



Assessment of the factors shaping the public's perception of physical and virtual water: A case study of Korean households

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ABSTRACT

Water demand management is a crucial approach for ensuring sustainable water supply. To ensure an effective water demand management, it is essential to have a good understanding of public perceptions of water use. In this study, we examined the perceptions of water use and virtual water of Daegu inhabitants in South Korea, with a focus on understanding their sociodemographic characteristics, water-saving behaviors, environmental attitudes, and accuracy in estimating water use and virtual water content. The results indicated that the majority of respondents were aware of the need for water conservation but exhibited only moderate engagement in water-saving behaviors. They consistently underestimated their water use across various activities (portable drinking water, shower, toilet flush, laundry and car wash), indicating a lack of understanding regarding the magnitude of water consumption. Similarly, respondents had limited awareness of the virtual water content in different products, with inaccurate perceptions of water-intensive products. Sociodemographic factors such as gender, education level, annual income, and family size significantly influenced perceptions of water use, while environmental attitudes played a significant role in the perceptions of both water use and virtual water content. The study highlights the need for educational initiatives to enhance public awareness and understanding of water use and virtual water, particularly in addressing misconceptions and promoting sustainable water management practices. While the findings are specific to Daegu city, they provide insights that can inform water management strategies in other cities globally.

1. Introduction

Water is an essential natural resource that sustains life on earth. With a rapidly growing global population and increasing demand for water in various sectors such as agriculture, industry, and domestic use, there is a pressing need to conserve water resources (Govender et al., 2022; Mazzoni et al., 2022). Water conservation is an important aspect of sustainable development, particularly in regions that experience water scarcity (Baron et al., 2002; Sharma and Vairavamoothy, 2009). However, due to industrialization, urbanization, and climate change, many countries around the world continue to face substantial issues in managing their limited water resources (Odey et al., 2023; Sønderlund

et al., 2016), with South Korea not being an exception (Wang and Choi, 2019). The high economic growth rate of South Korea over the past few decades has come at the expense of the environment (Thanh Nguyen et al., 2012), indicated by pressure on water resources (Cho, 2002). In addition, uncontrolled water usage has exacerbated the problem of water scarcity, having a significant detrimental impact on social and economic growth (Cai et al., 2016). As a result, increasing water efficiency is critical for long-term water consumption (Hu et al., 2016). Critics have suggested that rather than focusing solely on raising the supply of fresh water (supply-driven approach), we should also manage water demand (demand-driven approach) (Christian-Smith et al., 2011). Because inadequate management of water resources frequently results

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in inefficient utilization and distribution of water, thereby exacerbating water conflicts (Jiang, 2009). A very critical means of water demand management is the adequate creation of conservation awareness. An improvement and promotion of water conservation awareness would encourage the adoption of water conservation behaviour amongst consumers (Dolnicar et al., 2012). According to Abdulrazzak and Khan (1990), there was an 18 % reduction in water consumption (equivalent to approximately 17 liters per person per day) in Zaragoza, Spain, as a result of increased awareness and implementation of water conservation measures. Similarly, the implementation of water conservation awareness programs led to a significant decrease in residential water consumption in South-east Queensland, Australia (Beal et al., 2011). In addition, public perception studies by Fu et al. (2022) and Hou et al. (2021), suggested that the level of knowledge people have about water significantly affects their perceptions or stereotypes related to its usage, thus highlighting the importance of education and public awareness. Furthermore, the effectiveness of demand management approaches like pricing adjustments, restrictions, and educational initiatives focused on water conservation have demonstrated varying impacts on altering public attitudes toward water usage (Arbues et al., 2010). Van Vugt and Samuelson (1999) have also reported that localities equipped with water meters tend to consume less water compared to those lacking such meters, underscoring that a significant obstacle to water conservation lies in consumers not having a clear grasp of their water usage levels. The increasing events of water shortages around the world have led to an urgent need for governments and non-governmental organizations (NGOs) to champion the reduction in water demand by the improvement of water conservation awareness and consumer behaviour (Ahmed et al., 2022).

Understanding and knowledge of how consumers perceive and utilize water is critical to the effective and appropriate implementation of demand management and water conservation strategies (Jones et al., 2011). The public perception of physical and virtual water can influence how people use water, the extent to which they value it, and their motivation to conserve it (Attari, 2014; Fan et al., 2014). In other words, the effectiveness of water conservation strategies is largely dependent on public perception and behavior towards water usage (Beal et al., 2013). In recent years, there has been a growing interest in the use of

