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Metal leaching test of commercially available faucets in the Japanese market in 2016–2020

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ABSTRACT

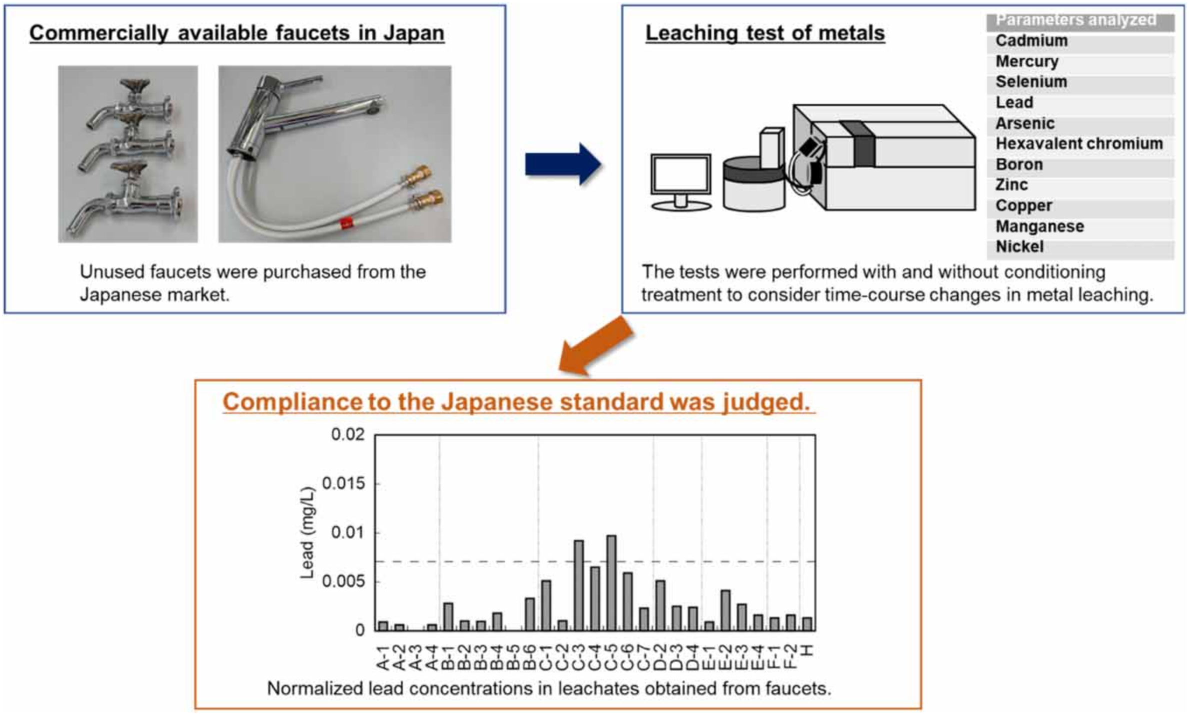
In this study, metal leaching was investigated in commercially available faucets in Japan to clarify their compliance to Japanese regulations. We purchased 37 faucets from the market and analyzed the leaching of cadmium, mercury, selenium, lead (Pb), arsenic, hexavalent chromium, boron, zinc (Zn), copper, manganese, and nickel. The leaching tests were performed with and without a conditioning treatment, that simulated approximately 1-month intermittent use of faucets on weekdays, and the results were compared to estimate the changes in metal leaching during the use of faucets. The results revealed that metal leaching from most of the faucets complied with Japanese regulations. However, the levels of Pb leaching from several faucets produced by certain manufacturers exceeded the Japanese standard. The conditioning treatment was generally effective in reducing metal leaching. However, the reductions in Pb and Zn leaching tended to be lower than those of the other metals. Nickel is not legally regulated in Japan; although the number of cases where nickel concentration in leachate exceeded the water quality management target value was greater, such cases were limited to faucets primarily made of copper alloys. We believe that these results will be helpful to improve the public health associated with metal leaching from faucets.

Key words: drinking water, faucet, metal leaching, public health

HIGHLIGHTS

- Metal leaching was tested in commercially available faucets in Japan.
- Leaching with and without conditioning was tested to estimate time-course decline in metal leaching.
- Faucets of a certain manufacturer repeatedly exceeded the Japanese standard.
- The declines in Pb and Zn leaching by the conditioning were limited.
- Using faucets not made mainly of copper alloys may be useful to reduce the effect of nickel leaching.

GRAPHICAL ABSTRACT



INTRODUCTION

The appropriate management of drinking water quality is important for public health. In addition to the removal of hazardous constituents in drinking water treatment facilities, preventing contamination during water distribution by introducing constituents from pipes, plumbing, and faucets, among others, is one of the most important issues. Contamination in distribution systems has been a major issue worldwide, and several incidents, where the standard was exceeded, have been of great concern. In April 2014, the lead (Pb) concentration in the drinking water of Flint, Michigan increased significantly, which was likely attributed to the breakdown of Pb-rich iron rust formed from old lead and galvanized iron pipes (Pieper *et al.* 2017). Multiple cases of water Pb levels exceeding the standards have also been reported in other regions, such as Washington DC (Edwards & Dudi 2004), Seattle (Boyd *et al.* 2008), United Kingdom (Hayes & Hydes 2012), and Hong Kong (Chan *et al.* 2020). Therefore, many research efforts have been devoted to addressing metal leaching from plumbing, including field surveys (Kimbrough 2001; Miller-Schulze *et al.* 2019; Chan *et al.* 2020), sampling protocols (as reviewed by Triantafyllidou *et al.* (2021)), effects of phosphate addition on water Pb levels (Edwards & McNeill 2002; Pieper *et al.* 2018), leaching mechanisms (Zhang & Edwards 2011), evaluation of the performance of test kits (Kriss *et al.* 2021), and model-based investigations (Chan *et al.* 2020). An intensive field survey was recently conducted in Japan (Asami *et al.* 2021).

