Using nudges for water demand management: A field experiment for water conservation

Yurina Otaki1*, Shuma Iwatani2, Hidehito Honda3, Kazuhiro Ueda2*

1 Graduate School of Social Sciences, Hitotsubashi University, Tokyo, Japan, 2 Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, Japan, 3 Faculty of Psychology, Otemon Gakuin University, Osaka, Japan

* yurina.otaki@r.hit-u.ac.jp (YO); ueda@g.ecc.u-tokyo.ac.jp (KU)

Abstract

With the growing need for water demand management, several nudge-based interventions have been undertaken from March to September 2019 to guide humans toward the socially desirable behavior of conserving resources and reducing the negative environmental impacts in the Tokyo Metropolitan area, Japan. In this study, we provided two types of visualized feedback to the participating households by applying social norms to their water consumption: one that conceptualized water as a public good, and one that compared the household’s usage to that of others by using a bar chart for eight months. We analyzed the change in water consumption of each household using the generalized linear mixed model (GLMM) and found that a nudge that visualized water as a public good was effective in saving water in low-consuming households, whereas a nudge using a bar chart had no impact. In addition, we asked the participants whether the information provided caused any kind of stress after the last feedback. An analysis of variance (ANOVA) indicated that the nudge method utilized in this study not only does not cause stress among the nudge recipients, but also improved their interest in residential water consumption. Households that received a nudge were less satisfied than the control group because they feel that they were not able to save water.

Introduction

Growing importance has been attached to demand side management for making effective use of limited resources and reducing negative environmental impacts. In contrast to traditional policy tools, which aim to change behavior through mandates, bans, or economic incentives [1], a non-fiscal, non-regulatory intervention known as a “nudge” steers people toward a specific direction while preserving their freedom of choice [2], for example in the field of pro-environmental behavior [3] and health management [4, 5]. This is one of the most dominant theoretical frameworks used for designing pro-social incentive programs [1]. Various nudge methods are used; several promising studies that employ socially normative messages use bar
charts, emoticons, or other visual aids for resource usage comparisons among individuals [6–11]. For example, Opower’s Home Energy Report uses bar graphs to compare monthly electricity usage with that of neighbors, emoticons to evaluate usage, line graphs to show trends over the past few months, and tips on resource conservation to save electricity [6]. Shen et al. [12] also found a reduction in energy consumption after displaying bar graphs that compared usage with that of neighbors and emoticons to evaluate usage through mailing home energy reports. With respect to water saving, Erickson et al. [13] showed a time series of water consumption for each household, comparisons with neighbors, and rankings to conserve water resources. However, as previous studies have used a combination of multiple nudges, it is still unclear which nudge is effective in saving resources, and to what extent. Therefore, in our previous research, we confirmed the effect of the nudge by type: ranking, comparison with the average, and comparison with others by using emoticons [14]. According to the results, presenting emoticons improves water conservation in high-consuming households. In this study, we examined the effect of using bar graphs exclusively to compare one’s water usage with others. Bar graphs were chosen because they are often used and have been included in many studies; however, to the best of our knowledge, their standalone effect has not yet been investigated. In addition, bar graphs are currently used by agencies for presentations pertaining to electricity consumption in Japan and to water consumption in Perth [15], and are also being considered for use in demonstration experiments conducted by some water utilities in Japan (e.g., Tokyo Metropolitan Government, Toyonaka city, and so on).

In addition to bar graphs, we also examined the effect of another type of nudge: presenting images depicting that water resources are public goods. In our previous study [16], the same presentation was made, but time and duration needed to be considered. In order to consider different time periods and duration, we re-conducted the field experiment under different conditions. In the previous study, the nudge caused low-consuming households to conserve water, but the effect lasted for four months and subsequently caused no effect in the fifth month. The first 2–4 months of the experiment was a period of drought concerns, which ended by the fifth month. It was unclear whether the effect disappeared because there was no longer a fear of drought or because the effect of the nudge waned over time. Therefore, we conducted this study by using images which show water as a public good, over a 7-month period that fell outside the drought period, to verify whether the effect of the nudge persisted.

Nudging by presenting information on people’s own water usage is effective but may cause discomfort for the participants, especially in the case of a downward or negative evaluation [17]. For example, Canfield et al. [18] compared methods of providing energy consumption information and found that among timeline display of usage, breakdowns by usage, and comparison with others by indicating the position in the histogram, the last was the least preferred method. However, past studies which use nudges have not examined whether a nudge is able to induce the desired conservation behavior without reducing satisfaction or causing psychological stress. Rather, they have only explored how nudges can be used to guide humans toward the socially desirable behavior of conserving resources [19, 20]. Therefore, in this study, at the end of the experiment, we asked the participants whether the information provided to them caused any kind of stress.

