Analysis of iron and lead in refilled drinking water from Yogyakarta Depots

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ABSTRACT

This study aims to analyze the concentrations of iron (Fe) and lead (Pb) in refillable drinking water from six depots located around Yogyakarta. Using an experimental design, water samples were collected from three depots in Karangmalang and three in Samirono, each with different water sources including municipal supply, mountain spring, and bore wells. The concentrations of Fe and Pb were determined using Atomic Absorption Spectrophotometry (AAS) following acid digestion procedures. Results showed that all Fe concentrations were significantly below the maximum limit of 0.3 mg/L set by the Indonesian Ministry of Health Regulation No. 492/MENKES/PER/IV/2010, indicating no health concern. However, Pb concentrations in four depots (A, B, E, and F) exceeded the permissible limit of 0.01 mg/L, with values ranging from 0.011 to 0.031 mg/L. The elevated Pb levels may result from contaminated plumbing materials, poor filtration maintenance, or leaching from metal components. These findings highlight a potential health risk, particularly for long-term consumers, and emphasize the need for regular monitoring, improved infrastructure, and stricter regulatory enforcement. This study contributes to the limited literature on trace metal contamination in refillable water depots, particularly in student-dense areas. The comparative analysis of multiple water sources adds novelty, offering insights for localized policy improvement and public health protection. Clearly stating such implications supports the formulation of more responsive public health regulations to ensure safe drinking water access.

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1. INTRODUCTION

Water is universally recognized as an essential element for sustaining life, health, and development. Its availability and quality directly influence the well-being of individuals and communities [1]. Approximately 55% to 78% of the human body is composed of water, and more than 90% of biochemical processes require water as a medium [2]. Daily water intake supports vital physiological functions, including nutrient absorption, metabolic regulation, temperature control, and the elimination of toxins [3]. The World Health Organization recommends a minimum of 1 to 2.5 liters of drinking water per day to maintain proper hydration and avoid health complications such as dehydration, fatigue, and metabolic imbalance [4].

In line with population growth, urbanization, and increased human mobility, the demand for clean and affordable drinking water in Indonesia has risen significantly [5]. One of the most visible responses to this need has been the widespread emergence of refillable drinking water depots, commonly known as Depot Air Minum

Isi Ulang (DAMIU). These depots offer a practical and cost-efficient solution for water access, particularly for low- to middle-income communities [6]. Unlike bottled water produced by large-scale industries, DAMIU water is available at lower prices and can be easily accessed through refill systems or home delivery services [7].

Yogyakarta, often referred to as the "Kota Pelajar" or City of Students, represents a unique context in the discussion of drinking water safety. With hundreds of thousands of students residing in the city from various regions of Indonesia, the demand for convenient and affordable water sources is exceptionally high [8]. The high density of student boarding houses and independent residences increases the reliance on DAMIU as a primary drinking water source [9]. For many, the practicality and low cost of DAMIU outweigh considerations of quality assurance—raising concerns regarding potential health risks associated with unmonitored water consumption [6], [9].

Despite the convenience and affordability of DAMIU, questions have arisen about the safety and regulatory compliance of these facilities. Although most depots claim to use water filtration technologies such as reverse osmosis and ultraviolet sterilization, a substantial number of them remain unregistered and operate without proper hygiene certification [10]. Reports from local health departments and previous studies have indicated that many DAMIU facilities, especially in urban and peri-urban areas of Yogyakarta, do not comply with national health and safety standards [11]. A notable concern is the absence of routine monitoring, maintenance neglect, and lack of public awareness regarding potential contamination.

One of the most pressing concerns regarding DAMIU is the potential presence of heavy metals such as iron (Fe) and lead (Pb) in the drinking water [12]. These contaminants may originate from natural sources (e.g., groundwater containing mineral deposits) or anthropogenic sources, including corroded distribution pipes, improper storage tanks, metal components of refill containers, or even the vehicles used for water transportation [13]. [14]. While iron is a biologically essential element required for hemoglobin synthesis and oxygen transport, its excessive presence in drinking water may result in toxicity, leading to gastrointestinal issues, organ damage, and increased oxidative stress. Iron can also cause staining, metallic taste, and aesthetic deterioration of water quality [15], [16].