In most of the aforementioned studies, metal leaching from pipes and plumbing materials containing lead was concerning. Moreover, faucets are a potential source of metal leaching and have been investigated for a long time (Samuels & Méranger 1984; Gardels & Sorg 1989). Since a degree of leaching from faucets in excess of the maximum permissible limit has been reported in several specimens (Samuels & Méranger 1984), the impact of metal leaching from faucets on public health should not be ignored.

In Japan, 44 items associated with leaching from faucets are legally regulated; among the 44 items, 13 are metals (Ministry of Health Labour and Welfare 1997a). A faucet specimen was subjected to a standardized leaching test, and the leachate obtained was analyzed for items listed in the regulations. All faucets installed in Japan are required to comply with the regulations by providing self-certification by manufacturers themselves or obtaining third-party certification from qualified certification bodies. Providing such certifications is obligatory for manufacturers to sell their products in Japan.

Although faucet manufacturers have devoted much effort to compliance, fair confirmation by a third party without any conflicts of interest is still required to clarify the accurate compliance state of the regulation. As a public research institute in Japan, the National Institute of Public Health (NIPH) has performed leaching tests on commercially available faucets that can be purchased in Japan. In this study, the results obtained from recent leaching tests are presented. Based on the results, the differences in compliance status depending on the manufacturer, degree of decline in metal leaching during intermittent use, and measures for improving public health are discussed.

Parameters analyzed in this study and standards for faucet leachate in Japan

In this study, we analyzed the metals included in current Japanese regulations. Among the items regulated (13 in total), aluminum, iron, sodium, and the compounds incorporating these elements were excluded from the analyses because these items are not of health concern (rather, aesthetic aspects including taste and color are of great concern for these items). The elements analyzed in the present study were cadmium, mercury, selenium, lead, arsenic, hexavalent chromium, boron, zinc, copper, manganese, and the compounds incorporating these elements. In addition to the items mentioned above, nickel and nickel compounds were analyzed, although this item is not legally regulated in the current regulation; rather, the water quality management target value was set for this item.

In the Japanese regulation, in addition to the monoatomic forms, the compounds of said atoms are regulated. In the following sections, the names of the elements are used to represent the sum of the monoatomic ion and all its compounds (e.g., 'cadmium' represents the 'sum of all the monoatomic ion forms of cadmium and all compounds incorporating cadmium'). It should be noted that, with regard to chromium, only the hexavalent chromium is regulated (trivalent chromium is not included in the current Japanese regulation). Therefore, 'chromium' in the rest of this paper represents the 'sum of the monoatomic ion of hexavalent chromium and all compounds comprised hexavalent chromium.'

Table 1 lists the standards for faucet leachate and drinking water quality in Japan determined for the parameters examined in this study. The guidelines for drinking water quality provided by the World Health Organization (WHO 2022) are summarized in Table 1. For all the selected parameters, the Japanese standard values were equal to or less than those in the WHO guidelines. In Japan, the standards for faucet leachate are defined as 10% of the drinking water quality standards, considering the allocation of other potential sources of metal leaching in plumbing (e.g., pipes, fittings, and valves). It should be noted that exceptional standard values (less stringent standard values) of lead, zinc, and copper have been set for faucets mainly composed of copper alloys, as shown in Table 1, owing to the following circumstances: (1) leachates from the faucets mainly

Table 1 | Standards for faucet leachate and drinking water quality standards in Japan, and the values of the guidelines for drinking water quality provided by the WHO

Items	Standards for faucet leachate in Japan	Drinking water quality standards in Japan	Guidelines for drinking water quality by WHO
Cadmium	0.0003	0.003	0.003
Mercury	0.00005	0.0005	0.006
Selenium	0.001	0.01	0.04
Lead	0.001 (0.007)[a]	0.01	0.01
Arsenic	0.001	0.01	0.01
Hexavalent chromium	0.005 (2019 and before) 0.002 (2020 and after)[b]	0.05 (2019 and before), 0.02 (2020 and after)	0.05
Boron	0.1	1.0	2.4
Zinc	0.1 (0.97)[a]	1.0	Not of health concern
Copper	0.1 (0.98)[a]	1.0	2
Manganese	0.005	0.05	Not of health concern
Nickel	0.02[c]	0.02	0.07

The values provided in this table are in mg/L.

[a]Values in parentheses are standards for faucets mainly comprised copper alloys.

[b]The standard for hexavalent chromium was amended from 0.005 to 0.002 mg/L in 2020.

[c]Water quality management target value (not legally regulated standard value).

composed of copper alloys are likely to contain more lead, zinc, and copper than other faucets and could exceed the standard values and (2) copper alloys are widely used materials for faucets and there are no alternatives.

MATERIALS AND METHODS

Selection of faucets

In this study, metal leaching from unused faucets (i.e., faucets that had not been installed in buildings) was investigated. For this purpose, we purchased unused faucets from the Japanese market. Table 2 lists the faucets examined in this study. The sample IDs used in Table 2 and in the rest of this manuscript indicate the manufacturer and sequential number in the leaching test: for example, 'B-2' indicates that this faucet is the second specimen of the manufacturer B. The photographs of several faucets subjected to the leaching test are provided in Figure 1. The faucets selected for the leaching tests were composed of different main materials such as plastic, brass, bronze, and other copper alloys. As previously mentioned, less stringent standard values for lead, zinc, and copper in the Japanese regulation are adopted for faucets primarily made of copper alloys than the values for those mainly comprised of other materials (e.g., plastics). The primary materials of several faucets analyzed in this study were not disclosed (denoted as 'Unknown' in Table 2); therefore, such faucets were dealt with as 'faucets not made primarily of copper alloys,' and their compliances with the standards were judged against the more stringent standard values. The standard for hexavalent chromium in Japan was revised in 2020; therefore, previous and current standards were used to verify the compliances for the tests performed before 2019 and in 2020, respectively.

Manufacturers A–F and H are domestic companies. As these manufacturers aim to provide their products to the Japanese market, all products from these manufacturers were certified products. The faucets supplied by manufacturers G and I–L were non-domestic products. Although these faucets were not certified products, they are also commercially available in the Japanese market (e.g., an internet shopping site). Therefore, confirming their compliance with Japanese standards is of great importance for the management of health risks in Japan.

