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Influence of point-of-use dispensers on lead level assessment in drinking water of a lead pipe-free campus

Saroj Adhikari[1,2], Yi-Pin Lin[3] and Ding-Quan Ng[1]✉

Point-of-use (POU) dispensers, referring to those directly connected to the water supply lines, are widely used in public facilities such as schools and universities in Taiwan. These dispensers are equipped with filters that can remove contaminants, including heavy metals in drinking water. Assessment of water lead (Pb) levels rely heavily on sampling surveys that involve various sampling protocols. This study evaluated the effects of using first draw (FD), flush (FL) incorporating at least 20 s of flushing, and random daytime (RDT) sampling protocols on Pb level assessment in water samples collected from faucets and POU dispensers of a Pb pipe-free campus between March 2017 and July 2020. This was the first study to examine the influence of POU dispensers on different sampling protocols and their survey results. Pb levels in 19% of faucet and 11% of dispenser samples exceeded the Taiwan EPA standard of 10 µg/L. FL sampling produced the lowest Pb levels, followed by RDT and FD in the samples collected from faucets. Interestingly, all three sampling protocols exhibited similar Pb levels in samples collected from dispensers. Thus, any of the three sampling protocols can be employed to monitor Pb levels in water samples collected from dispensers.

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INTRODUCTION

Lead primarily occurs in drinking water through its leaching from plumbing systems[1–4]. The extent of Pb release depends on the types of plumbing materials used, properties of water flowing through those materials, and the use of Pb-containing solders or fittings[5–7]. Irrespective of the sources, drinking water contaminated with Pb can retard intellectual development in the fetus and young children, increase the risks of miscarriage in pregnant women, and high blood pressure, kidney failure, and reproductive problems in adults[8–11]. Pb is also one of ten chemicals on the World Health Organization's (WHO) list of chemicals of major public health concern[12], and its effects are sometimes significant even at concentrations below the WHO guideline value of 10 µg/L[13–15].

The standards for Pb in drinking water in most Asian cities follow the WHO guideline value. Singapore[16], Hong Kong[17], Japan[18], India[19], and Taiwan[20] are among a few examples. In the United States, the Lead and Copper Rule Revisions (LCRR) have introduced a 10 µg/L Pb trigger level, in addition to the 15 µg/L action level[21]. The trigger level alerts water utilities in prioritizing Pb control efforts before an action level exceedance. Furthermore, if the 90th percentile of the first draw (FD) samples exceeds the action level, additional remedial measures must be taken, ranging from planning to monitoring to treatment[21]. Similarly, the maximum contaminant level goal (MCLG) of zero under the US Safe Water Drinking Act[22] indicates that any amount of Pb can be harmful to human health. However, a wide variation exists among regulated sampling protocols and acceptable Pb levels in different regions of the world[23]. The main protocols are FD in United States[21], random daytime (RDT) and 30-minute stagnation (30 MS) in Canada and Hong Kong[17,24], RDT and fixed stagnation in the UK and the EU[25,26], and flush (FL) sampling in Australia[27]. Additionally, sequential sampling/profile sampling[28,29], service line sampling (second draw), and 3 T's (training, testing, and taking action) sampling for schools[7,30] are also being used in the US, aiming specifically at Pb source assessment. Furthermore, composite proportional sampling[31] and particle simulation sampling are also practiced while assessing exposure levels. The maximum acceptable concentration of Pb in RDT and 30 MS samples in Canada is 5 µg/L[24]. In the United Kingdom, where Pb pipes are a major source of Pb in drinking water, 99% of the RDT samples must comply with the 10 µg/L Pb standard[32]. The regulations for Pb in drinking water in the above-mentioned countries have been associated with their sampling method. Hence, a standalone WHO guideline value may not be sufficient for effective Pb control in drinking water as Pb levels can be highly dependent on the sampling method employed.