Materials and methods
Participating households
The survey was conducted among households within the Tokyo metropolitan area that are registered with the research company (Rakuten Insight; https://insight.rakuten.co.jp/en/). Although 1118 households expressed their willingness to participate, 77 households were...
unable to obtain baseline usage data due to incomplete data reporting. Therefore, the experiment was conducted with 1041 households. Ultimately, 80% of these (i.e., 834 households) continued to cooperate until the end of the survey. A high persistence rate was achieved despite the study span of eight months, as 97–99% of participants continued during each meter reading. We analyzed the data of 783 households, after excluding households that had meter reading errors or missing readings due to water meter replacements. The participating households were randomly assigned to one of the three groups (i.e., a control group and two experimental groups). The number of households in each group is shown in Table 1. These households read and reported their water meter values once every fortnight to determine the amount of water consumed by each household.

Feedback implementation

We provided visualized feedback to participating households on the basis of social norms with respect to their water consumption for two weeks preceding the feedback. We chose two types of feedback: one conceptualizing water as a public good (i.e., the public goods group) and one comparing the household’s usage to that of others by using a bar chart (i.e., the comparison group). Four different images were prepared for each group, and feedback was provided according to the amount of water used. Specifically, the per capita daily water consumption of individual participating households was arranged in order of usage for all surveyed households. These were then evenly divided into four categories (to correspond to the four different feedback images), with a corresponding image being sent to both the public goods and comparison groups.

Fig 1 shows an example of the images received by the public goods group. The geographic outline of Tokyo was presented as a water vessel, and the water level was shown as being set to change in four stages, depending on the amount of water used by each participating household. The water level reduced when each household consumed more water, and it increased when each household consumed less water. This approach allowed us to conceptualize water

| Table 1. Descriptive statistics and randomization checks. |
|----------------------------------------------------------|
| Household size (persons) | Full Sample | Control Group | Public Goods Group | Comparison Group | F-statistics (p-value) |
| Full | 2.64 | 2.66 | 2.65 | 2.62 | 0.16 |
| (1.23) | (1.25) | (1.27) | (1.18) | (0.69) |
| Low | 2.42 | 2.38 | 2.48 | 2.41 | 0.05 |
| (1.22) | (1.22) | (1.29) | (1.18) | (0.82) |
| High | 2.86 | 2.95 | 2.80 | 2.84 | 0.59 |
| (1.20) | (1.22) | (1.23) | (1.14) | (0.44) |
| N (households) | Full | 783 [767] | 257 [249] | 272 [270] | 254 [248] |
| Low | 392 [385] | 130 [126] | 131 [130] | 131 [129] |
| High | 391 [382] | 127 [123] | 141 [140] | 123 [119] |
| Mean baseline water use (L/capita/day) | Full | 207 | 205 | 210 | 207 | 0.12 |
| | (86) | (88) | (84) | (86) | (0.73) |
| Low | 147 | 146 | 147 | 147 | 0.13 |
| | (43) | (46) | (43) | (42) | (0.72) |
| High | 268 | 265 | 269 | 271 | 0.39 |
| | (74) | (80) | (69) | (74) | (0.53) |

Note. Mean values are represented in the top row. Standard deviations are represented in the bottom row, in parentheses. The number of households that responded to four questions at the end of the questionnaire survey is enclosed in [ ] in column N.
If all Tokyo households used water to the same extent your home had used for the past two weeks, this would be the result of the water resource level.

Fig 1. Example of the feedback images for the public goods group. Note: Map is an illustration prepared by Ms. Yuki Amasaka, Ochanomi zu University.

https://doi.org/10.1371/journal.pwat.0000057.g001

as a public good (i.e., a higher level implies that more water is being conserved for the benefit of Tokyo residents). All feedback images of the public goods group are shown in S1 Fig. Fig 2 provides an example of the feedback type used for the comparison group—a bar chart comparing household usage with others’ usage. This approach also used four different images to show the amount of usage in each household compared to the average household. All feedback images of the comparison group are shown in S2 Fig.