virtual water as a means of conserving physical water resources. Physical water refers to the water that is present in lakes, rivers, groundwater, and other natural sources, that can be seen and accessed directly for various purposes such as irrigation, industrial processes, and household use; while virtual water is the amount of water used to produce goods and services that people consume (Hoekstra and Hung, 2003). By lowering their water footprint (i.e., the amount of virtual water embedded in consumed products of choice), consumers may help keep human water use to a sustainable level. However, a lack of knowledge about how much water is used directly and indirectly during the production of various items will prevent traders and end users from conserving water (Liu et al., 2022). Studies have shown that the public's perceptions of water use frequently differ from actual water use (Beal et al., 2013). For instance, Liu et al. (2022) in their study on public perceptions of physical and virtual water in China, discovered an overall underestimation of water use, and a general lack of knowledge on virtual water embedded in daily consumed products. Fan et al. (2014) also discovered that most of the respondents had misconceptions about water use. In addition, Attari (2014) found that most of the people underestimated their water use, with poor discrimination of low vs. high virtual water content in food products. While these studies have provided valuable information about water use perceptions and their determinants in China and the United States respectively, there is still a lack of understanding about people's perceptions of water use in South Korea, given the country's different natural water endowment as well as sociodemographic and cultural characteristics. Furthermore, the domestic sector has over the years been a significant consumer of South Korea's water resources (Fig. 1), accounting for 24.6 % of the total water use as at 2020. This makes it an important sector that must be managed, recognizing that natural water availability is not always able to meet the ever-increasing demands, hence raising a need for demand management (Savenije, 2002).

This study thus focuses on enhancing the comprehension of public attitudes towards water usage, aiming to provide a more profound understanding of water use in the domestic sector in order to enhance demand-side policy responses to fluctuations in freshwater availability. Specifically, the study will i) assess the extent of over- or under-estimation of water use among Korean people, with the metropolitan

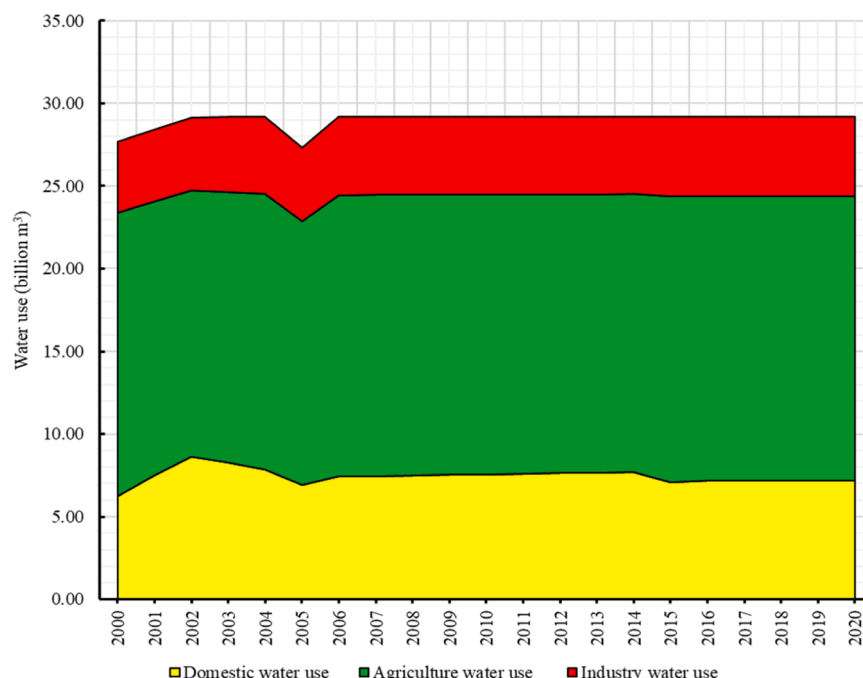


Fig. 1. South Korea's water use trend by sector from 2000 to 2020.

city of Daegu as a case study; ii) examine the awareness status of people with respect to virtual water embedded in daily-consumed food, iii) examine the key factors influencing perceptions of physical and virtual water. Daegu city was selected for this study due to such factors as its densely populated nature (fourth largest city in South Korea) (KOSIS, 2023), characterized by a diverse range of water users (agricultural, industrial, and domestic). The significance of this study lies in its potential to inform water conservation policies that are based on public perception and behavior. By understanding how the public perceives physical and virtual water, policymakers can develop interventions that are more effective in promoting water conservation. Additionally, the study will contribute to the growing body of literature on water conservation and promote a more holistic understanding of the social and psychological factors that influence water conservation behaviors.

The structure of this research article continues as follows. Firstly, we will present the materials and methods used in this study. Secondly, we will present the findings of the study, followed by a discussion of the implications for water conservation policy. Finally, we will conclude the article by summarizing the main findings and suggesting avenues for future research.

2. Materials and methods

2.1. Study area

Daegu city, often referred to as Daegu Metropolitan City, is a prominent urban center located in the southeastern part of South Korea (Fig. 2). It is situated in the Gyeongsangbuk-do province and serves as its capital. Daegu is the fourth-largest city in South Korea behind Seoul, Busan, and Incheon respectively, with a population of approximately 2.5 million people (KOSIS, 2023). The city covers an area of around 883 square kilometers, encompassing a diverse range of landscapes and urban developments. Water plays a crucial role in the daily life of Daegu's residents and the city's economic activities. Daegu relies on a combination of water sources to meet its water demands. The Nakdong River, South Korea's longest river, flows through the city and serves as a primary source of surface water. Additionally, the city has developed several reservoirs and dams to store water for consumption and agricultural purposes (Zeng et al., 2012). Daegu experiences a temperate climate with distinct seasons. Summers are hot and humid, with temperatures reaching up to 35⁰ C (95 degrees Fahrenheit), while winters are relatively cold, with temperatures dropping below freezing (KMA, 2023). These weather conditions affect water demand and consumption patterns throughout the year.