Lead (Pb), by contrast, is a non-essential and highly toxic heavy metal that poses a serious threat even at trace levels [17]. Long-term exposure to lead can result in irreversible damage to the nervous system, kidney dysfunction, cardiovascular diseases, and cognitive impairment, especially in children [18], [19]. As a cumulative toxicant, lead tends to accumulate in bones, tissues, and vital organs over time, causing chronic health effects that are difficult to reverse [20]. According to the Indonesian Ministry of Health Regulation No. 492/MENKES/PER/IV/2010, the maximum permissible limits for Fe and Pb in drinking water are 0.3 mg/L and 0.01 mg/L, respectively. Exceeding these thresholds renders water unsafe for human consumption.

Several studies in Indonesia have identified elevated levels of heavy metals in refillable drinking water, raising public health concerns about long-term exposure [15]. However, these studies have rarely focused on depot-level variation or directly compared DAMIU facilities based on geographic location and water source type [10]. In addition, the demographic vulnerability of student populations—who represent a major consumer group in Yogyakarta—has been largely overlooked [11]. The absence of strict regulatory enforcement, inadequate infrastructure, and insufficient consumer education continue to exacerbate this issue.

This study addresses those gaps by conducting a localized, comparative analysis of Fe and Pb levels in DAMIU from different areas in Yogyakarta, each using distinct water sources (municipal supply, spring, and bore wells). This approach enables identification of specific risk factors related to water origin and location. Ensuring the quality and safety of drinking water is critical, particularly in a region where consumption patterns are heavily influenced by affordability and convenience [21].

The novelty of this study lies in its integrated focus on geographic diversity, source variation, and consumer vulnerability in a city with high student density. Unlike previous studies that examined DAMIU generally, this research highlights the intersection of technical, infrastructural, and socio-demographic risk factors. Given the potential risks posed by Fe and Pb contamination, there is an urgent need to conduct scientific assessments of water quality in DAMIU operating in Yogyakarta. The findings are expected to contribute to local evidence-based policy development and to strengthen public awareness campaigns, inspection systems, and regulatory enforcement.

This study aims to analyze the concentration of iron (Fe) and lead (Pb) in refillable drinking water sold by DAMIU in Yogyakarta. By comparing the measured values with the national safety standards, the findings are expected to provide evidence-based insights into the safety of DAMIU consumption and to encourage strengthened monitoring, certification, and consumer awareness regarding water quality.

2. METHODS

This study employed an experimental research design to determine the concentrations of heavy metals—iron (Fe) and lead (Pb)—in refillable drinking water obtained from various depots (Depot Air Minum Isi Ulang or DAMIU) across Yogyakarta, Indonesia. The objective was to assess whether the levels of Fe and Pb in DAMIU water complied with the maximum permissible limits specified in the Regulation of the Minister of Health of the Republic of Indonesia No. 492/MENKES/PER/IV/2010. Water samples were collected purposively from several DAMIU located in different areas of Yogyakarta, selected not only based on accessibility and high consumer usage but also to represent diverse geographic locations and water sources (municipal supply, mountain spring, and bore wells), thereby ensuring variation in potential contamination levels. A total of six samples were collected using sterilized polyethylene bottles. All samples were properly sealed, labeled, and stored in cool boxes to maintain their quality prior to laboratory analysis.

Laboratory testing was carried out at the Analytical Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta. The testing procedure followed the Indonesian National Standard (SNI) for drinking water quality analysis. The flowchart illustrating the analytical method is presented in Fig. 1. Each sample's metal concentration was measured in milligrams per liter (mg/L), with calibration using certified standard solutions to ensure precision and reliability of the results. In the laboratory, each 25 mL water sample was mixed with 2 mL of concentrated nitric acid (HNO_3), then heated until boiling to aid in digestion. After cooling, the sample was transferred into a 25 mL volumetric flask and diluted to the mark with distilled water (aquadest). The prepared solution was then analyzed using Atomic Absorption Spectrophotometry (AAS), which enables accurate detection of trace metals through their light absorption characteristics.