Water consumption was monitored between February and September 2019. As there is no other way to measure water consumption automatically, for instance, through smart meters in Japan, the participants were instructed on how to read their water meters and were then asked

Per capita daily water use during the past two weeks

Fig 2. Example of the feedback image for the comparison group.

https://doi.org/10.1371/journal.pwat.0000057.g002
to read and report their own water meter readings to determine their water consumption. In the month when the survey began (i.e., February 2019), all groups performed the task of reporting meter readings twice. The average of those two readings was used as the baseline water use by each household. Thereafter, all groups read and reported their meter readings once every two weeks, and all the groups except the control group received feedback. Households within the public goods group and the comparison group received the visual feedback via e-mail every two weeks, and 15 times in total.

**Changes in water use**

The per capita daily water consumption values, calculated on the basis of water meter values that were reported every two weeks and the number of family members, were used for the analysis. Since water use is greatly influenced by the presence or absence of people in a household, the values that were either extremely small or large were excluded by using z values (i.e., less than -2.5 and greater than 2.5). Hence, we excluded 2.0% of the data (0.5% of the control group, 0.6% of the public goods group, and 1.0% of the comparison group) from the water consumption data collected during the survey period for each household.

The change in water consumption of each household was evaluated as the percentage change from baseline consumption, as follows:

$$LRP_n = \log\left(\frac{C_n}{C_b}\right)$$  \hspace{1cm} (1)

where $C_b$ is the baseline consumption (L/capita/day), $C_n$ is the average water consumption per month, after $n$ months passed from the baseline ($n = 1,2,3,4,5,6,7$), and $LRP_n$ is the log-transformed relative proportion. A negative $LRP_n$ indicates that water consumption decreased, whereas a positive $LRP_n$ indicates that it increased. With $LRP_n$ as the dependent variable, a generalized linear mixed model (GLMM) was performed as follows:

$$LRP_n = \beta_0 + \beta_1(T_{public}) + \beta_2(T_{comparison}) + Household_i + Month_j + \epsilon$$  \hspace{1cm} (2)

where $T_{public}$ is a dummy variable indicating whether the household belongs to the public goods group, and $T_{comparison}$ is a dummy variable indicating whether a household belongs to the comparison group. We used $Household_i$ and $Month_j$ as random variables to account for household-by-household and month-to-month variation in intercepts.

As previous studies have shown that changes in water usage vary depending on low or high consumption [8–10, 15], we classified the households into “low-consuming households” and “high-consuming households” on the basis of their baseline water consumption and analyzed them separately. Generally, as the number of household members increases, water consumption per capita decreases. To eliminate the influence of household size, we converted each household’s baseline water consumption per capita into a value that is assumed for a one-person household. Specifically, we calculated the extent to which water consumption decreased as the number of family members increased, using the average daily water consumption per capita by family size in Tokyo: 273 L for a one-person household, 265 L for a two-person household, 227 L for a three-person household, 203 L for a four-person household, 190 L for a five-person household, and 188 L for a six-person household (Bureau of Waterworks Tokyo Metropolitan Government, 2018). For example, if a four-person household used 250 L/capita/day, the converted value was 336 ($250 \times 273/203$)). Subsequently, we sorted these in order of quantity. Half were classified as “low-consuming households” and the other half as “high-consuming households”.

---

**Using nudges for water demand management**

PLOS WATeR | https://doi.org/10.1371/journal.pwat.0000057 October 20, 2022 5/14
Perception of the participating households

At the end of the survey, the participating households answered the following four questions in Japanese using a visual analog scale by moving the bars shown online (the statements in this paper have been translated into English). They were also asked to articulate the reason for the rating by answering an open-ended question: 1) Were you satisfied with your own water use during the study period? This question was to ensure if the nudge that they received did not cause any dissatisfaction about their water use and to record the reasons for their satisfaction/dissatisfaction. 2) Did you feel stressed when using water during the survey? 3) Is there any change in your interest in water from before the survey began and at present? 4) Has your current water use changed, compared to that before the survey? The complete questionnaire is provided as S3 Fig.

A two-way analysis of variance (ANOVA) was conducted for each question. The independent variables were consumption (high consumption or low consumption) and groups (the public good groups, the comparison groups, and the control groups). For post hoc analyses, Modified Sequentially Rejective Bonferroni Procedures [21] were performed.

Ethics statement

The experimental procedure was approved by the Ethics Review Committee for Experimental Research with Human Subjects at the Graduate School of Arts and Sciences, University of Tokyo (approval number: 627, 627-(2)). The formal consent of the participants was obtained online (i.e., only those who clicked "I agree" were able to participate).