In recent years, Daegu has made efforts to manage its water resources more efficiently and promote sustainable water use (Cho and Jung, 2018). Water conservation policies and initiatives have been implemented to address water scarcity and reduce water wastage (Adelodun et al., 2021). The city has also focused on developing water recycling and reuse systems to optimize water resources and minimize environmental impacts (Han et al., 2012). Therefore, the combination of the city's rapid urban development, diverse economic sectors, and water management initiatives make it an ideal study area for researching water use and virtual water perception among its inhabitants. By delving into the city's unique characteristics, we can gain valuable insights that can contribute to sustainable water management practices and policies not only in Daegu but also in similar urban contexts around the world.

2.2. Data collection

Extensive data collection for this research study in Daegu city involved the participation of its residents. In order to gather the necessary information, a questionnaire was prepared and distributed. The data collection process spanned over a period of approximately one month, commencing from January 30, 2023, and concluding on February 28, 2023. To ensure a wide reach and convenience for the participants, data was collected through two methods: online via Google Forms (accessible at <https://docs.google.com/forms/>) and offline. Online, we strategically shared the survey link across various platforms, including professional and academic email lists, and social media channels such as WhatsApp and KakaoTalk (the most popular Korean social media channel). We tailored our approach to reach residents of Daegu, with an aim for a diverse representation. We shared a clear and accessible Google Forms link accompanied by a brief introduction explaining the survey's purpose and encouraging honest and thoughtful responses. Emphasizing the voluntary and anonymous nature of participation, we highlighted the significance of their insights in contributing to meaningful research on water conservation. This approach allowed us to engage a wide audience, leveraging the ease of online accessibility and the power of digital networks to disseminate the survey widely. In parallel, the offline survey used in-person methods. Adopting a random sampling approach, we stationed surveyors at local community events, shopping areas, and worship centers within our target region. These places attracted a diverse group of potential participants, presenting an opportune setting for our study. Surveyors explained the survey's purpose and relevance, offering printed introductions to interested individuals. This personal interaction facilitated a deeper understanding of the survey and encouraged

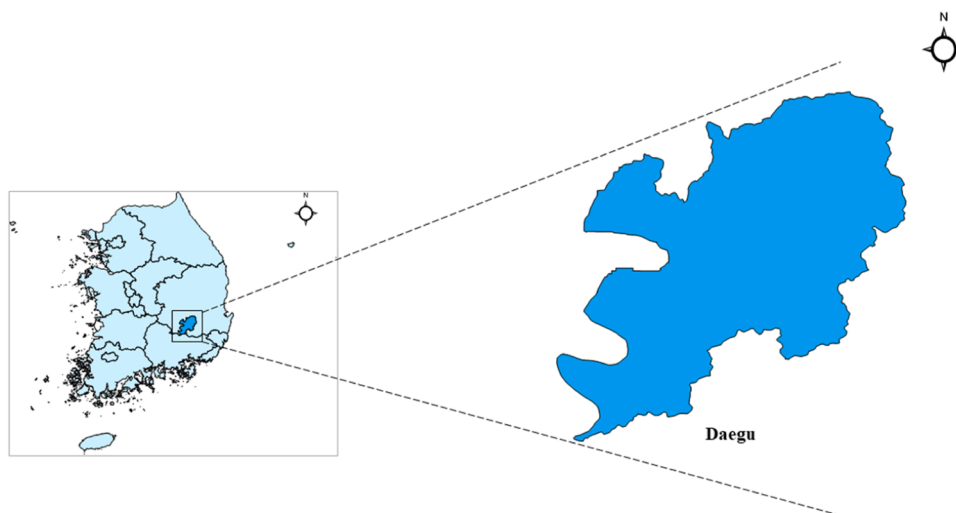


Fig. 2. Map of South Korea with focus on Daegu City.

participation. Participants who expressed interest in the offline survey were handed hard copies of the survey to complete. Surveyors were readily available to address any questions and guide participants through the survey process. This face-to-face interaction added a personalized touch to the survey process, enabling real-time assistance and fostering a sense of engagement and understanding. A total of 402 responses were received, but 13 of them were deemed incomplete or perfunctory and were subsequently excluded from the analysis. This left a total of 389 valid responses that were considered for further analysis. Before the questionnaires were officially distributed, the survey items were first composed in English. They were then translated into Korean and evaluated for clarity and suitability by a professor and two Korean experts. This evaluation aimed to ensure that the questionnaire items were acceptable and free from any ambiguity. Based on the feedback received, necessary modifications were made to the questionnaire items, and the final version was ultimately approved for distribution and data collection.