Protocols of leaching tests

The degree of leaching from faucets is generally time-dependent; leaching tends to be greater immediately after installation and gradually declines over time. To consider such time-course changes, a protocol related to the conditioning treatment is specified in the standardized protocols adopted in Japan (the Ministry of Health, Labour and Welfare (MHLW) Notice 111 'Standard Test Related to Water Supply Devices and Materials' (Ministry of Health Labour and Welfare 1997b)). The flowchart of the leaching test protocols, including the conditioning treatment, is graphically described in Figure 2. As shown in Figure 2, samples of leachate obtained before subjecting the specimens to the conditioning treatment were also collected and analyzed in this study. The samples without the conditioning treatment reflected the conditions of the faucets immediately after installation. After taking the sample without implementing the conditioning treatment, the faucet specimen was subjected to the conditioning treatment comprising a series of washes by filling it with the reference tap water. The characteristics of the reference tap water used in the leaching test were pH 7.0 ± 0.1, hardness of 45 ± 5 mg/L, alkalinity of 35 ± 5 mg/L, and residual chlorine concentration of 0.3 ± 0.1 mg/L as free chlorine, which are specified in the MHLW Notice 111 (Ministry of Health Labour and Welfare 1997b). At the end of the conditioning treatment, the leachate samples were collected again. These samples were designated as leachate after the conditioning treatment. The conditioned faucets roughly equate to faucets used for approximately 1 month in facilities actively utilized only on weekdays (e.g., offices, schools, and factories). The leaching test was performed in ordinary temperature (approximately 23 °C) in accordance with the MHLW Notice 111 (Ministry of Health Labour and Welfare 1997b).

Normalization of the concentration of metals in the leachate

The results of the analyses of the concentrations of leached metals determined in the leaching test mentioned above were normalized by multiplying a normalization factor (NF) based on the percentage of consumption of water stagnated in faucets in daily total water consumption to the concentrations in leachates. The determination of the NF is based on the following assumptions: (a) the frequency of drinking tap water stagnated in faucets for one person is 2 times per day and (b) the volume of daily total consumption of drinking water for one person is 2,000 mL. Therefore, the equation used in the normalization is

Table 2 | Faucets examined in this study

Sample ID	Main material	Year	Contact volume (mL)	Primary purpose	Faucet type	Certification in Japan
A-1	Copper alloys	2016	47	Multi-purpose	Single	Yes
A-2	Copper alloys or plastic	2017	112	Kitchen	Mixing	Yes
A-3	Copper alloys	2018	92	Kitchen	Mixing	Yes
A-4	Copper alloys	2019	125	Kitchen	Mixing	Yes
A-5	Plastic	2020	80	Kitchen	Mixing	Yes
B-1	Brass	2016	121	Kitchen	Mixing	Yes
B-2	Bronze	2016	24	Multi-purpose	Single	Yes
B-3	Brass	2017	120	Kitchen	Mixing	Yes
B-4	Bronze	2018	152	Kitchen	Mixing	Yes
B-5	Brass	2019	80	Bathroom sink	Mixing	Yes
B-6	Brass	2020	122	Kitchen	Mixing	Yes
C-1	Bronze	2016	151	Kitchen	Mixing	Yes
C-2	Brass	2017	156	Kitchen	Mixing	Yes
C-3	Bronze	2018	131	Kitchen	Mixing	Yes
C-4	Bronze	2019	128	Kitchen	Mixing	Yes
C-5	Bronze	2019	132	Kitchen	Mixing	Yes
C-6	Bronze	2020	150	Kitchen	Mixing	Yes
C-7	Bronze	2020	178	Kitchen	Mixing	Yes
D-1	Plastic	2016	130	Kitchen	Mixing	Yes
D-2	Bronze	2016	26	Multi-purpose	Single	Yes
D-3	Brass	2017	168	Kitchen	Mixing	Yes
D-4	Brass	2018	145	Kitchen	Mixing	Yes
D-5	Plastic	2019	125	Kitchen	Mixing	Yes
D-6	Plastic	2020	54	Kitchen	Mixing	Yes
E-1	Brass	2017	126	Kitchen	Mixing	Yes
E-2	Brass	2018	128	Bathroom sink	Mixing	Yes
E-3	Bronze	2019	190	Kitchen	Mixing	Yes
E-4	Brass	2020	113	Kitchen	Mixing	Yes
F-1	Brass	2018	132	Kitchen	Mixing	Yes
F-2	Brass	2020	155	Kitchen	Mixing	Yes
G-1	Unknown	2016	100	Kitchen	Mixing	No
G-2	Unknown	2017	128	Kitchen	Mixing	No
H	Brass	2019	100	Bathroom sink	Mixing	Yes
I	Unknown	2017	110	Kitchen	Mixing	No
J	Unknown	2018	105	Bathroom sink	Mixing	No
K	Unknown	2019	210	Kitchen	Mixing	No
L	Unknown	2020	180	Kitchen	Mixing	No

as follows:

$$C_{Normalized} = C_{Leachate} \times NF$$

$$NF = \frac{V \times 2}{2,000} \times TF$$

Figure 1 | Examples of faucets examined in this study. Left: single faucet, right: mixing faucet.