Results

Descriptive statistics and randomization checks

Table 1 shows the descriptive statistics for the full sample and for each group individually; that is, the mean values and standard deviations for key variables (i.e., household size, baseline water consumption) and the number of households for each group. There were no statistically significant differences in household size and baseline water consumption among the three groups (F-statistics and p-values are presented in Table 1). Table 2 shows the distribution of annual household income for each group. Again, there were no statistically significant differences in annual household income among the three groups (chi-squared value and p-values are presented in Table 2). The statistical analysis shows that randomization produced a balance between the groups.

| Annual Household Income | Less than 4 mil Yen | 4–6 mil Yen | 6–8 mil Yen | More than 8 mil Yen | Chi-squared (p-value) |
|-------------------------|---------------------|-------------|-------------|---------------------|----------------------|
| Full Sample             |                     |             |             |                     |                      |
| Control Group           | 58                  | 53          | 52          | 94                  | 5.90 (0.43)          |
| Public Goods Group      | 56                  | 70          | 43          | 103                 |                      |
| Comparison Group        | 44                  | 60          | 55          | 95                  |                      |
| Low-consuming Households|                     |             |             |                     |                      |
| Control Group           | 35                  | 22          | 31          | 42                  | 8.28 (0.22)          |
| Public Goods Group      | 27                  | 32          | 26          | 46                  |                      |
| Comparison Group        | 20                  | 36          | 29          | 46                  |                      |
| High-consuming Households|                    |             |             |                     |                      |
| Control Group           | 23                  | 31          | 21          | 52                  | 5.10 (0.53)          |
| Public Goods Group      | 29                  | 38          | 17          | 57                  |                      |
| Comparison Group        | 24                  | 24          | 26          | 49                  |                      |

https://doi.org/10.1371/journal.pwat.0000057.t002
Impact of feedback on water consumption

The changes in the timeline of the mean values are depicted in Fig 3 plots of $LRP_n$ ($n = 1–7$). When all the households were analyzed together, the feedback did not have a significant effect on water use as compared to the control group. However, the results of the analysis that were divided on the basis of high and low water usage provided descriptive evidence of the effects of feedback for low-consuming households. $LRP_n$ for the low-consuming households that received feedback was consistently lower than that of the control group starting from the first month. GLMM analysis indicated that water consumption decreased when the public goods image was presented to low-consuming households (Table 3). In contrast, for high-consuming households, the feedback did not have a significant effect on water use, as compared to the control group.

Perception of the participating households

The results of the two-way ANOVA for each question pertaining to the independent variables as low-consuming or high-consuming households and the three groups are listed in Table 4. Regarding satisfaction (i.e., whether participants were satisfied with their own water use during the study period to ensure they were not dissatisfied with the nudge they received), there was a
significant main effect of the groups ($F(2, 761) = 5.4655, p = 0.0044, \eta^2 = 0.0142$). Then, we conducted multiple comparisons with Holm’s sequentially rejective Bonferroni procedure. The results revealed that the public goods group and the comparison groups were less satisfied than the control group ($t(761) = 2.1957, p = 0.0568$, and $t(761) = 3.2454, p = 0.0037$, respectively), and there was no difference between the public goods group and the comparison groups ($t(761) = 1.1167, p = 0.2645$). As shown in Fig 4, an interaction effect was found between the consumption level and the experimental group ($F(2, 761) = 5.9667, p = 0.0027, \eta^2 = 0.0154$). A simple effects analysis indicated that there was no difference in the satisfaction levels between groups among the low-consuming households ($F(2, 761) = 0.4146, p = 0.6607, \eta^2 = 0.0011$), whereas satisfaction differed between groups among high-consuming households ($F(2, 761) = 10.7312, p < .001, \eta^2 = 0.0274$). We conducted multiple comparisons for high-consuming groups. The results revealed that the control group was more satisfied than the public goods group and the comparison group (public goods < control: $t(761) = 2.3881, p = 0.0323$], comparison < control: $t(761) = 4.6327, p < .0001$]). In addition, the comparison group was less satisfied than the public goods group ($t(761) = 2.4105, p = 0.0323$). More than 60% of those who responded to the open-ended questionnaire commented on water saving, indicating that “being able to save water” is related to satisfaction and that receiving feedback tended to reduce the satisfaction of high-consuming households, as they perceived that they were not able to save water. For example, the participants commented: “I was satisfied because I was able to save water to the extent that it did not interfere with my daily life”; “The awareness regarding water conservation has increased, and the whole family has been able to work on it”; “I thought I had been saving water, but I realized I haven’t been able to do it”; and “I could have saved a little more water if I had turned off the water a little more frequently when washing my hands, washing my face, having a shower, etc.”