2.3. Survey materials

The participants were requested to provide estimates for five different ways they use water in their daily lives. These included the amount of potable water an adult consumes in a day, the water used during a shower, the water used for flushing a standard-flow toilet, the water used for washing one load of clothes with a standard washing machine, and the water used for washing a car. All the estimates were measured in liters. Following that, the participants were asked to rank the virtual water content present in six agricultural and livestock products that they consume on a daily basis. These products included 1 kg of rice, chicken, milk, wheat, pork, and beef. The selection of these five end uses of water and six products was based on previous research conducted in the United States (Attari, 2014) and China (Liu et al., 2022). However, the researchers took into consideration the water usage practices and dietary habits that are more relevant to the Korean population. For example, practices such as garden hose water usage from the American study and filling a single bath from the Chinese study, which are not common in Korean households, were excluded. The survey also encompassed questions related to socio-demographics, environmental attitudes, water saving behaviour, and other pertinent information that could potentially influence perceptions of water usage. The role of various demographic and contextual factors in shaping consumer perception of water use has been the subject of investigation in several existing studies. These factors are crucial in understanding how individuals perceive and interact with water consumption practices. For instance, Liu et al. (2022) reported a significant influence of gender, education, age, environmental attitude, water saving behaviors, water price and residential water source on water use perceptions. Attari (2014) also reported a significant influence of age and gender on perception of water use in the United States. Similarly, Beal et al. (2013) revealed the substantial impact of income, age, gender, and family size on how individuals perceive their water usage. These studies highlight the diverse array of factors that come into play when it comes to consumer perceptions of water use.

To ensure the quality of responses, participants were asked to solve a simple arithmetic test question (i.e. "20 - 6 = __?"). The need for ethical approval was waived by the Scientific Research and Publication Ethics Committee of the corresponding author's institution as the research article included no sensitive personal information in the study. In addition, informed consent was obtained from all participants, and the complete survey questionnaire can be accessed in the [Supplementary Information](#).

2.4. Data analysis

IBM SPSS statistical software (version 20) and Origin Pro 2021 (OriginPro, 2021) were used to perform the statistical analysis. The

frequency and percentage values of the sociodemographic variables and responses to open-ended water conservation questions were presented. To examine the level of perception (over-, accurate, or under-estimation) and significant differences between perceived and actual water use and virtual water ranks, we calculated the mean ratios and performed a one-sample Wilcoxon Signed Rank Test (significant at 0.05 level) respectively. To calculate the mean ratio, we first determine individual ratios. These ratios are obtained by dividing each respondent's perceived value by the corresponding actual value. For water use, the individual ratio is computed as the perceived water use divided by the actual water use. Similarly, for virtual water ranks, the ratio is calculated by dividing perceived virtual water ranks by actual virtual water ranks. This process allows us to establish how much each respondent's perception deviates from the actual values. In our study, 1 was used for product with least amount of embodied water and 6 represented product with largest amount of embodied water. Once we have the individual ratios for all respondents, we proceed to calculate the mean ratio. This involves summing up all the individual ratios and then dividing this sum by the total number of respondents. The resulting mean ratio serves as a representation of the average degree of over-estimation, accurate estimation or underestimation across the entire respondent pool. Ratios greater than 1 signify an overall tendency to overestimate, ratios equal to 1 indicate accurate estimation, and ratios less than 1 suggest a general inclination towards underestimation. The one-sample Wilcoxon Signed Rank Test is a non-parametric statistical test used to compare the distribution of paired or matched samples (Wilcoxon, 1945). It is used when we have one sample and want to determine if its median is significantly different from a hypothesized value. The test assesses the null hypothesis that the median of the sample is equal to the hypothesized value. The one-sample Wilcoxon Signed Rank Test was used in this study based on the assumption of a fixed value of actual water use and virtual water rank for all respondents (more details in the supplementary file). The test provides a robust method for testing the significance of differences between paired observations without relying on the assumptions of parametric tests.

To examine the influences on perception of water use/virtual water embedded in products at the individual level of socio-demographics, water price, environmental attitudes and water-saving behaviour, we constructed a two-step binary logistic regression model. We utilized this modeling technique because the dependent variables were categorized into two classes, while the independent variables consisted of both categorical and continuous variables. In this model, the water use and virtual water perceptions served as dependent variables and were 2-point scale variables. In the independent variables listed in Table 1, age, environmental attitudes and water-saving behaviour were treated as continuous variables; others were treated as dichotomous or categorical variables. In the first step, only selected sociodemographic factors were employed as independent variables. In the second step, we introduced water price, environmental attitudes, and water-saving behavior as independent variables to assess their potential impact on both perceptions. We present odds ratios (ORs) to demonstrate the influence of the various factors. Models can be shown as follows:

$$\text{logit}(Y) = \beta_0 + \beta_1 \text{gender} + \beta_2 \text{age} + \beta_3 \text{edulevel} + \beta_4 \text{income} + \beta_5 \text{famsize} + \beta_n X_n \quad (1)$$

$$\text{logit}(Y) = \beta_0 + \beta_1 \text{gender} + \beta_2 \text{age} + \beta_3 \text{edulevel} + \beta_4 \text{income} + \beta_5 \text{famsize} + \beta_6 \text{waterprc} + \beta_7 \text{attitudes} + \beta_8 \text{behaviour} + \beta_n X_n \quad (2)$$

Where Eqs. (1) and (2) represent the first and second steps of the regression, $\text{logit}(Y)$ is the log-odds of the event (success in dependent variable binary classification), $\beta_0, \beta_1, \beta_2, \beta_3, \dots, \beta_n$ represents the coefficients of the independent variables: gender, age, educational level, annual income, family size, water price, environmental attitudes and water-saving behaviour.