The selection of sampling method/s is critical in the assessment of Pb levels in drinking water, as each method has its benefits and drawbacks and can yield vastly different outcomes. For instance, FD sampling could detect Pb contamination near the faucets and inside the premises, but not from outside sources because of the limited volume[33]. Similarly, sequential sampling could assist in identifying and locating Pb sources inside and outside the premise. Nevertheless, a large number of samples to be collected may pose a practical constraint[33–35]. Likewise, although RDT sampling can be conducted easily at large scales, it may not be capable of locating the Pb sources and requires a large sample size to be more accurate[32]. FL sampling is easier to conduct as a long stagnation after flushing is not required. However, this is often considered to underestimate the Pb levels in consumer water[31,36,37]. Thus, the choice of sampling methods and protocols can vary among and within the countries, depending on their objectives, which include exposure identification and source detection. In Taiwan, either FL or RDT sampling can be used based on procedures described in the regulation "Drinking water quality sampling methods" (NIEA W101.56 A) issued by the Taiwan Environmental Protection Administration[38]. For FL sampling, a 1 L

[1]Department of Environmental Engineering and Management, Chaoyang University of Technology, No. 168, Jifeng E. Rd, Wufeng District, Taichung 413310, Taiwan. [2]Department of Applied Chemistry, Chaoyang University of Technology, No. 168, Jifeng E. Rd, Wufeng District, Taichung 413310, Taiwan. [3]Graduate Institute of Environmental Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei 10617, Taiwan. ✉email: ndq@cyut.edu.tw

water sample is collected after flushing for at least 20 s, while RDT sampling requires no flushing. Although FL sampling has been heavily criticized as an ineffective method in the assessment of Pb levels because the action of flushing often reduces the true Pb exposure in consumer tap water[31,36,37], such sampling is still practiced in some countries. The rationale behind allowing FL sampling was that consumers should be responsible for the water quality within private premises, not the water utilities. In practice, however, water utilities are generally involved in water quality analysis as most consumers do not have the means to analyze their drinking water. In Taiwan, water analysis is carried out by environmental analysis laboratories authorized by the local government to conduct sampling, testing, and analysis[39].

Pb levels in drinking water are being monitored more closely over the last two decades. Several studies have documented Pb levels surpassing the regulated standards in the water samples collected from childcare centers and schools/campuses in Los Angeles, Washington DC, Baltimore, Seattle[40], North Carolina[7,41], Central Kansas[42], Philadelphia[43] in the US, Ontario[44] in Canada, and Taipei[36,45] in Taiwan. These instances associated with the use of either old Pb pipe or plumbing materials containing Pb additives reinforce the notion that Pb contamination can occur in drinking water whether lead pipes are in use or not and underscore the importance of exploring Pb levels in drinking water at public utilities such as schools. In Taiwan, Pb pipes were used before their ban in 1979. Hence, buildings constructed before the ban could still have such pipes in service, and those constructed after the ban were equally likely to have Pb-containing plumbing materials such as brass fittings and solders[12,33,46]. Additionally, other than pH and alkalinity adjustments, addition of orthophosphate and other corrosion inhibitors is not practiced in Taiwan because downstream wastewater treatment plants may not be able to cope with the increased phosphorus loading. Under such scenarios, the possible exposure risk to Pb via drinking water consumption can be easily overlooked and neglected. Since the health consequences of Pb contamination are known to be more apparent in young children than adults, a sampling survey investigating the Pb levels in drinking water at public utilities such as schools and hospitals is essential.

The local definition of “drinking water” has evolved with changing habits in water consumption. The water that comes out directly from the faucet is largely not considered “drinking water” by local residents, which has led to the widespread implementation of water dispensers in Taiwan, especially in public facilities such as schools[47,48]. Water dispensers can either be directly connected to the water lines (point-of-use (POU) dispensers) or bottled water dispensers (Supplementary Figure 1). POU dispensers are becoming popular since these are equipped with (usually activated carbon) filters that can remove impurities by adsorption and size separation, and water from such dispensers is generally deemed safe to drink. However, depending on the types of filters installed in the POU dispensers, the quality of water dispensed could vary. Majority of the POU dispensers manufactured in Taiwan are equipped with activated carbon filters while few have reverse osmosis (RO) unit due to the increased cost. The dispensers used in this study were equipped with ultra-filters (UF-504). The filters were certified by Water Quality Association (WQA), whereas the tubes delivering water after filtration were National Sanitation Foundation (NSF) 61 certified. The filters had a one-year service life and a total treatment capacity of 1500 GAL (5813 L). Storage tanks in the dispensers were made of stainless steel, and the downstream materials delivering the filtered water were made of plastic tubing. Numerous factors can affect the performance of filters. First, the quality of the supply water can determine the lifespan of the filter. For example, suspended solids in supply water after typhoon events will increase many folds, and such waters will drastically shorten the lifespan of the filters. Second, the maintenance of the filter is often determined by a fixed duration recommended by the manufacturer and not by the quality of the filtered water. The over-reliance in POU dispensers to provide safe drinking water raises concern as the public may have let their guard down. This study thus collected filtered water samples from POU dispensers and unfiltered water from faucets in a university campus for Pb level assessment. The comparison of Pb levels between filtered and unfiltered water samples within the same sampling location can reveal important information on the effects of filter systems on Pb levels. Studies on various types of faucet filters have reported that some filters are ineffective in lowering Pb levels below the regulatory standard[49,50]. As a result, future research into the impact of different types of filters used in POU dispensers on Pb level assessment may yield useful results.