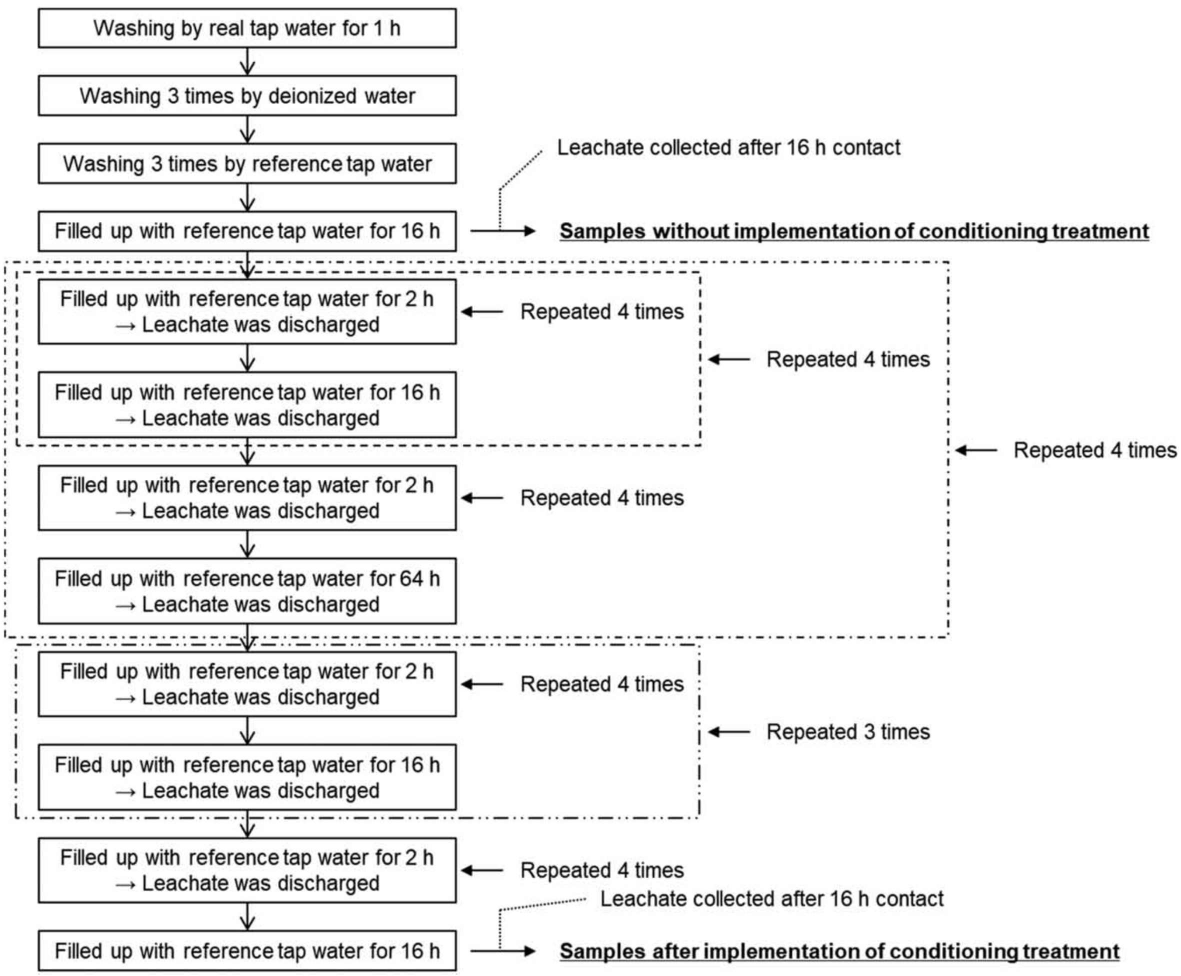


Figure 2 | Flowchart of the leaching test including conditioning. Leachate represents the reference tap water containing the metals leached during the contact to the faucet specimen.

where $C_{Normalized}$ is the normalized concentration in mg/L, $C_{Leachate}$ is the metal concentration determined for leachate in mg/L, and V is the contact volume of the faucet examined in mL. *TF* is a type factor that incorporates the effect of the faucet type into the normalization. In the case of a mixing faucet, where cold water and hot water are separately introduced and mixed in the faucet, the contact volume accounted for the normalization mentioned above should be limited to that available for cold water, whereas the entire contact volume of a single faucet should be accounted for the normalization. Therefore, the values for TF are 1 for single faucets and 0.5 for mixing faucets.

In Japan, standards for leaching from faucets have been established for the concentrations of compounds leached after applying the normalization mentioned above. Therefore, it was reasonable to compare the normalized concentrations with the standards. Based on the background mentioned above, all results presented in this paper were normalized by the protocols mentioned above.

Analytical methods

The concentrations of mercury and the incorporated compounds were determined using cold vapor atomic absorption spectrometry (CV-AAS). Inductively coupled plasma mass spectrometry (ICP-MS) was used to analyze other parameters. The limits of quantification for each parameter are presented in Table 3.

RESULTS AND DISCUSSION

Among the parameters examined in this study, the normalized concentrations of mercury, selenium, and arsenic were below the limits of quantification in all samples. For cadmium, copper, and manganese, the normalized concentrations determined for several samples exceeded the limits of quantification. However, the normalized concentrations of these compounds were below the standard values for all samples. On this basis, the results and discussion of these compounds will not be presented in the following sections, and the discussion will focus on the rest of the parameters (lead, zinc, hexavalent chromium, and boron), where certain specimen(s) exceeded the standards.

Leaching after the conditioning treatment

Figure 3 shows the normalized concentrations of lead, zinc, hexavalent chromium, and boron in the leachate obtained from the specimens after the conditioning treatment. Therefore, the values presented in this figure should comply with the standards for each item. For hexavalent chromium and boron, all the specimens examined in this test complied with the standards. This result indicates that the health risks associated with these metals during the long-term use of faucets are negligible.

As shown in Figure 3, most of the faucets examined in this test (30 of 37 faucets) satisfied the Japanese standards for all parameters. This suggests that the health risks associated with metal leaching during the long-term use of faucets are generally well managed in Japan. However, in several specimens, the normalized concentrations of lead in the leachates exceeded the

Table 3 | Limits of quantification

Parameters	Limit of quantification (mg/L)[a]
Cadmium	0.00002
Mercury	0.00005
Selenium	0.0005
Lead	0.0005
Arsenic	0.0005
Hexavalent chromium	0.001 (2016), 0.0001 (2017), 0.0002 (2018–2020)
Boron	0.01
Zinc	0.005
Copper	0.005
Manganese	0.0005
Nickel	0.0005

[a]Values defined by analysis agency.