Table 3. Generalized linear mixed model results.

|                   | \(\beta\) | s.e. | \(t\) | \(p\)   |
|-------------------|-----------|------|-------|---------|
| Low-consuming Households |           |      |       |         |
| Intercept         | +0.05630  | 0.01759 | 3.201 | 0.00149 |
| Public Goods      | -0.04591  | 0.02464 | -1.863 | 0.06323 |
| Comparison        | -0.03479  | 0.02464 | -1.412 | 0.15886 |
| High-consuming Households |        |      |       |         |
| Intercept         | -0.04102  | 0.01314 | -3.122 | 0.00344 |
| Public Goods      | +0.00589  | 0.01443 | 0.408  | 0.68346 |
| Comparison        | -0.02339  | 0.01492 | -1.567 | 0.11788 |
| All Households    |           |      |       |         |
| Intercept         | +0.00821  | 0.01131 | 0.725  | 0.46910 |
| Public Goods      | -0.02142  | 0.01462 | -1.465 | 0.14310 |
| Comparison        | -0.02830  | 0.01487 | -1.903 | 0.05740 |

https://doi.org/10.1371/journal.pwat.0000057.t003

Table 4. Two-way ANOVA results for each questionnaire.

|                   | Low-consuming Households | High-consuming Households | Main Effect (\(F\)) | Interaction |
|-------------------|--------------------------|---------------------------|---------------------|-------------|
|                   | Control | Public Goods | Comparison | Control | Public Goods | Comparison | Consumption Level | Group |                     |
| Satisfaction      | M (SD) |            |           | M (SD) |            |           |                    |       |                     |
| Control           | 72 (27) | 69 (23)     | 72 (23)   | 69 (25) | 61 (25)     | 54 (28)   | 28.16***           | 5.47*** | 5.97***               |
| Public Goods      | 75 (29) | 75 (30)     | 80 (26)   | 75 (28) | 74 (30)     | 78 (24)   | 0.32               | 1.77    | 0.20                 |
| Comparison        | 63 (16) | 70 (16)     | 67 (18)   | 61 (12) | 69 (15)     | 70 (16)   | 0.01               | 17.48***| 1.70                 |
| Stress            | M (SD) |            |           | M (SD) |            |           |                    |       |                     |
| Use               | 37 (25) | 45 (24)     | 43 (25)   | 42 (23) | 46 (21)     | 45 (26)   | 2.53               | 4.90*** | 0.63                 |

Note. Consumption level refers to low-consuming households or high-consuming households.

***: \(p < 0.01\), **: \(p < 0.05\), *: \(p < 0.1\)

https://doi.org/10.1371/journal.pwat.0000057.t004
Based on the responses to the second question (i.e., whether the nudging had ever made them feel stressed), we found that the feedback did not create stress. This was common in both low- and high-consuming households ($F(2, 761) = 1.7685, p = 0.1713, \eta^2 = 0.0046$) (Fig 5). Further, there was a main effect of the groups (control, public goods, and comparison) on responses to the third question (i.e., whether the interest in water had changed ($F(2, 761) = 17.48, p < .001, \eta^2 = 0.0439$). We conducted multiple comparisons with Holm’s sequentially
rejective Bonferroni procedure (Fig 6). The results revealed that the interest among the public goods group and the comparison group was larger than that among the control group ($t(761) = 5.47, p < .0001$, and $t(761) = 4.73, p < .0001$, respectively), and there was no difference between the public goods group and the comparison groups ($t(761) = 0.6395, p = 0.5227$). Additionally, as Fig 7 shows, there was a main effect of the groups (control, public goods, and comparison) on their reported changes in water use ($F(2, 761) = 4.90, p = 0.0077, \eta^2 = 0.0127$).

We conducted multiple comparisons with Holm’s sequentially rejective Bonferroni procedure. The results revealed that the reported changes in water use were larger among the public goods group and the comparison group than in the control group ($t(761) = 3.08, p = 0.0065$, and $t(761) = 2.07, p = 0.0785$, respectively), and there was no difference between the public goods group and the comparison group ($t(761) = 0.6395, p = 0.3340$). Their perceived water use was inconsistent with the fact that only low-consuming households actually lowered the amount of water they used.