This study employed three sampling protocols, namely FD, FL, and RDT sampling, to assess Pb levels in drinking water in a university campus without any lead pipes in use. None of the buildings in the campus is expected to contain Pb pipes as they were constructed in the early 1990s, almost a decade after the use of lead pipes was outlawed in Taiwan. The FD sampling method was selected as it represents a worst-case scenario, while FL and RDT were chosen since both are permissible in Taiwan while collecting drinking water samples. This study also explores the comparative effect of POU dispensers and faucets on Pb survey results from the three sampling protocols in order to assess the relative usefulness of each protocol. Using the same sampling protocol to collect dispenser and faucet samples from a designated location may yield different outcomes, which may consequently result in vastly different conclusions. The findings in this study will provide valuable information on Pb levels in drinking water using various sampling protocols, which will be useful for future exposure assessment studies. This study is also expected to aid in improving the existing heavy metal monitoring regulations, including those for Pb in Taiwan. Current regulations do not mandate heavy metal testing routinely. However, depending on the inventory, which would reveal the extent of contamination, assessment of heavy metals might be essential on a regular basis.

RESULTS AND DISCUSSION

Lead levels in a lead pipe-free campus

Figure 1 (number of dispenser and faucet samples not stacked but overlapped) shows the distribution of Pb levels in the 558 water samples collected from POU dispensers ($n = 204$) and faucets ($n = 354$) during the survey. The distribution of total number of

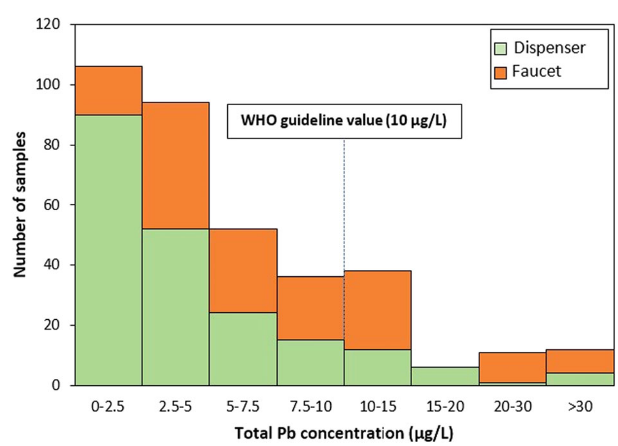

Fig. 1 Pb levels in water samples. Distribution of Pb levels in water samples collected from POU dispensers ($n = 204$) and faucets ($n = 354$). Dotted line refers to the WHO guideline value of 10 μg/L for Pb in drinking water.

Table 1. Water quality parameters of samples.

Sampling units	Water quality parameters		
	Temperature (°C)	pH	Alkalinity (mg/L as $CaCO_3$)
POU dispenser	19.2–36.7	6.7–7.3	40.2–44.6
Faucet	17.3–29.5	6.9–7.7	42.5–48.3

samples collected using different protocols is shown in Supplementary Table 1. Table 1 shows the water quality parameters of the sample water. Among the total 558 samples collected, regardless of sampling protocols used, 89 samples (16%) had Pb levels greater than the Taiwan EPA standard value (or the WHO guideline value) of 10 µg/L.

Samples with Pb levels above 10 µg/L are considered "unsafe" in this study. Since the number of samples collected from dispensers and faucets varied, a percentage was used to represent the proportion of unsafe samples. In this regard, 66 out of 354 (19%) samples from faucets and 23 out of 204 (11%) samples from dispensers were not safe for consumption. Hence, faucet samples were approximately twice as likely to be contaminated as dispenser samples. As expected, the use of POU dispensers could effectively reduce Pb levels, but not always below the regulatory standard of 10 µg/L. Possible reasons include inadequate removal efficiency of dispenser filters and Pb-containing components in the filter system. The extent of Pb reduction (or unlikely addition) through a dispenser was, however, not determined in this study. Although POU dispensers have become necessary in delivering safe drinking water, the occurrence of unsafe samples from such dispensers showed that water from dispensers does not always meet the regulatory standard. The results also indicated that Pb contamination issues could be prevalent even if no aged Pb pipes were present. For faucet samples, the Pb sources are most likely Pb-containing plumbing materials such as brass fittings and Pb solders[5,6]. Although regulations of Pb in plumbing materials have evolved with time, legacy plumbing materials may still be present in the buildings. Harvey et al.[5] collected water samples from kitchen tap fittings in Australia and demonstrated that Pb-containing fittings could significantly contribute to Pb in drinking water. Similarly, Ng and Lin[6] concluded that brass fittings were the main source of Pb in drinking water in a simulated copper pipe premise plumbing.