Prior to conducting the regression analysis, we assessed the presence of multicollinearity issue among the independent variables using

Table 1
Description of the variables.

Category	Variables	Description
Dependent variables	Water use perception (Y1)	2-point scale variable, representing the perceptions of 5 end uses of water; (0 = accurate estimation (reference category), 1 = inaccurate estimation). Note: categorizing water use into accurate and inaccurate perception typically involved comparing the estimated water use (achieved by summing up the perceived amount of water for 5 end-uses of water) to the actual water use (sum of actual amount of water for 5 end-uses of water). In this case, accurate estimation was defined as being within plus or minus 10 % of the actual water use.
	Virtual water perception (Y2)	2-point scale variable, representing the perceptions of virtual water embedded in 6 products; (0 = accurate estimation (reference category), 1 = inaccurate estimation). Note: categorizing virtual water into accurate and inaccurate perception typically involved comparing the estimated virtual water rank to the actual rank using a weighted average approach. This allowed us to take into account the rankings of the 6 different products and assign different weights to them based on the volume of water utilized in their production (in ascending order). In this case, accurate estimation was defined as being within ± 1 of actual virtual water rank.
Independent variables	Gender	Dichotomous variable, representing respondents' gender; (male = 0; female = 1).
	Age	Continuous variable, representing respondents' age (year).
	Educational level	Categorical variable, representing respondents' level of education; (0 = middle school, 1 = high school, 2 = undergraduate, 3 = graduate school).
	Annual income	Categorical variable, representing the household annual income (₩/yr); (1 = <₩30,000,000; 2 = <₩70,000,000; 3 = >₩70,000,000).
	Family size	Categorical variable, representing the number of persons per household; (1 = one person, 2 = two people, 3 = three people, 4 = four people, 5 = five or more people).
	Water price	Categorical variable, representing the respondents' price perception; (1 = I don't know, 2 = below ₩0.5, 3 = ₩0.5 - ₩1, 4 = ₩1 - ₩2, 5 = ₩2 and above). Note: the option, "I don't know" suggests a lack of concern regarding the price and is assigned a comparatively low value (₩0.01) in the analysis.
	Environmental attitudes	Continuous variable, representing respondents' attitudes towards the environment (treated as a quantitative measurement ranging between 0 and 1 without any inherent categorical order). During the survey, the candidates were questioned about their environmental attitudes using two specific questions. The candidates were required to rate their responses on a five-level scale ranging from "strongly disagree" to "strongly agree." Each level of attitude is assigned a score: 0 for "strongly disagree," 0.25 for "disagree," 0.5 for "neutral," 0.75 for "agree," and 1 for "strongly agree." To determine each

Table 1 (continued)

Category	Variables	Description
	Water-saving behaviour	candidate's environmental attitudes, the scores of the two questions were averaged together. Continuous variable, representing respondents' behaviour as it concerns saving water (treated as a quantitative measurement ranging between 0 and 1 without any inherent categorical order). Candidates were posed four questions regarding the frequency of their engagement in various water-saving actions, ranging from "never" to "always," which are divided into five levels. The responses "never," "rarely," "sometimes," "often," and "always" were assigned values of 0, 0.25, 0.5, 0.75, and 1, respectively. The average score of the four questions for each candidate was used as a measure of their water-saving behavior.

Note: annual income and water price are expressed in Korean won (₩). ₩1273 = \$1 (June 2023).

variance inflation factors (VIF) and tolerance values. To prevent multicollinearity among the independent variables, it was necessary for the VIF values to be less than 4 (O'Brien, 2007) and the tolerance values to be greater than 0.2 (Hosmer et al., 2008). The results of this study had VIF values below 2 and all tolerance values were above 0.2, signifying the absence of multicollinearity problem in the regression analyses. To further check for multicollinearity, we assessed the correlations between all the independent variables by examining the correlation matrices.