**Discussion and conclusion**

The study shows that a nudge which visualizes water as a public good decreased water usage among low-consuming households. The results show that the effects of nudges persist; in other words, the disappearance of nudge effects in the previous study [16] was because the drought concern had ended and not because the effect of the nudge waned over time. Even though only low-consuming households of the public goods group saved water, self-reported water use decreased for all the households who received feedback. As shown in Beal et al. (2013) [22], the householders’ perceptions of their water use did not match the change in their actual consumption.

The nudge that used a bar chart to compare the usage by the household with that of their neighbors (i.e., the comparison group) did not have an impact on either low-consuming or high-consuming households. When compared to past studies pertaining to social comparisons using emoticons, which reported a decrease in use by high-consuming households [6, 11, 14, 23], the bar chart was found to be an unsuitable visualization tool for water demand.

---

**Fig 6. Response to the question of whether interest in water had changed.** Note. Error bars show the standard error.

https://doi.org/10.1371/journal.pwat.0000057.g006
management because it is unable to communicate an injunctive message of approval or disapproval for the consumption.

Among the high-consuming households, feedbacks resulted in lower levels of satisfaction; however, on the basis of the evaluation of responses on the open-ended question describing the reason for their dissatisfaction, it was found that people seemed to be frustrated with their lack of one’s own water conservation, and not on receiving the nudge. On the contrary, among the low-consuming households, reception of feedback did not result in any significant difference with respect to satisfaction. More importantly, there was no significant difference between the groups regarding the response to the question of whether they ever felt stressed. This suggests that receiving this sort of nudges did not cause any dissatisfaction or stress among the participants.

It can be said that presenting a public goods image to households with relatively low usage is effective for managing water demand without causing stress. However, this nudge was unsuccessful in managing relatively high consumption levels. Since it is clear from this study, as well as previous studies, that relatively low- and high-use households differ in their behavioral changes in response to feedback, it is necessary to devise appropriate and effective ways of providing feedback to both of these categories of households, such as separating the methods of feedback according to the usage level and, in turn, providing effective feedback to each group.

Future research should investigate not only how this intervention brought about behavioral changes, but also how it brought changes in the participants’ cognitive processes. In recent years, the nudge approach has been eagerly adopted by administrations around the world [24]. However, it is suggested that using nudges for all kinds of policymaking is inappropriate and that a distinct kind of intervention, namely, a “boost”, is important [18]. The objective of a boost is to foster people’s competence in making their own decisions; that is, an intervention to help them exercise their own agency by fostering existing competencies or instilling new ones [25, 26]. In the field of water demand management, some studies have provided a series of water-saving tips, such as using low-flow showerheads or running only full loads in the dishwasher and washing machine [9, 27–29]. Offering tips about specific actions that may save
water (e.g., turn off the bathroom faucets when brushing teeth and shaving, brush teeth with a cup, wash dishes with a filled sink, etc.) can help people choose whether to perform these actions. However, the provision of tips alone did not result in continuous water saving [9, 27, 29, 30]. We suggest that water demand management cannot be achieved with this kind of boosting method only. Tips with weak social norms (i.e., “Water resource protection is important, and we need your help”) can encourage people to save water for a short period of time [28]. Moreover, tips with information about water usage and the suggested goal (sustainability-based per-person water consumption goal) resulted in immediate and long-term changes in habits [31]. Offering the nudge and detailed end-use information using smart-metering data increased awareness of water, as verified in a previous study as well [32]. Thus, we will consider integrating tips on water usage in future research. Most importantly, knowing how to save water might improve the satisfaction of those who receive the nudge.

Despite the above-mentioned findings, this study had several limitations. First, although we had carried out the survey for the longest possible duration, the seasonal variations within a full year could not be investigated. Second, the result of annual variations in rainfall and water resources were not examined. It is difficult to conduct the survey over a long time because water consumption is determined by reading the water meter of each participant, every fortnight. If the data can be captured automatically, for example, with smart meters, it will be possible to extend the study for a longer period of time and to determine the effect of different interventions. Third, there will be a selection bias in that only those people who are happy to be observed will continue to participate. As smart metering becomes more widespread and usage notifications become more common, it will be possible to obtain unbiased data.