All buildings except Building VIII (Supplementary Table 1) had at least one sample from the faucet and dispenser exceeding 10 µg/L Pb. Building VIII is the only building without any unsafe samples from the dispensers. Buildings VII had the highest percentage of samples that were unsafe (24%), followed by buildings VI (23%), IV (17%), and III (16%) (Supplementary Table 2). Although the percentage of unsafe samples from faucets was approximately twice that from dispenser samples (Fig. 1), a higher proportion of faucet samples compared to dispenser samples collected in a building did not always correspond with an increase in the proportion of unsafe samples among the buildings (Supplementary Table 2). For example, Building III had more samples collected from faucets (70%) than Building VII (63%). Still, the proportion of unsafe samples in Building III (16% of samples) was less than in Building VII (24% of samples).

Figure 2 shows the median total Pb concentration for dispensers and faucets in the eight buildings surveyed. The median Pb level ranged from 1.3 to 5.7 µg/L and 2.2 to 5.7 µg/L for dispenser and faucet samples, respectively. The median Pb level for dispenser samples was lower than faucet samples in six of the eight buildings. The difference in medians between dispenser (filtered) and faucet (unfiltered) samples were significantly different using *t* test (p value < 0.05) (Supplementary Table 3). This suggests that filter systems in POU dispensers contribute to reducing Pb levels in drinking water. However, the anomaly observed in the remaining two buildings may be due to higher water usage, as those buildings are mainly catered for routine class activities, causing the filters to reach their treatment capacity prematurely. Figure 2 also shows the sporadic Pb levels in the dispenser and faucet samples among the buildings surveyed, implying that Pb-containing materials may be used in common practice. Similar findings regarding the sporadic Pb release in plumbing systems with no Pb pipes have been reported[51,52]. Both studies attributed Pb release to the use of brass fittings, fixtures, and water meters.

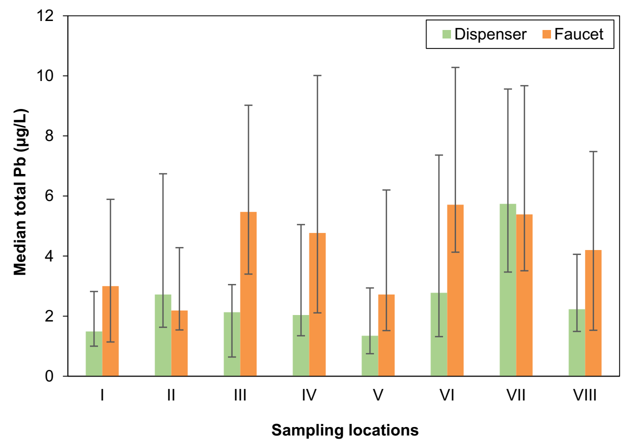

Fig. 2 Comparison of Pb concentration at different sampling locations. Median total Pb concentration in water samples collected from dispensers and faucets in various sampling buildings on a school campus. Error bars represent the values of the first (Q1) and third (Q3) quartiles.

The distribution of Pb in the samples was further investigated in Building VII, which had the highest proportion of unsafe samples, using the modified FD method, which involved collecting 10 × 100 mL samples from dispensers and faucets (Fig. 3). Thirty of the 90 sequential samples collected from the dispenser exceeded the regulatory standard. Six samples within the first 100 mL indicated that Pb was released from the dispenser component near the outlet. The rest showed a more uniform distribution (Fig. 3a). In contrast, 43 of the 100 sequential samples collected from the faucets exceeded the standard, with 27 samples within the first three 100 mL, including 10 first 100 mL samples (Fig. 3b). This finding for faucets reveals that the fittings and components near the faucets were the most likely source of Pb in the samples. In many circumstances, sequential sampling can help identify Pb leaching from plumbing materials at various sampling locations[6,28,35] because a Pb source is expected to be present when at least one sequential sample exceeds the regulatory standard.

