQ, and F (0.192 mg/L), which exceeded the LOQ. Ammonia concentrations at the remaining refill stations were below the LOD and therefore well below the regulatory limit of 1.5 mg/L.

In contrast to ammonia, phosphate exhibited an opposite distribution pattern between the two water source types. All campus tap water samples were below the LOD, whereas phosphate was detected in all refills drinking water samples at concentrations ranging from 0.074 to 0.134 mg/L, although all remained below the regulatory limit. The consistent detection of phosphate in refill drinking water may be related to the characteristics of the source water or residual phosphate originating from the treatment process. Because excessive phosphate contributes to eutrophication in receiving water bodies [7], routine monitoring is recommended, particularly for water intended for direct consumption. Overall, the low ammonia and phosphate concentrations observed in both water source types indicate a relatively low nutrient pollution burden.

3.5. Comparative Synthesis and Study Limitations

Comparison of the three water source types revealed distinct water quality issues associated with each source. Turbidity represented the only parameter that failed to comply with the regulatory standard across all samples. Tap water from public facilities and residential areas (Water Source Type I) exhibited a source-specific risk of elevated manganese concentrations associated with groundwater. Campus tap water (Water Source Type II) was characterized by predominantly acidic pH values, which may increase the potential for pipe corrosion despite the absence of detectable metal contamination. Refill drinking water (Water Source Type III) showed the most stable performance with respect to pH and metal concentrations but remained affected by elevated turbidity and consistently detectable phosphate concentrations. Overall, none of the three water source types fully complied with all parameters specified in the Indonesian Minister of Health Regulation No. 2 of 2023, indicating that improvement strategies should be tailored to the dominant water quality issues associated with each source.

To evaluate within-group consistency, the dispersion of key parameters within each source type was examined (mean ± standard deviation; coefficient of variation, CV). Refill drinking water (Water Source Type III) was the most homogeneous group for pH (8.16 ± 0.30; CV 3.7%) and turbidity (4.79 ± 0.35 NTU; CV 7.2%), reflecting the standardizing effect of treatment. However, this homogeneity occurred at turbidity levels that consistently exceeded the standard, indicating a systematic rather than a random problem. In contrast, TDS remained highly variable among depots (7–146 mg/L; CV 64.3%), suggesting differences in raw-water source and treatment among providers. By comparison, public-facility water (Water Source Type I) exhibited the greatest turbidity variability (CV 85.4%), consistent with its dependence on local source conditions. Operational details of individual depots (treatment technology, maintenance practices, and raw-water source) were not documented and could not be directly correlated with the observed variability, which is acknowledged as a limitation.

Placing these findings in a broader international context, the localized, geogenically derived manganese enrichment observed in shallow-groundwater-fed sources is consistent with patterns reported in other regions, where manganese mobilization from aquifer minerals is a recurrent and frequently underestimated drinking-water concern, particularly for shallow and privately abstracted sources [23,24]. This comparison indicates that the water-quality characteristics observed in the Ciputat-South Tangerang area are not unique to the study region but reflect common challenges in rapidly urbanizing settings, where distribution-related

particulates and geogenic groundwater metals coexist, thereby strengthening the general relevance of the present findings.

4. CONCLUSIONS

The physicochemical characterization and water quality assessment of three water source types in the Ciputat-South Tangerang area yielded three major findings. First, turbidity exceeded the regulatory limit (<3 NTU) in all samples from the three water source types, with values ranging from 3.70 to 23.81 NTU, indicating a widespread deficiency in particulate control across all water sources. Second, campus tap water (Water Source Type II) exhibited predominantly acidic pH values in six of the eight sampled buildings (5.40–6.20), below the minimum regulatory limit of 6.5. Although no metal contamination was quantitatively detected, these acidic conditions may increase the long-term corrosivity of the distribution system. Third, manganese concentrations exceeded the regulatory limit of 0.1 mg/L exclusively in tap water from public facilities and residential areas (Water Source Type I), with concentrations of 0.853 mg/L at the educational building and 0.336 mg/L at the police post. Ammonia and phosphate concentrations in Water Source Types II and III complied with the regulatory standards specified in the Indonesian Minister of Health Regulation No. 2 of 2023, except for a single isolated ammonia anomaly at one campus sampling site, which was most likely attributable to sample contamination.

Overall, none of the three water source types complied with all regulatory parameters simultaneously, indicating that improvement strategies should be tailored to the dominant water quality issues associated with each source. Future studies should include other parameters, including nitrate, nitrite, residual chlorine, sulfate, and total hardness, microbiological parameters (particularly *Escherichia coli* and total coliforms), expand the sampling period and the number of sampling sites to better capture temporal variability, and improve the sensitivity of metal analyses through appropriate preconcentration techniques to enable reliable quantification at concentrations close to the regulatory limits.

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Conflict of Interest

The authors declare no conflict of interest.

DECLARATION OF GENERATIVE AI

Not applicable.

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