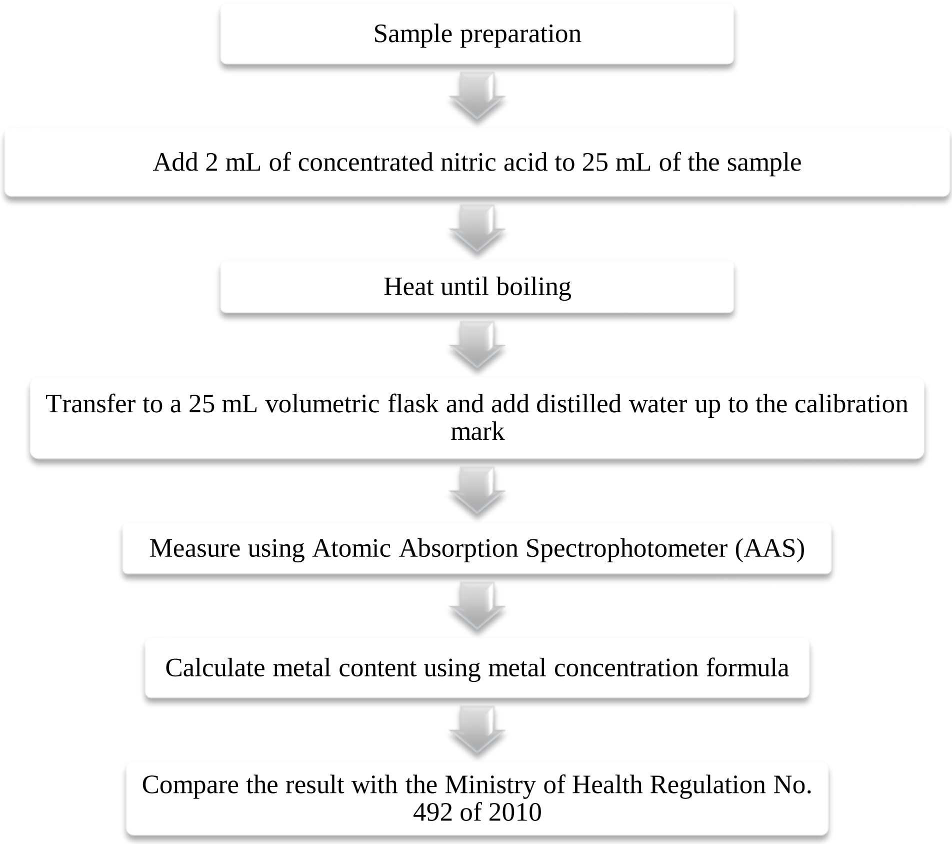

Fig. 1. Flowchart of research methodology

To ensure quality assurance, blank samples and duplicate analyses were employed, and instrument calibration was performed using multi-point standard solutions to confirm linearity and analytical accuracy. Quality control procedures included the use of certified reference materials and repeated measurements for selected samples. The concentration iron (Fe) and lead (Pb) in the sample was calculated using the following formula (1).

$$\text{Metal Concentration}\left(\frac{mg}{L}\right) = \left(\frac{C\left(\frac{mg}{L}\right)}{B(mL)}\right) x\ F(mL) \quad (1)$$

Where C is the concentration from the AAS reading, B is the volume of sample used, and F is the final volume after dilution. The calculated concentrations of Fe and Pb were then compared to the national drinking water quality standards. According to PERMENKES No. 492/MENKES/PER/IV/2010, the maximum allowable concentration is 0.3 mg/L for iron and 0.01 mg/L for lead. Descriptive statistical analysis was applied to evaluate minimum, maximum, and average values for each element and to assess their compliance with national safety standards.

3. RESULTS AND DISCUSSION

3.1. Results

This study analyzed the concentrations of iron (Fe) and lead (Pb) in refillable drinking water obtained from six DAMIU (Depot Air Minum Isi Ulang) around Yogyakarta. Three depots (A, B, and C) were located in the Karangmalang area, while the remaining three (D, E, and F) were located in Samirono. The water sources for these depots varied: Depot A used water from PDAM Yogyakarta, Depot B, E, and F sourced water from Turi mountain springs, and Depot C and D utilized groundwater extracted through bore wells.