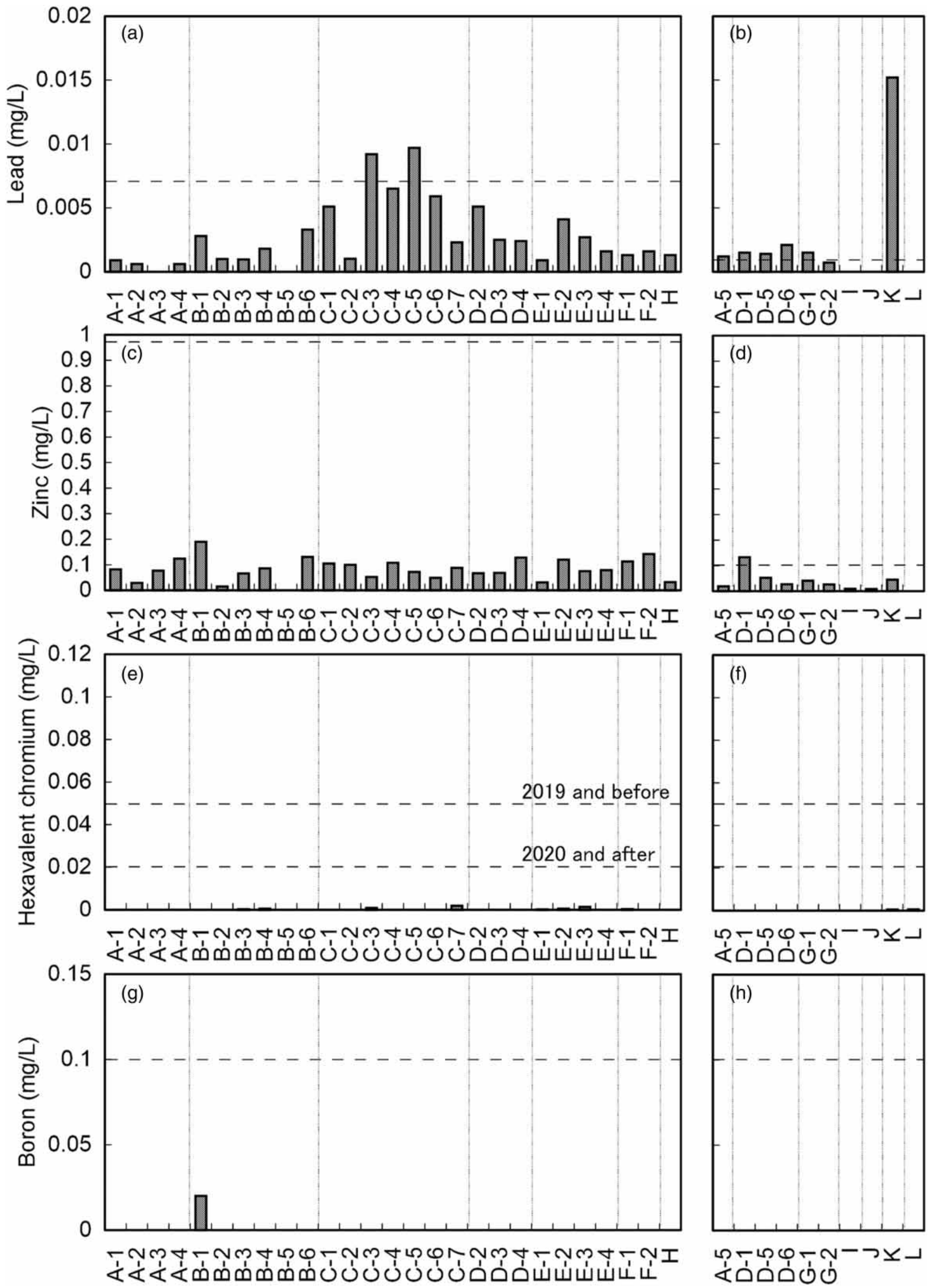


Figure 3 | Normalized concentrations of lead, zinc, hexavalent chromium, and boron in leachates obtained from faucets after conditioning treatment. Panels (a), (c), (e), and (g) present the results of leaching tests for faucets primarily composed of copper alloys, whereas those for faucets not made predominantly of copper alloys are presented in panels (b), (d), (f), and (h). Top row (panels (a) and (b)): lead; second row (panels (c) and (d)): zinc; third row (panels (e) and (f)): hexavalent chromium; and bottom row (panels (g) and (h)): boron. Dashed lines indicate the standard concentrations.

standard. For faucets whose main materials were copper alloys (Figure 3(a)), faucets C-3 and C-5 did not satisfy the standard. Relatively large amounts of lead, with normalized leachate lead concentrations above 50% of the standard, were also leached from other products from manufacturer C (faucets C-1, C-4, and C-6), although the degrees of lead leaching did not exceed the standard. In the case of faucets made primarily of copper alloys, all the faucets produced by other manufacturers met the standard. Reducing lead leaching from the products of manufacturer C would contribute to a great improvement in public health associated with lead leaching in Japan.

In the faucets whose primary material was a not copper alloy (Figure 3(b)), the degree of lead leaching was generally lower than those predominantly made of copper alloys, except for tap K. However, because of the difference in standards based on the main material of the faucets, faucets A-5, D-1, D-5, D-6, and G-1 slightly exceeded the standard. Many faucets, including those mainly composed of copper alloys (faucets A-1, A-2, A-3, A-4, B-3, B-5, E-1, and J), met the standard for lead leaching set for faucets not made primarily of copper alloys; therefore, satisfying this more stringent standard is thought to be technically possible. Further efforts to reduce lead leaching are required in faucets not made primarily of copper alloys to further reduce the health risks associated with lead leaching from faucets.