Impact of POU dispenser on different sampling protocols

Maximum Pb levels measured using FD, RDT, and FL sampling protocols, irrespective of dispenser and faucet samples, were 88.6, 54.1, and 37.8 µg/L, respectively (Supplementary Table 1). This finding on the trends in Pb level among protocols was consistent with the previous studies[23,31,36,53], which have shown that FL sampling exhibited the lowest total Pb compared to other protocols. However, as water is filtered in the dispenser before being discharged, the extent of impact due to dispensers on the overall Pb assessment may vary depending on the types of sampling protocol employed to collect the samples. Hence, to elucidate the impact of POU dispensers on the survey results of three sampling protocols, a comparison between dispenser and faucet samples exceeding the Taiwan EPA standard for Pb among

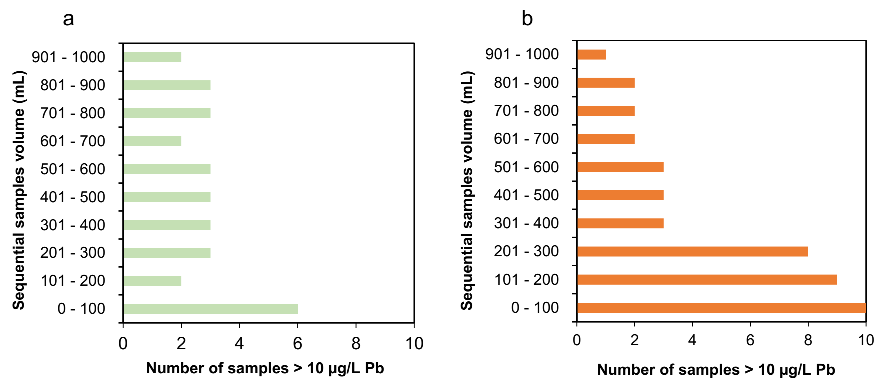

Fig. 3 Distribution of sequential samples exceeding 10 µg/L Pb. Number of sequential samples exceeding 10 µg/L Pb in the building with the largest proportion of unsafe samples. 0–100 mL refers to the first 100 mL collected. **a** Dispenser ($n = 90$) and **b** faucet ($n = 100$).

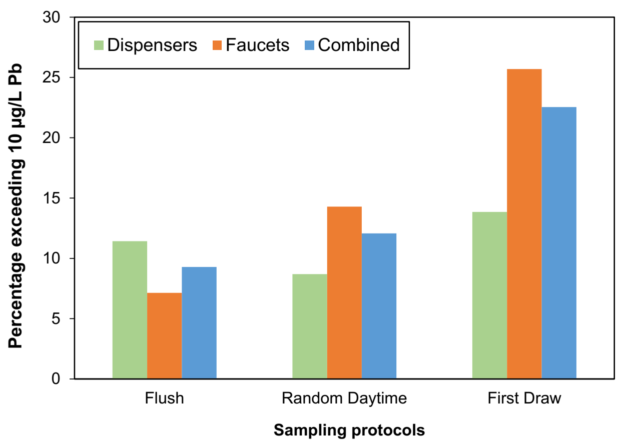

Fig. 4 Pb contamination in water samples using different sampling protocols. Percentage of samples exceeding 10 µg/L Pb from dispensers and faucets using flush, random daytime and first draw sampling protocols. Combined represents both dispenser and faucet samples considered collectively.

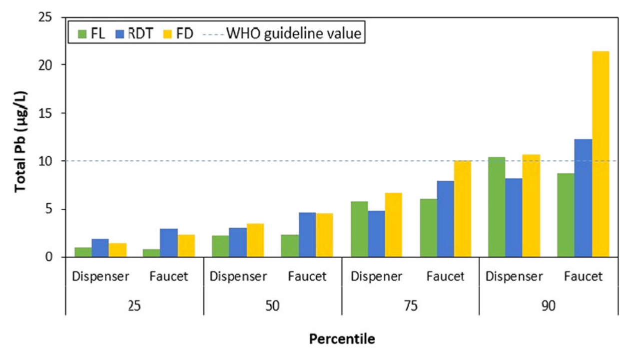

Fig. 5 Cumulative Pb levels. Total Pb levels at 25th, 50th, 75th and 90th percentiles in dispenser and faucet samples using flush (FL), random daytime (RDT) and first draw (FD) sampling protocols. Dotted line refers to the WHO guideline value of 10 µg/L for Pb in drinking water.

the protocols is shown in Fig. 4. In FD and RDT samples, respective percentages exceeding the standard were the highest for faucet samples considered alone (26%, 14%), followed by a combination of faucets and dispensers (23%, 12%), and the lowest for dispenser samples considered alone (14%, 9%). These findings indicate that POU dispensers can differentially affect survey outcomes. In contrast, exceedance in FL samples was higher in dispensers than faucets. This result contradicts the findings of previous sampling surveys[23,31,53], which primarily collected samples from faucets.