The calibration curves for iron (Fe) and lead (Pb) analyses were highly linear, indicating reliable quantification. For Fe, the absorbance vs. concentration regression yielded $R^2 \approx 0.993$, and for Pb, $R^2 \approx 0.9896$, demonstrating excellent correlation between standards and instrument response. These calibration models (Fig. 2 and 3) were used to calculate metal concentrations in each refill water sample. The measured Fe levels (Table 1) were extremely low – essentially non-detectable in most cases. In fact, five of the six depot samples (A, C, E, F) registered Fe concentrations below the detection limit (<0.0005 mg/L), and the remaining two (depots B and D) showed only trace amounts of approximately 0.00102 mg/L and 0.00056 mg/L, respecticely.

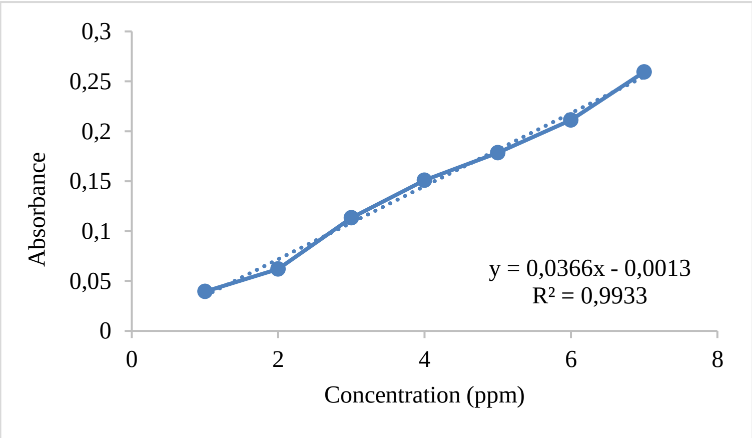

Fig. 2. Iron (Fe) standard calibration curve

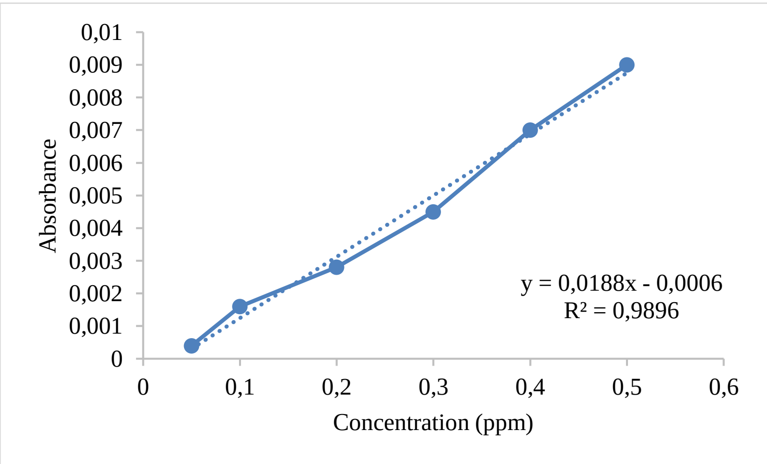

Fig. 3. Lead (Pb) standard calibration curve

All values are orders of magnitude below the Indonesian drinking-water standard of 0.3 mg/L for Fe. This 0.3 mg/L limit (Permenkes No. 492/2010) aligns with secondary (aesthetic) standards elsewhere: for example, the U.S. EPA cites 0.3 mg/L Fe as the threshold above which water develops reddish color, metallic taste, and staining. In practical terms, the observed Fe concentrations (≤0.001 mg/L) would not produce any noticeable taste or color in the water and pose essentially no health risk. Indeed, only when Fe exceeds about 1 mg/L does gastro-intestinal irritation or tissue damage become a concern. Thus, the refill water samples here are effectively free of excess Fe, likely thanks to source water quality and treatment. (For context, an earlier study of community well water in Indonesia reported Fe levels as high as ~1.9 and ~0.73 mg/L in two wells, well above the 0.3 mg/L standard, illustrating how unusual such high Fe contamination can be when untreated.