Many of the water demand management studies have been conducted mainly in drought-prone areas. However, to encourage water demand management and pro-environmental behavior globally, it is necessary to conduct extensive studies in various regions with different water resources, in different societies, and cultures. We expect this study to contribute to this endeavor as it is based in Tokyo in a context which is quite different from that of the drought-prone areas.

Supporting information
S1 Fig. All feedback images of the public goods group.
(TIF)
S2 Fig. All feedback images of the comparison group.
(TIF)
S3 Fig. Complete questionnaire.
(TIF)

Author Contributions
Conceptualization: Yurina Otaki, Hidehito Honda, Kazuhiro Ueda.
Data curation: Yurina Otaki, Shuma Iwatani.
Formal analysis: Shuma Iwatani, Hidehito Honda.
Funding acquisition: Kazuhiro Ueda.
Investigation: Yurina Otaki, Shuma Iwatani, Hidehito Honda.
Methodology: Yurina Otaki, Shuma Iwatani, Hidehito Honda.
Project administration: Yurina Otaki, Kazuhiro Ueda.
Supervision: Hidehito Honda, Kazuhiro Ueda.
Validation: Hidehito Honda, Kazuhiro Ueda.
Visualization: Yurina Otaki.
Writing – original draft: Yurina Otaki.
Writing – review & editing: Shuma Iwatani, Hidehito Honda, Kazuhiro Ueda.

References
1. Benartzi S., Beshears J., Milkman K. L., Sunstein C. R., Thaler R. H., Shankar M. et al. (2017). Should governments invest more in nudging? Psychological Science, 28(8), 1041–1055. https://doi.org/10.1177/0956797617702501 PMID: 28581899
2. Thaler R., Sunstein C. R. (2008). Nudge: Improving decisions about health, wealth and happiness. Simon and Schuster, New York, NY.
3. Mertens S.N., Schultz P.W. (2021). Referent group specificity: Optimizing normative feedback to residential recycling. Journal of Environmental Psychology, 73. https://doi.org/10.1019/j.jenvp.2020.101541.
4. Chapmen G.B., Colby H., Convey K., Coups E.J. (2016). Goals and social comparisons promote walking behavior. Medical Decision Making, 36, 472–478. https://doi.org/10.1177/0272989X15592156 PMID: 26139447
5. Ghose A., Guo X., Li B., Dang Y. (2021). Empowering patients using smart mobile health platforms: Evidence from a randomized field experiment. MIS Quarterly, 2102.05506. https://doi.org/10.48550/arXiv.2102.05506
6. Allcott H. (2011). Social norms and energy conservation. Journal of Public Economics, 95, 1082–1095. https://doi.org/10.1016/j.jpubeco.2011.03.003.
7. Ayres I., Raseman S., Shih A. (2013). Evidence from two large field experiments that peer comparison feedback can reduce residential energy usage. Journal of Law, Economics, and Organization, 29, 5, 992–1022. https://doi.org/10.1093/jleo/ews020.
8. Bhanot S. (2017). Rank and response: A field experiment on peer information and water use behavior. Journal of Economic Psychology, 62, 155–172. https://doi.org/10.1016/j.joep.2017.06.011.
9. Goette L., Leong C., Qian N. (2019). Motivating household water conservation: A field experiment in Singapore. PLoS ONE, 14(3), e0211891. https://doi.org/10.1371/journal.pone.0211891 PMID: 30893305
10. Landon A. C., Woodward R. T., Kyle T., Kaiser R. A. (2018). Evaluating the efficacy of an information-based residential outdoor water conservation program. Journal of Cleaner Production, 195, 56–65. https://doi.org/10.1016/j.jclepro.2018.05.196.
11. Schultz P. W., Nolan J. M., Cialdini R. B., Goldstein N. J., Griskevicius V. (2007). The constructive, destructive, and reconstructive power of social norm. Psychological Science, 18(5), 429–434. https://doi.org/10.1177/1745691617693325.
12. Shen M., Young R., Cui Q. (2016). The normative feedback approach for energy conservation behavior in the military community. Energy Policy, 98, 19–32. https://doi.org/10.1016/j.enpol.2016.08.014.
13. Erickson, T., Podlasek, M., Sahu, S., Dai, J. D., Chao, T., Naphade, M. (2012). The Dubuque water portal: Evaluation of the uptake, use and impact of residential water consumption feedback. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ACM.
14. Otaki Y., Ueda K., Sakura O. (2017). Effects of feedback about community water consumption on residential water conservation. Journal of Cleaner Production, 143, 719–730. https://doi.org/10.1016/j.jclepro.2016.12.051.
15. Water cooperation (2002) https://www.watercorporation.com.au/Bill-and-account/My-charges (Accessed on 8 Aug, 2022)
16. Otaki Y., Honda H., Ueda K. (2020) Water demand management: Visualising a public good. PLoS ONE, 15(6), e0234621. https://doi.org/10.1371/journal.pone.0234621 PMID: 32544207
17. Taylor S., Lobel M. (1989). Social comparison activity under threat: Downward evaluation and upward contacts. Psychological Review, 96, 569–575. https://doi.org/10.1037/0033-295x.96.4.569 PMID: 2678204
18. Canfield C., de Bruin W.B., Wong-Paodi G. (2017). Perceptions of electricity-use communications: Effects of information, format, and individual differences. Journal of Risk Research, 20(9), 1132–1153. https://doi.org/10.1080/13669877.2015.1121909.