Furthermore, the cumulative Pb levels in dispenser and faucet samples collected using three sampling protocols are shown in Fig. 5, to illustrate the lead levels at each quartile and 90th percentile, which would reflect the extent and severity of contamination. In addition, a comprehensive cumulative graph is provided in Supplementary Figure 2, which shows the maximum Pb levels measured using each protocol for dispenser and faucet samples. Such graphs can provide crucial information regarding the type of remediation measures based on the extent of the contamination. FL sampling yielded lower Pb levels in faucet samples (Fig. 5), for each percentile, consistent with results in the literature[31,34,36,37,54]. Lower Pb levels in FL samples for faucets might be due to higher flow rates (compared to dispenser samples) involved during flushing. Several previous studies[35,36,55,56] have demonstrated that different flow rates during pre-flushing may produce different Pb levels in drinking water. Flushing is generally known to reduce the exposure to Pb at the consumer end and its efficiency is governed by variables including premise plumbing configuration, water use, duration, and extent of flushing prior to sampling, which is usually difficult to control[35,56]. FL samples for faucets had a 90th percentile value of 8.8 µg/L, which was much lower than those for FD (21.5 µg/L) and RDT (12.3 µg/L) samples. The difference between the highest and lowest 90th percentile Pb levels yielded respectively by FD and FL sampling was 12.7 µg/L indicating that FL sampling should not be used for faucets as it tends to produce lower Pb levels than other sampling methods unless a more stringent guideline for FL sampling can be proposed and implemented. The guideline may have to consider the effects of flushing time and flushing flow rate on the Pb assessment.

Interestingly, unlike in faucet samples, all three sampling protocols produced similar Pb levels in dispenser samples, as evident by 90th percentile values of 10.7, 10.4, 8.2 µg/L for FD, FL, and RDT sampling, respectively. The difference between the highest and lowest 90th percentile Pb levels yielded by FD and RDT sampling was only 2.5 µg/L, compared with 12.7 µg/L in faucet samples. This phenomenon is likely due to storage tanks in dispensers which provided a buffering effect against changes in water quality and sampling methods. The buffering effect was illustrated by the distribution of the unsafe samples collected using a follow-up sequential FD from the building with the highest contamination. A more even distribution was observed in samples collected from dispensers than in faucets (Fig. 3), where contamination tends to occur near the faucet. There are no reported studies that considered collecting water samples only from the POU dispensers, and hence, the effects of dispensers on sampling surveys have not been documented yet. As water from

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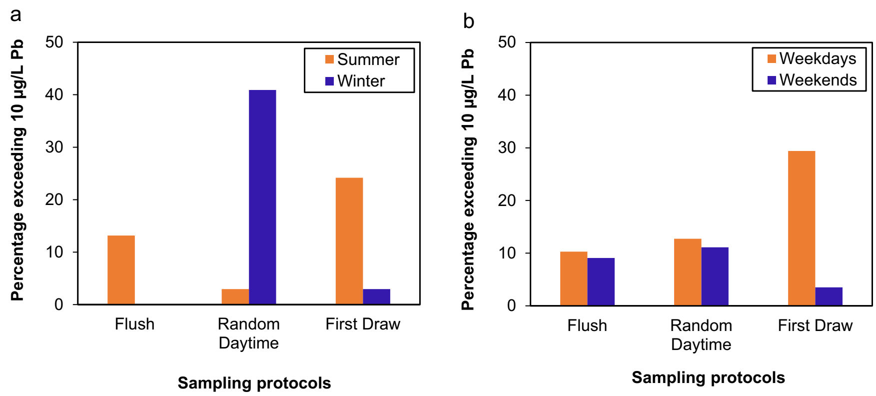

Fig. 6 Effects of water use on Pb exceedance. Variations in Pb exceedance in water samples using three sampling protocols. **a** Seasonal and **b** weekday versus weekend.

the faucet is generally not consumed directly, water samples collected from dispensers are more representative of drinking water quality in schools in Taiwan. Although some previous studies suggest that the choice and guideline for a particular sampling protocol varies among countries[23,32,57], which depend on factors such as the minimum number and volume of samples collected, and stagnation period[58], the findings of this study illustrate that any of the three sampling protocols can be recommended for sampling drinking water. The limitation, however, is that only dispenser samples should be considered during sampling.