Table 1. Iron (Fe) content

Sample	Concentration (ppm)	Absorbance	Concentration (mg/L)
A	-0,0165	-0,0006	N/A
B	0,0551	0,002	0,00102
C	-0,0193	-0,0007	N/A
D	0,0028	0,0001	0,00056
E	-0,011	-0,0004	N/A
F	-0,0386	-0,0014	N/A

The extremely low Fe content suggests that neither the source water nor the depot infrastructure is contributing significant Fe. All depots using municipal or spring sources appear to produce water far below the regulatory threshold. Any small Fe detected could originate from residual corrosion of iron-based pipes or equipment, or from natural Fe in groundwater, but at the microgram-per-liter scale these effects are negligible. In summary, iron did not exceed permissible limits in any sample and is not expected to impact consumer safety or acceptability. This contrasts with cases where aged well water or malfunctioning filters have allowed Fe buildup – the present refill systems appear effective at controlling iron.

In comparison, a study conducted in Makassar found Fe levels in household wells reaching up to 1.27 mg/L—substantially exceeding health-based guidelines due to iron-rich soil and corroded pipes [27]. Thus, the results from this study indicate that DAMIU in Yogyakarta demonstrate better control over iron content than similar systems in some other Indonesian urban regions.

In contrast, measured Pb (lead) concentrations were notably higher in several depots (Table 2). Four of the six samples contained Pb above the 0.01 mg/L limit set by Permenkes 492/2010, which mirrors the WHO guideline for lead in drinking water. Specifically, depots A, B, E, and F showed Pb levels of roughly 0.031, 0.021, 0.011, and 0.013 mg/L, respectively – all exceeding 10 µg/L. Depots C and D were below the limit (≈0.0099 and 0.0014 mg/L). These exceedances are substantial: for example, Depot A's Pb (0.031 mg/L) is more than three times the national standard. By WHO criteria, even these modest concentrations are of concern. The WHO notes that a provisional guideline of 0.01 mg/L was set to protect bottle-fed infants (a sensitive subpopulation) and by extension all consumers. Further, extensive evidence links lead exposure at very low levels to neurological and developmental harm, as well as cardiovascular and renal effects. Indeed, lead is a well-known neurotoxin, especially in children, affecting IQ and growth, and no blood lead level is considered entirely safe. Thus, detecting any lead above 0.01 mg/L in drinking water triggers a red flag. The finding that 66% of the sampled depots exceed this safety threshold implies potential health risks to consumers relying on these refill sources.

Table 2. Lead (Pb) content

Sample	Concentration (ppm)	Absorbance	Concentration (mg/L)
A	0,1562	0,0023	0,03124
B	0,1029	0,0013	0,02058
C	0,0496	0,0003	0,00992
D	0,007	-0,0005	0,0014
E	0,055	0,0004	0,011
F	0,0656	0,0006	0,01312

The patterns of contamination suggest likely causes. Depot A (using city PDAM water) and Depot B (spring water) yielded the highest Pb. Depot E and F (also spring sources) were marginally above the limit. Depot C and D (borehole water) had negligible Pb. This pattern implicates the treatment/distribution system more than the raw source, since the municipal-supplied site unexpectedly showed the worst Pb level. A plausible explanation is leaching from lead-containing infrastructure. It is well documented that lead commonly enters drinking water through corrosion of lead pipes, solder, brass fixtures or other plumbing materials. Older or uncoated pipes (especially if water is corrosive) can leach lead into the flow. Refill depots often use polyethylene tanks and piping, but any metal fittings or older tubes could be culprits. Frequent use of plastic barrels and filtration units also presents risk: if filters or connectors are poorly maintained or made with lead solder, they may introduce Pb. Alternatively, some spring sources in volcanic areas can carry elevated metals, though geology in Yogyakarta is not especially lead-rich. Regardless, the spatial variation (very low Pb in bore wells vs. higher in treated/municipal samples) strongly points to system contamination rather than uniform natural levels.