An interesting result was obtained for faucet K; it significantly exceeded the standard. Because the main material of this faucet was not disclosed, it is possible that this faucet was primarily composed of copper. However, this is not a critical issue because the normalized lead concentration in the leachate obtained from faucet K (0.0152 mg/L) exceeded the standard for faucets mainly made of copper alloys. On this basis, it can be said that faucet K is unacceptable in Japan. The normalized lead concentration in the leachate obtained from faucet K exceeded the guidelines for drinking water provided by the WHO (0.01 mg/L) (WHO 2022). This means that water lead levels cannot satisfy the WHO recommendation even when faucet K is the sole source of lead leaching in an entire distribution system. The health risks posed by using faucet K for drinking purposes are not accepted worldwide. Faucet K is not a domestic product; therefore, it is an uncertified product (Table 2). It is highly likely that this product was not designed to be installed in Japan or other countries following the WHO guidelines. As mentioned previously, this product can be purchased by a user through an internet shopping site. Appropriate guidance to avoid the use of uncertified faucets is thought to be critically important for managing public health associated with metal leaching from faucets.

The normalized zinc concentrations in the leachate obtained from most of the specimens after the conditioning treatment met the standard. However, the leachate from faucet D-1 slightly exceeded the standard. This issue will be further discussed in a later section in relation to the effect of the conditioning treatment to reduce metal leaching.

Leaching without the conditioning treatment

Figure 4 shows the normalized metal concentrations in the leachates obtained prior to the conditioning treatment. The impacts of metals leached at this stage on health risks are relatively limited, and metal leaching without the conditioning treatment is not legally regulated in Japan. However, the degree of metal leaching is generally the greatest immediately after installation. A detailed analysis of the changes in metal leaching during the use of faucets is thought to be useful for avoiding possible temporally high health risks in water users. Based on the background mentioned above, metal leaching from faucets without conditioning was also investigated in this study.

As expected, the degree of metal leaching without the conditioning treatment was generally greater than that with conditioning. With regard to lead leaching, normalized leachate lead concentrations higher than the standard were also detected in faucets C-1, C-2, C-4, G-2, and I, in addition to the faucets from which lead leaching greater than the standard was observed after the implementation of the conditioning treatment, as mentioned in the previous section. As shown in Figure 4, normalized leachate concentrations higher than the standard were also observed for hexavalent chromium (faucet C-3) and boron (faucet C-7), although all the faucets examined in this study satisfied the standards for these parameters in the leaching test performed after the conditioning treatment (Figure 3). These results indicate that the number of parameters to which special attention should be paid increases immediately after the installation of faucets.

The effects of conditioning on the amount of metal leaching from faucets, which reflects the degree of decline in metal leaching during the long-term use of faucets, differed based on the metal species. For example, significant reductions in leaching have been observed for hexavalent chromium and boron. These metals leached substantially from several faucets when they had not been subjected to the conditioning treatment, whereas the normalized concentrations of these metals in the leachates obtained from most of the faucets were relatively low to the standards in the leaching tests performed after conditioning. In contrast, the reductions in lead and zinc leaching owing to conditioning were relatively limited. For both metals, in addition to the limited degree of reduction in leaching, increases in leaching after conditioning were detected at relatively high frequencies. The increase in leaching after conditioning was