Unlike several previous studies that have deemed FL sampling undesirable, this study demonstrated that FL sampling does not necessarily produce lower Pb levels, especially samples from dispensers. Hence, FL sampling being recommended in Taiwan can reflect Pb levels in drinking water only if the water samples are collected from dispensers. Since the public generally regards filtered water as their drinking water, sampling only from dispensers can provide a more accurate Pb assessment for human exposure risk.

Effects of water usage

Water usage varies among the seasons and during weekdays which may result in different Pb levels in the water samples. The seasonal variation in Pb levels in drinking water obtained using three sampling protocols and differences between weekday and weekend samples are illustrated in Fig. 6. The proportion of unsafe samples was higher in summer (June–August) than in winter (December–February) for FL and FD sampling, whereas RDT showed otherwise. The maximum Pb level recorded in summer (49.0 μg/L) was nearly twice as high as the Pb level in winter (26.0 μg/L) (Data not shown). Source of water, temperature, configuration of premise plumbing, and water chemistry are among some factors causing variations in Pb level in drinking water[58,59]. The effects of these factors were not individually addressed in this study. Nevertheless, the findings regarding higher Pb levels in summer samples were consistent with the previous studies[1,60,61]. The higher temperature in summer is expected to increase the dissolution rate of the Pb-containing scale and Pb release from plumbing materials[34].

Similarly, all three sampling protocols showed higher proportions of unsafe samples during weekdays than weekends. The extent of difference was the most pronounced in FD sampling (29% on weekdays compared to 4% on weekend samples). This finding contradicts previous literature reporting an increasing Pb contamination during the weekends, possibly due to lower water usage and longer stagnation of water[1,62–64]. Prior studies are based on premises with Pb service lines where the stagnation can affect Pb scales and their dissolution in the supply water. However, this study was conducted on a Pb pipe-free campus. The effects of stagnation on Pb levels in distribution systems with Pb-containing plumbing materials may be less significant than a system containing Pb pipes. In addition, site-specific factors such as local water quality and plumbing configuration can also influence Pb levels[65]. However, both factors can be challenging to determine in a large-scale survey. Thus, conducting pilot studies to elucidate the impact of each of these factors on Pb level assessment might be imperative.

Implications for decision-makers

This study uncovers the scenarios of possible Pb contamination in a lead pipe-free campus using a systematic sampling survey method. Findings are expected to provide crucial information for decision-makers (government) in selecting appropriate sampling protocols. The incidence of Pb levels exceeding the Taiwan EPA standard for dispenser samples warrants a comprehensive and large-scale sampling survey for Pb level assessment studies in drinking water supplies. Sampling guidelines should also include important factors, such as the number of samples required, the frequency of sampling, the location of sample collection, and proposed corrective measures. Information on such factors can substantially contribute to updating the existing local EPA guideline[38], which provides information on the sampling protocols allowed for collecting drinking water samples. Very low Pb concentrations below 10 μg/L have also been shown to be harmful to human health[13–15]. Thus, the existing standard of 10 μg/L for Pb in drinking water can be recommended to be gradually reduced to below 10 μg/L (such as 5 μg/L) for drinking water samples, especially samples collected from dispensers.

The harmful consequences of Pb contamination in drinking water have been well reported[8–11]. This study shows that even Pb pipe-free plumbing could not eliminate exposure risks. Hence, sampling surveys should be performed on a regular basis as part of a monitoring program, especially in places such as nurseries, elementary schools, and hospitals catered for vulnerable groups.

Discussion of the key findings

This study, for the first time, investigated the influence of POU dispensers on the assessment of Pb levels in the drinking water of a lead pipe-free campus. Some of the important findings of this study are:

- Owing to the extensive use of POU dispensers for drinking water in Taiwan, the study concludes that such dispensers can effectively reduce the Pb levels in water but do not always guarantee meeting the regulatory standard and, hence, monitoring the filters used in the dispensers and their periodic maintenance are recommended.

- Pb concentration in water samples varied among three sampling protocols employed for the faucets, whereas all the protocols produced similar Pb levels for dispenser samples. Hence any of the three protocols can be used for collecting water samples from dispensers.
- The FL sampling method, incorporating at least 20 s of flushing, does not necessarily demonstrate lower Pb concentrations than other sampling methods. In particular, this protocol can be as effective as other sampling protocols when collecting water samples from dispensers.
- Considering water consumption habits, sampling only from dispensers is recommended while assessing Pb levels in drinking water in public utilities.