Comparing to other studies, elevated Pb in refill water is not unprecedented. Previous Indonesian investigations have detected heavy metals in "premium" refill depots, often attributing them to poor maintenance or contaminated sources. For example, a risk assessment study noted that many refill stations used untreated groundwater and aging equipment, leading to chemical hazards in the water. More broadly, in low- and middle-income settings, refill or bottled water schemes can suffer from lapses in oversight, resulting in leaching of Pb or other metals during distribution. In contrast, our study's Fe results are reassuring and consistent with findings that well-operated treatment (e.g. carbon filtration) effectively removes iron and manganese, whereas lead requires more caution.

These findings are consistent with a study conducted in Kalimantan [28], where 30% of refillable water stations exceeded the Pb threshold due to poor pipe maintenance and use of non-food-grade materials. Similarly, research in Nepal and Ghana also reported Pb contamination in commercial water refill stations attributed to substandard equipment and lack of regulatory enforcement [29], [30].

In summary, while Fe contamination was negligible and well below both national and international standards, Pb contamination was observed in four out of six depots, indicating a clear risk to consumers and emphasizing the need for improved quality control. Comparative studies across Indonesia and other low- and middle-income countries highlight the broader relevance of this issue and the importance of regular water quality monitoring in refillable drinking water systems.

3.2. Discussion

The main findings of this study indicate that iron (Fe) concentrations in all refill water samples from six depots in Yogyakarta were significantly below the maximum allowable limit of 0.3 mg/L as stipulated by Indonesian regulations (PERMENKES No. 492/2010). In contrast, lead (Pb) levels exceeded the permissible limit of 0.01 mg/L in four depots (A, B, E, and F), with concentrations ranging between 0.011–0.031 mg/L. These Pb concentrations represent a potential public health concern, especially for vulnerable populations such as children and pregnant women.

These results are consistent with prior studies conducted in Indonesia and other countries in the Global South. For example, Fahimah et al. reported Pb concentrations exceeding 0.01 mg/L in refill water in Bandung due to poor infrastructure and irregular filter maintenance [31]. Similar findings were reported in Sub-Saharan Africa, where refill and bottled water often failed to meet WHO safety standards due to inadequate regulation and contamination during storage or transport. Conversely, the low Fe concentrations found in this study reflect findings from well-maintained systems where sediment filtration and low-Fe source water were effectively employed.

The presence of Pb at 0.02–0.03 mg/L can result in chronic exposure risks. According to WHO, even intermittent intake of water with Pb levels above 10 µg/L is associated with neurodevelopmental damage, particularly in infants and children [22]. WHO reports multiple studies linking low-dose lead exposure to irreversible IQ decline, behavioral issues, and developmental delays. Chronic exposure is also linked to hypertension, renal dysfunction, and reproductive toxicity [23]. Regulatory agencies such as the U.S. EPA have adopted a zero-tolerance approach, maintaining a maximum contaminant level goal of zero for Pb in drinking water. WHO recommends that Pb levels be kept 'as low as reasonably practicable' to ensure public health [24].

By contrast, the Fe levels measured in this study are not a concern. Iron is an essential micronutrient and only becomes harmful at concentrations significantly above 1 mg/L. The negligible levels detected here are unlikely to pose health risks or cause undesirable changes in water taste or color.

The elevated Pb levels likely originate from the corrosion of plumbing components made of lead-containing alloys or fittings. Despite regulations requiring "lead-free" components, many depots may still use outdated infrastructure, especially in smaller-scale or informal operations. Depot A, which used PDAM municipal supply, showed the highest Pb levels, indicating possible leaching from pipes or connectors within the municipal or depot distribution system [25]. Depots B, E, and F, which sourced water from mountain springs, may have used storage tanks or filters that introduced Pb. Depots C and D, relying on bore wells, exhibited the lowest Pb levels, possibly due to simpler infrastructure composed of inert plastic materials.