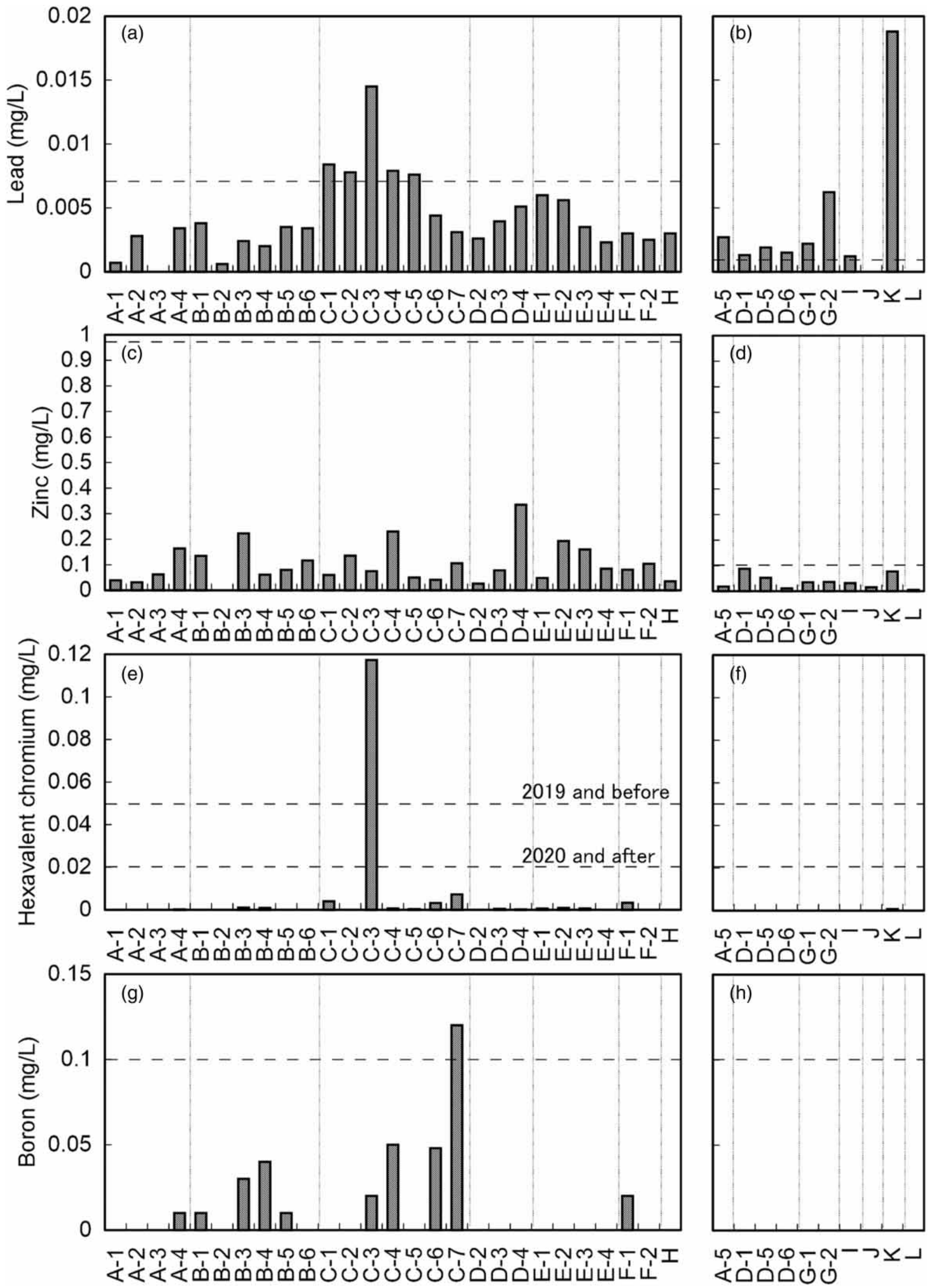


Figure 4 | Normalized concentrations of lead, zinc, hexavalent chromium, and boron in leachates obtained from faucets without conditioning treatment. Panels (a), (c), (e), and (g) present the results of leaching tests for faucets primarily composed of copper, whereas those for faucets not primarily made of copper alloys are presented in panels (b), (d), (f), and (h). Top row (panels (a) and (b)): lead; second row (panels (c) and (d)): zinc; third row (panels (e) and (f)): hexavalent chromium; and bottom row (panels (g) and (h)): boron. Dashed lines indicate the standard concentrations.

particularly pronounced for zinc leaching from faucet D-1; the normalized zinc concentration in the leachate obtained from faucet D-1 after the conditioning treatment exceeded the standard, whereas that obtained before conditioning met the standard.

The number of cases where the degree of metal leaching increased after the implementation of the conditioning treatment was greatest for zinc (16 cases). In 9 of the 16 cases, the normalized zinc concentrations in the leachate obtained after conditioning were more than 10% of the standard (not negligible levels). Seven similar cases of increases in metal leaching after conditioning were observed for lead and copper. In the case of lead, all seven cases showed normalized leachate concentrations of more than 10% of the standard; therefore, the impact of the increase in the leaching level is likely to be significant. On the other hand, most of the cases (6 of the 7 cases) where the normalized leachate copper concentration increased after conditioning were not likely to be significant, as the normalized leachate concentrations were well below (less than 10%) the standard. Increases in leaching after conditioning were also observed for nickel in several faucets (five cases). Because nickel is currently not legally regulated, as mentioned previously, this issue is discussed separately in the following section. For the other parameters, the cases where metal leaching after conditioning was more prominent were limited (two cases for cadmium and hexavalent chromium and one case for boron). At present, the reasons for the increase in lead and zinc leaching after conditioning treatment are not clear. Sacrificial effects on galvanic corrosion, as pointed out by Zhang & Edwards (2011), could be a possible explanation. The results previously mentioned indicate that the reductions in zinc and lead leaching after conditioning were not prominent. This finding suggests that declines in the leaching of these metals during the intermittent use of faucets require a relatively long time. For such metal species, countermeasures to reduce leaching during factory shipment are critically important.

Nickel leaching

In this study, we also tested nickel leaching from the faucets. Currently, nickel is not legally regulated in Japan; however, nickel in drinking water has been identified as a potential cause of systemic contact dermatitis in nickel-sensitized individuals (Jensen *et al.* 2006; WHO 2022). Therefore, it can be said that appropriate monitoring of nickel leaching is important for protecting public health. A recent field survey in Japan revealed that the nickel concentration in the first flush water collected from 20% of household taps did not meet the water quality management target value for nickel in Japan, 0.02 mg/L (Asami *et al.* 2021).

Figure 5 shows the normalized nickel concentrations in the leachates obtained before and after conditioning. Unlike the other parameters investigated in this study, many faucets were unable to meet the target. Although exceeding the water quality management target value does not result in a violation of the current Japanese drinking water quality standard, many manufacturers may have to reduce nickel leaching if the regulation for nickel is upgraded to water quality standards (e.g., when the impact on nickel-sensitive individuals is emphasized or unknown health risks related to nickel are recognized). Although nickel leaching was effectively alleviated after conditioning, several faucets (five cases) leached more nickel after the conditioning treatment. This suggests that reducing nickel leaching, as lead and zinc, during factory shipment is critically important. It should be noted that the cases where the normalized nickel concentration in the leachate exceeded the target value were limited to faucets composed primarily of copper alloys. Using faucets that are not made primarily of copper alloys would be an effective measure for reducing nickel leaching when more stringent regulations are required.

Measures for improving public health associated with metal leaching from faucets

In both the leaching tests performed before and after conditioning, most of the faucets examined did not produce leachates with normalized concentrations higher than the standards for each parameter. All products provided by manufacturers B and E met the standards completely. In the cases of manufacturers A and D, the products composed mainly of copper alloys completely met the standards, although the normalized lead concentrations in the leachates of the faucets not made primarily of copper alloys exceeded slightly the standard. Manufacturers A–E are major suppliers of faucets in the Japanese market. Most faucet manufacturers in Japan provide products of sufficient quality to protect public health. In contrast, many products from manufacturer C did not meet the lead standard. As shown in Table 2, all faucets provided by manufacturer C are certified products. The findings obtained in this study revealed that the standards for metal leaching from faucets were exceeded even in certified faucets. Elucidating this issue is one of the most important outcomes of the leaching tests conducted in this study. The results obtained in this study revealed that faucets produced by a certain manufacturer repeatedly exceeded the standards, suggesting that intensive guidance to such manufacturers would effectively improve the public health associated with metal leaching from faucets. Revealing such trends is another important contribution to performing regular leaching tests, as in this study.