3. Results

3.1. Sociodemographic analysis

The characteristics of the respondents in this study are presented in Table 2. 47.8 % of the respondents were male and 52.2 % were female, constituting the majority. According to the age, majority of the respondents ranged between 18 and 29 years (34.6 % of the sample size), followed by those whose age was greater than 60 years (19.9 %), 50 and 59 years (19.3 %), 40 and 49 years (17.1 %), and those between 30 and 39 years (9.1 %) accordingly. Based on level of education, most of the respondents had undergraduate degrees (58.6 %) as their highest educational attainment. This was followed by respondents with high school certificates (27.8 %), graduate degrees (11.8 %), and middle school (1.8 %) respectively. The predominant level of income amongst respondents ranged between ₩30,000,000 and ₩70,000,000 (20.3 %), with the least level ranging between ₩100,000,000 and ₩150,000,000 (6.2 %). Occupation-wise, about 86.1 % of the respondents worked in the tertiary industry (e.g. public institutions, education sector, health-care, finance, trade), 6.2 % were in the secondary industry (manufacturing), 3.6 % were in the primary industry (farming, forestry, animal husbandry and fishery production), and 4.1 % were unemployed. Majority of the households had a family size of 4 members (45.2 %) and the primary water source was the combination of tap and bottled water (56.3 %). A significant portion of the participants (85.3 %) lacked knowledge about the exact amount they are charged per unit of water consumed. Domestic water price in Daegu per unit water use is mostly between 0.5 and 1 ₩/liter (KOSIS, 2023).

Fig. 3 shows the distribution of the respondents' water-saving behaviour and environmental attitudes. The median score of 0.44 in the box normal plot for water-saving behavior suggests that, on average, the respondents exhibited a tendency to engage in water-saving behaviors at a level between "rarely" and "sometimes." This indicates that while they may not consistently practice water-saving habits, there is

Table 2
Socio-demographic characteristics of respondents.

Characteristic	Groups	Frequency (n)	Percentage (%)
Gender	Male	186	47.8
	Female	203	52.2
Age	18 – 29	134	34.6
	30 – 39	36	9.1
	40 – 49	67	17.1
	50 – 59	75	19.3
	≥ 60	77	19.9
Educational Level	Middle school	7	1.8
	High school	108	27.8
	Undergraduate	228	58.6
	Graduate school	46	11.8
Annual Income	Below ¥10,000,000	69	17.7
	¥10,000,000 – ¥30,000,000	63	16.2
	¥30,000,000 – ¥50,000,000	79	20.3
	¥50,000,000 – ¥70,000,000	79	20.3
	¥70,000,000 – ¥100,000,000	45	11.6
	¥100,000,000 – ¥150,000,000	24	6.2
	¥150,000,000 & above	30	7.7
	Primary industry	14	3.6
	Secondary industry	24	6.2
	Tertiary industry	335	86.1
Family size	Unemployed	16	4.1
	1	33	8.5
	2	52	13.4
	3	80	20.6
	4	176	45.2
Water source	5 or more	48	12.3
	Tap water	169	43.4
	Bottled water	1	0.3
	Tap water & bottled water	219	56.3
Water price perception	I don't know	332	85.3
	Below ¥0.5	15	3.9
	¥0.5 – ¥1	20	5.1
	¥1 – ¥2	6	1.5
	¥2 & above	16	4.1

some level of awareness and effort to conserve water. However, the majority of respondents do not exhibit strong adherence to water-saving behaviors as indicated by the score below 0.5. On the other hand, the box normal plot for environmental attitudes indicated a median score of 0.75 suggesting that on average, the respondents tend to agree with environmental attitudes. The score of 0.75 suggests a relatively strong inclination towards environmental concerns and a positive attitude towards environmental issues. The respondents were more likely to express agreement with environmental values and principles rather than disagreement or neutrality. In addition, they may demonstrate a higher level of support for environmental protection and sustainable practices, indicating a positive environmental attitude among the respondents. While the respondents in this study were more pro-environment than water-saving, results from Liu et al. (2022) showed slight opposites.

3.2. Perception of “water conservation actions”

Table 3 and Fig. 4 show participants' responses to two hybrid questions regarding the most effective action they could personally take

Table 3
Categorizing responses to the two hybrid water conservation questions.

Action	Curtailment (C) or Efficiency (E)	Self (%)	Others (%)
Turn off the shower or faucet if you do not use it when showering or washing things	C	31.0	30.2
Reuse water at home, e.g. reusing laundry water to flush the toilet	E	6.3	6.5
Wash all the clothes together	C	25.9	22.0
Avoid wasting food	–	10.0	8.7
Repair leaking equipment on time	E	9.4	9.4
Dissuade people from wasting water, and participate in water-saving publicity activities	–	3.1	5.9
Purchase and use household water saving appliances (e.g. shower timer, low-flow showerheads, etc.)	E	9.7	11.1
Harvest rainwater	E	1.6	2.2
Wash car less	C	2.9	3.8