Another plausible source of Pb is inadequate filter management. When ion-exchange or carbon filters are saturated or degraded, they may release rather than remove contaminants. Interviews with depot managers revealed irregular maintenance schedules and inconsistent filter replacement practices. Additionally, although Yogyakarta is not a heavily industrialized region, urban runoff or agricultural chemicals could introduce Pb into source water; however, the selective nature of the contamination (only in certain depots) suggests that the problem lies within the post-source handling process [26].

From a regulatory standpoint, this study underscores the urgency of enforcing existing water quality regulations. PERMENKES 492/2010 applies to all potable water, including refill stations. The observed Pb exceedances represent clear regulatory violations. Routine water testing, currently required by law, appears inconsistently enforced. Enhancing oversight by requiring third-party testing and public reporting of water quality metrics would improve transparency and accountability [32].

The practical implications of these findings call for immediate action. Depot owners should be mandated to conduct heavy metal testing at least quarterly and maintain documentation of filter changes and sanitation procedures. Local health agencies could assist by providing training on proper water treatment and infrastructure maintenance. Regulatory bodies should increase inspection frequency and ensure enforcement of non-compliance penalties. Investing in advanced treatment technologies, such as reverse osmosis or specialized lead-removal media (e.g., KDF-85), is recommended for depots with repeated violations. Public awareness campaigns can also help educate consumers about the risks of heavy metal exposure and the importance of choosing certified refill stations.

The strength of this study lies in its use of atomic absorption spectrophotometry (AAS), which offers high sensitivity and reliability in detecting trace metal concentrations. The use of validated calibration curves with strong linearity ($R^2 > 0.99$) enhances the credibility of the results. Additionally, the study integrates contextual interviews with depot operators, offering insights into maintenance behaviors that may affect water quality.

However, the study is not without limitations. The sample size was limited to six depots within two neighborhoods, which may not represent the broader situation across Yogyakarta or other cities. Furthermore, the study did not include microbial analysis, which is another critical aspect of drinking water safety. Future research should expand geographic scope, examine seasonal variation in contamination, and include microbiological parameters to offer a more holistic evaluation of refill water safety.

In conclusion, this study reveals that while refill drinking water in Yogyakarta is free from iron-related concerns, lead contamination in some depots exceeds national and WHO safety limits. These findings highlight the importance of stringent quality control, infrastructure improvements, and regulatory enforcement to safeguard public health. Targeted efforts by depot owners, local authorities, and national regulators are essential to ensure that refill water remains a safe and trusted resource for communities.

4. CONCLUSION

This study contributes to the growing body of knowledge on drinking water safety in Indonesia by providing empirical data on the levels of iron (Fe) and lead (Pb) in refillable drinking water around Yogyakarta—a region heavily dependent on such sources due to its dense student population and urban growth. The findings confirm that Fe concentrations in all six sampled depots were significantly below the national standard (0.3 mg/L), indicating no health or aesthetic risks from this metal. However, the Pb content in four of the six depots (A, B, E, and F) exceeded the permissible limit of 0.01 mg/L set by the Indonesian Ministry of Health Regulation No. 492/MENKES/PER/IV/2010. These depots primarily sourced their water from mountain springs or municipal PDAM supplies. In contrast, depots C and D, which utilized bore well water, maintained Pb levels within acceptable limits.

The study highlights a pressing need for improved monitoring and infrastructure maintenance in refill water depots, particularly those not using groundwater sources. It is recommended that regulatory agencies enforce mandatory quarterly testing for heavy metals, provide routine inspections, and publish water quality results publicly. Depot owners should be trained and incentivized to adopt best practices in filtration and storage, while policymakers must prioritize updating aging water distribution systems that may be leaching toxic metals such as Pb.

For future research, longitudinal monitoring of metal concentrations across a wider geographic scope is necessary to track trends over time. Additionally, investigating the effectiveness of different filtration technologies and materials in preventing heavy metal contamination would provide valuable insights for both industry stakeholders and regulators. Such studies can help build a more comprehensive framework for safe drinking water practices in low- and middle-income settings.

Author Contribution
All authors contributed equally to the main contributor to this paper. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest
The authors declare no conflict of interest.

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