METHODS

Sampling strategies

Water samples were collected from Chaoyang University of Technology (CYUT), located in Taichung, Taiwan. All major buildings on the campus were selected for sampling to determine the Pb levels in water samples. The buildings were provided with unique codes such that their identities were hidden to remain neutral on the objectives. A systematic sampling survey was conducted within each building to collect water from the faucets and POU dispensers between March 2017 and July 2020 using three sampling protocols: a modified FD, FL, and RDT based on an independent sample design. In contrast to a paired study design, filtered and unfiltered water samples were collected separately from POU dispensers and faucets, respectively to elucidate the effects of POU dispensers on Pb level assessment. The sampling strategy was designed to include at least one dispenser and two faucets from each floor of the buildings. However, the number of samples collected from dispensers and faucets among the buildings varied due to the randomness in real situations where sampling surveys are exposed to accessibility and availability. For instance, dispensers and faucets in offices were not available for sampling due to restricted access. A modified FD sampling method was used in which 10×100 mL sequential samples were collected instead of 1×1 L. For FD samples, a stagnation period of at least 6 h was maintained. The samples were collected in the early morning before classes commenced. To ensure that the faucets and dispensers were not used during the stagnation period, the faucets were sealed with tape the night before sampling. The vicinity of the dispensers was ensured to be dry before sampling. FL samples were collected by flushing the water for at least 20 seconds in accordance with NIEA W101.56 A before a 1 L sample was collected. RDT samples were collected at any RDT (7 am–7 pm). The faucets were fully opened during sampling. Glass bottles were used to collect 100 mL samples, while high-density polyethylene (HDPE) bottles were used to collect 1 L samples.

Analysis techniques

A mercury thermometer was used to determine the temperature on-site, and the pH was measured, within 2 h of sample collection, with a pH meter (Hanna, HI2020-01, Edge). The pH meter was calibrated with pH 4, 7, and 10 buffer solutions (Fisher Scientific). Total alkalinity was measured in accordance with Standard Method 2320-B[66]. For the acid-preserved 1 L sample collected using an HDPE bottle, the sample was well-stirred before a 100 mL aliquot was collected for acid digestion in accordance with USEPA method 3500A[67]. The 100 mL sample was digested with 2% v/v HNO_3 and heated at 85 °C for at least 2 h before measuring the total Pb concentration. Inductively coupled plasma mass spectrometry (ICP-MS) (Thermo Scientific, iCAP Q) was used to measure total Pb concentrations following Standard Method 3125-B[66].

Statistical analysis

The difference between the Pb levels in dispenser and faucet samples was tested statistically using the *t* test (test of statistical significance).

Quality assurance and quality control

Before usage, all sampling bottles were rinsed in a 10% HNO_3 solution, washed with ultrapure water, and dried in the oven. To avoid precipitation and adsorption to the bottle walls, 100 mL and 1 L samples were acidified below pH 2 with 0.3 mL and 3 mL $1 + 1$ HNO_3, respectively[67].

Pb concentration in the acidified samples was analyzed at least 24 h after collection. Pb ICP standard solution (Merck Millipore, Germany) of 1000 mg/L was used to calibrate the ICP-MS, diluted to various concentrations using ultrapure water. The method detection level (MDL) for Pb was determined to be 0.2 μg/L. An instrument blank was examined after every ten samples to ensure no background contamination. The method blank was used to determine whether sample preparation, which began with acid digestion, led to any contamination and was found to be below the MDL. The field blank was prepared by collecting ultrapure water (Merck, Milli-Q) in the sampling bottles in the field and was also below the MDL, suggesting that the bottles were not the source of contamination. Spiked samples (10 μg/L) were used regularly, and recoveries were between 98% and 105%.

DATA AVAILABILITY

The datasets generated during and/or analyzed during the current study are openly available as Dispenser_open access data.xlsx and Faucet_open access data.xlsx.

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AUTHOR CONTRIBUTIONS

S.A.: formal analysis, investigation, data curation, writing - original draft, writing - review and editing. Y.P.L.: validation, formal analysis, visualization, writing - review and editing. D.Q.N.: conceptualization, methodology, resources, data curation, writing - original draft, writing - review and editing, visualization, supervision, project administration, funding acquisition.

COMPETING INTERESTS

The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to Ding-Quan Ng.