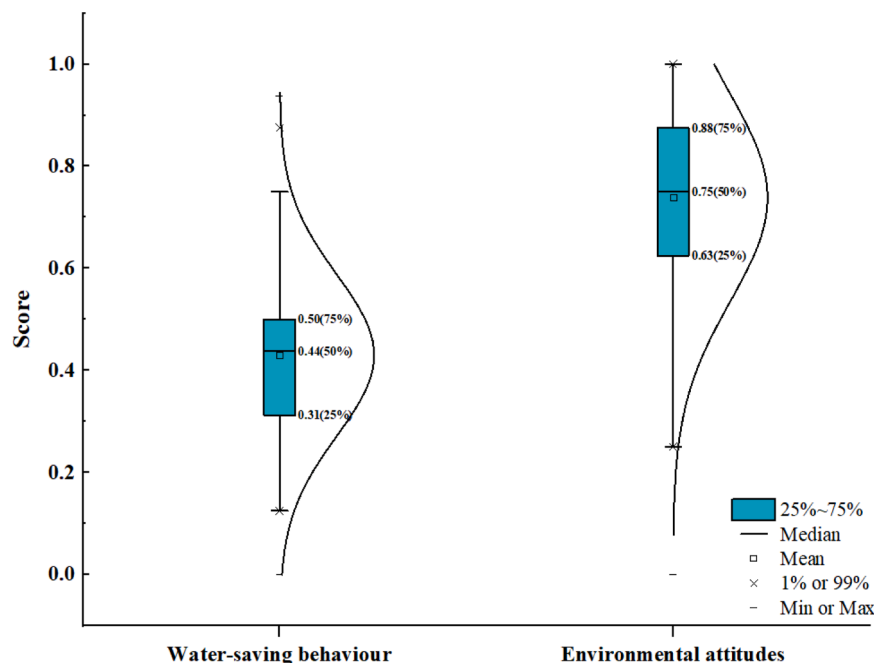


Fig. 3. Data distribution of participants Environmental Attitudes and Water-saving Behaviour.

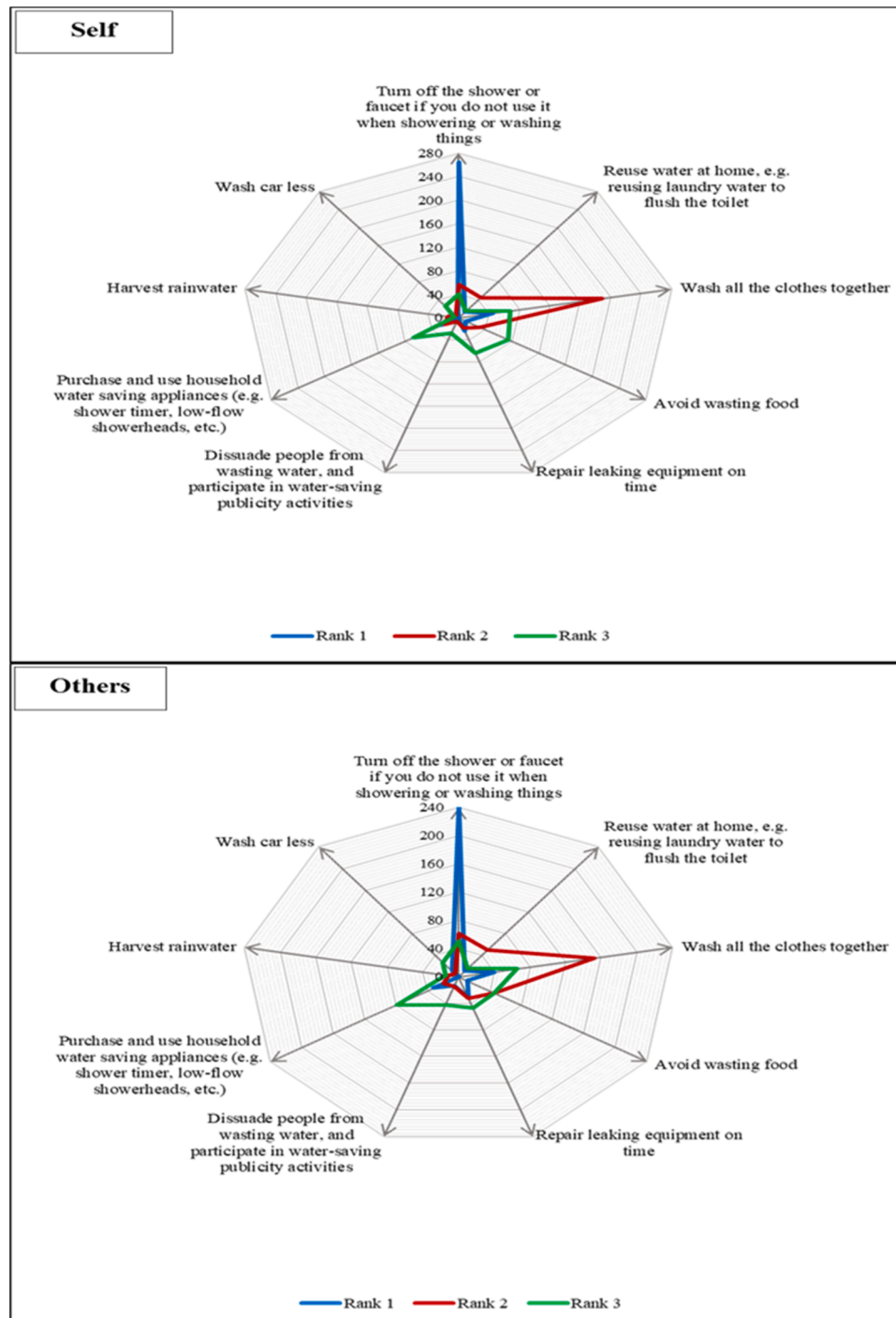


Fig. 4. Respondents ranking of water conservation actions.