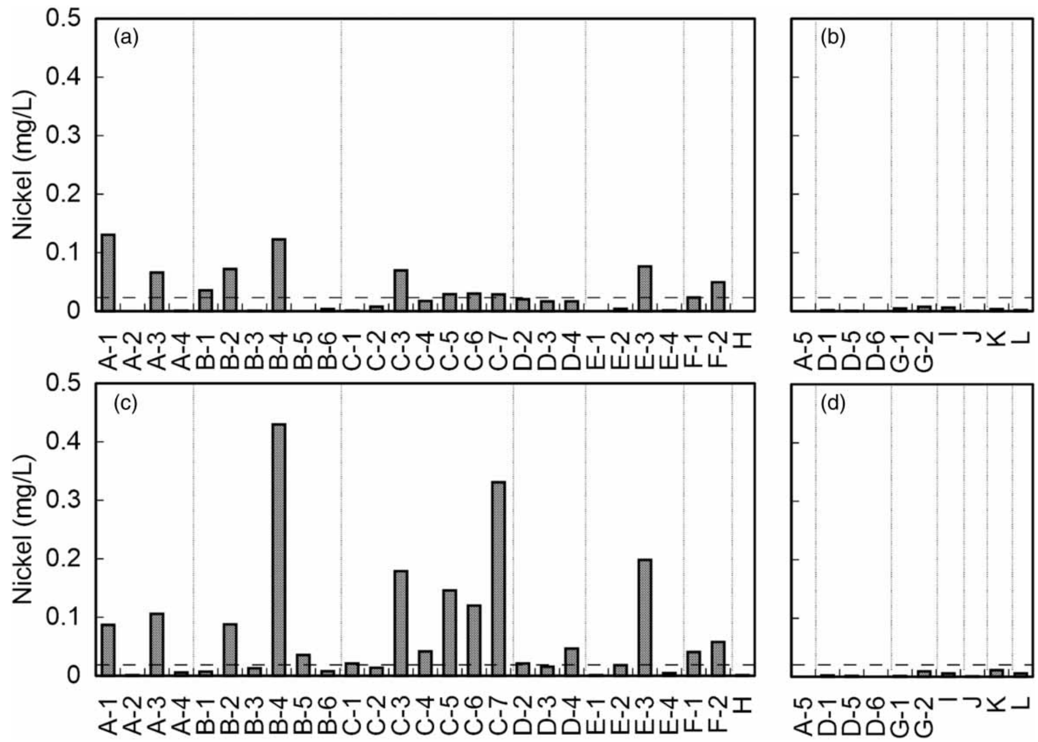


Figure 5 | Normalized nickel concentrations in leachates obtained from faucets before and after conditioning. Panels (a) and (b) present the results of leaching tests after conditioning and panels (c) and (d) show those of leaching tests without conditioning. The results of leaching tests on taps composed mainly of copper alloys are presented in panels (a) and (c), whereas those of faucets not made mostly of copper alloys are shown in panels (b) and (d). Dashed lines indicate the drinking water quality management target of nickel for a leachate.

As expected, in leaching tests performed without conditioning, more metals were leached than those performed after the conditioning treatment. It is clear that metal leaching from faucets is more significant immediately after their installation. Not only the number of cases of exceeding standards, but also the number of parameters which exceeded the standards increased in the leaching tests performed before the conditioning treatment. This indicates that, when using new faucets, we should pay attention to a wide range of metal species. Water suppliers should provide preventive guidance, such as encouragement of flushing before use, to water users to reduce such discriminative health risks specifically found for new faucets.

A comparison of the results of the leaching tests performed before and after the conditioning treatment suggested that the degree of decline in metal leaching during the intermittent use of a faucet differed depending on the metal species. Specifically, reductions in lead and zinc leaching from faucets are likely to take a relatively long time. This implies that water users would be exposed to higher health risks for a long time if the leaching of these metals exceeded the standards. Considering the adverse effects of increased lead levels in water on human health (Edwards *et al.* 2009; Hanna-Attisha *et al.* 2016), such events are likely to be a heavy burden on public health. To avoid such issues, measures to reduce leaching of these metals during factory shipment are thought to be critically important. Although such improvements may impose additional efforts on faucet manufacturers, achieving reduction in leaching at the factory shipment is technically possible because most of the manufacturers selected in this study produced faucets with metal leaching levels that could satisfy the standards.

With regard to nickel leaching, the normalized nickel concentrations in the leachate obtained from several faucets examined in this study exceeded the water quality management target value in Japan. This could be particularly problematic for nickel-sensitive individuals who suffer from contact dermatitis following oral exposure to nickel. According to a review published by Jensen *et al.* (2006), nickel intake by drinking water with a nickel concentration of 0.02 mg/L (the Japanese drinking water quality management target value and the maximum level permitted in drinking water in Denmark) corresponds to one-fourth of the nickel dosage that could cause dermatitis response in 1% of the most sensitive individuals. One possible approach for alleviating the health impact on nickel-sensitive individuals is the preventive use of faucets not made primarily of copper alloys. In the leaching tests performed in this study, faucets that were not composed mainly of copper alloys did not produce leachate with a normalized nickel concentration above the drinking water quality management target value. This finding is an important contribution to the leaching tests performed in this study.

CONCLUSIONS

In this study, we investigated the metal leaching from commercially available faucets in Japan. The levels of metal leaching from most of the faucets examined in this study satisfied the legally regulated Japanese standards, indicating that the risks associated with metal leaching are limited in Japan. However, the faucets provided by a certain manufacturer repeatedly resulted in lead leaching that exceeded the standard for lead. Intensive guidance for such manufacturers is considered an effective measure for improving public health. In addition to the number of cases, the number of parameters where the levels of leaching from the faucets exceeded the standards is likely to increase immediately after the installation of a new faucet. Water suppliers should provide preventive guidance, such as encouraging flushing before use, to water users. The effects of conditioning on reducing the leaching of lead and zinc were not significant compared with the other parameters, suggesting that the time-course declines in the leaching of these metals during the intermittent use of faucets are limited. In the case of nickel, the number of cases where the normalized nickel concentrations in the leachates exceeded the water quality management target value was greater than that of the other parameters. Because none of the leachates obtained from the faucets not made mainly of copper alloys exceeded the target, preventive use of such faucets would be recommended for nickel-sensitive individuals.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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