19. Grune-Yanoff T., Hertwig R. (2016). Nudge versus boost: How coherent are policy and theory? Minds & Machines, 26, 149–183. https://doi.org/10.1007/s11023-015-9367-9.

20. Hertwig R., Grune-Yanoff T. (2017). Nudging and boosting: Steering or empowering good decisions. Psychological Science, 12(6), 973–986. https://doi.org/10.1177/0174696816672496 PMID: 28792862

21. Shaffer J. P. (1986). Modified sequentially rejective multiple test procedures. Journal of American Statistical Association, 81, 826–831. https://doi.org/10.1080/01621459.1986.10478341

22. Beal C.D., Stewart R.A., Fielding K. (2013). A novel mixed method smart metering approach to reconciling differences between perceived and actual residential end use water consumption. Journal of Cleaner Production, 60, 116–128. https://doi.org/10.1016/j.jclepro.2011.09.007.

23. Schultz P., Messina A., Tronu G., Limas E., Gupta R., Estrada M. (2016). Personalized normative feedback and the moderating role of personal norms: A field experiment to reduce residential water consumption. Environment & Behavior, 48(5), 686–710. https://doi.org/10.1177/0013916514553835.

24. Einfeld C. (2019) Nudge and evidence based policy: Fertile ground. Evidence & Policy: A Journal of Research, Debate and Practice, 15(4), 509–524. https://doi.org/10.1332/174426418X1531403659759.

25. Grune-Yanoff T., Hertwig R. (2017) Nudging and boosting: Steering or empowering good decisions. Perspectives on Psychological Science, 12(6), 973–986. https://doi.org/10.1177/1745691617702496 PMID: 28792862

26. Hertwig R. (2017). When to consider boosting: Some rules for policy-makers. Behavioral Public Policy, 1(2), 143–161. https://doi.org/10.1017/bpp.2016.14.

27. Bernedo M., Ferraro P. J., Price M. (2014). The persistent impacts of norm-based messaging and their implications for water conservation. Journal of Consumer Policy, 37, 437–452. https://doi.org/10.1007/s10603-014-9266-0.

28. Ferraro P. J., Miranda J. J., Price M. K. (2011). The persistence of treatment effects with norm-based policy instruments: Evidence from a randomized environmental policy experiment. American Economic Review, 101, 318–322. https://doi.org/10.1257/aer.101.3.318.

29. Seyranian V., Sinatra G., Polikoff M. (2015). Comparing communication strategies for reducing residential water consumption. Journal of Environmental Psychology, 41, 81–90. https://doi.org/10.1016/j.jenvp.2014.11.009.

30. Fielding K.S., Spinks A., Russell S., McCrea R., Stewart R., Gardner J. (2013). An experimental test of voluntary strategies to promote urban water demand management. Journal of Environmental Management, 114, 346–351. https://doi.org/10.1016/j.jenvman.2012.10.027 PMID: 23168251

31. Vivek V., Malghana D., Mukherjee K. (2021). Toward achieving persistent behavior change in household water conservation. Proceedings of the National Academy of Sciences of the United States of America, 118(24), e2023014118. https://doi.org/10.1073/pnas.2023014118 PMID: 34099567

32. Liu A., Giurco D., Mukheibir P. (2016). Urban water conservation through customised water and end-use information. Journal of Cleaner Production, 112, 3164–3175. https://doi.org/10.1016/j.jclepro.2015.10.002.