to conserve water in their daily lives, and the most effective action others can take to conserve water in their lives. These actions were classified into curtailment (measures taken to reduce or limit water usage) and efficiency (practices that maximize the efficient use of water). Some actions were not categorized because unlike the curtailment or efficiency that are considered direct water conservation actions, they were indirect water conservation actions. 59.8 % of the respondents selected curtailment actions for themselves and 56 % for others. On the other hand, 27 % of the respondents selected efficiency actions for themselves and 29.2 % for others. These distinctions suggest that respondents were more inclined towards curtailment actions for personal use, potentially reflecting a self-interest or a greater willingness to

engage in actions that directly affect them. On the other hand, respondents demonstrate a slightly higher inclination towards recommending efficiency actions for others. These differences, while not extreme, signify nuanced behavioral patterns worth exploring further. The result is similar to that from Attari (2014), who posited that respondents were more likely to recommend curtailment actions for themselves and efficiency actions for others, due to the inherent cost involved with efficiency actions (for instance, the purchase of water-saving appliances).

3.3. Actual versus perceived water use

All respondents provided their estimations for the end water uses of the 5 different activities. The ratio of the mean of perceived to actual water use was 0.44, 0.59, 0.50, 0.57 and 0.68 for daily portable drinking water, shower for 8 min, single toilet flush, washing one load of clothes in a standard washing machine, and car washing respectively (Fig. 5). This indicates that on average, the respondents underestimated their actual water use by 56 %, 41 %, 50 %, 43 %, and 32 % for the 5 end water use activities respectively. A value less than 1 suggests that the perceived water use is lower than the actual water use. In addition, the one-sample Wilcoxon signed-rank test gave negative Z scores of -9.843 , -13.257 , -9.037 , -12.966 , and -8.487 for daily portable drinking water, shower for 8 min, single toilet flush, washing one load of clothes in a standard washing machine, and car washing respectively, which were all significantly different at $p < 0.05$. This indicates significant differences between the perceived and actual water use of all 5 end water use activities. Specifically, the negative sign of the Z scores suggests that the perceived water use tends to be lower than the actual water use for most of the respondents, further corroborating the results of the mean ratios.

These results suggest that the respondents in this study underestimated their actual water use and that the difference between the perceived and actual water use was statistically significant, indicating a lack of understanding of the relative magnitude of water use. In other words, on average, there is a systematic discrepancy (consistent difference) between the participants' perception and the actual water use, with the perceived water use being lower than the actual value. These findings align with prior studies by Fan et al. (2014) and Hassell and Cary (2007) which also reported significant relations between perceived and actual water consumption, and that water users generally underestimated their water consumption.

3.4. Actual versus perceived virtual water embedded in 6 products

The respondents ordered the products between 1 and 6, based on the perceived level of virtual water contained in 1 kg of each product. The results revealed the following mean ratio ranks for the products: rice (2.99), chicken (1.00), milk (2.08), wheat (1.34), pork (0.62), and beef

(0.45). Furthermore, the one-sample Wilcoxon signed rank test yielded the following Z score values: 12.752 for rice, which was significant ($p < 0.05$); 0.143 for chicken, which was not significant; 16.130 for milk, 11.022 for wheat, -15.220 for pork, and -16.468 for beef, which were all significant ($p < 0.05$) (Fig. 6). Based on these results, we can observe that the participants perceived rice to have the highest virtual water content among the products, as it received the highest mean ratio rank. The Wilcoxon signed rank test confirmed this perception, with a significant Z-score of 12.752. In contrast, beef was perceived to have the lowest virtual water content, as indicated by its mean ratio rank of 0.45. These results reveal that there are differences between the perceived and actual virtual water ranks of the products. Rice, milk, and wheat were generally overestimated, while pork and beef were underestimated. Chicken, on the other hand, was perceived accurately in terms of its virtual water content. However, similar to observations by Liu et al. (2022) in their study of China, the respondents in this study had no clue of the fact that more water is involved in the production of livestock products in comparison to equivalent crop production. This is evidenced by the fact that the respondents had difficulty discerning which product required a greater amount of water in the production process compared to another, indicating a potential lack of awareness regarding the water footprint of different products.

3.5. Factors influencing water use/virtual water perceptions

To investigate the factors that influence perceptions, eight variables that describe the individual characteristics of the respondents were taken into account as predictors of perceptions. The results of the first step model solely demonstrate the impact of selected sociodemographic variables (as shown in Table 4), which are regarded as common factors influencing perceptions (Beal et al., 2013; Juárez-Nájera et al., 2010; Russell and Fielding, 2010). The results showed that only family size had significant influence on both water use and virtual water perceptions. For water use, the odds of a one-member family size (Famsize_1, Odds ratio (OR) = 0.204; 95 % confidence interval (CI): 0.055, 0.749) accurately estimating water use was 20.4 % of the odds of those with a family size of 5 members or more, suggesting that individuals belonging to one-member families have significantly lower odds of accurately estimating water use compared to those from larger families (5 or more

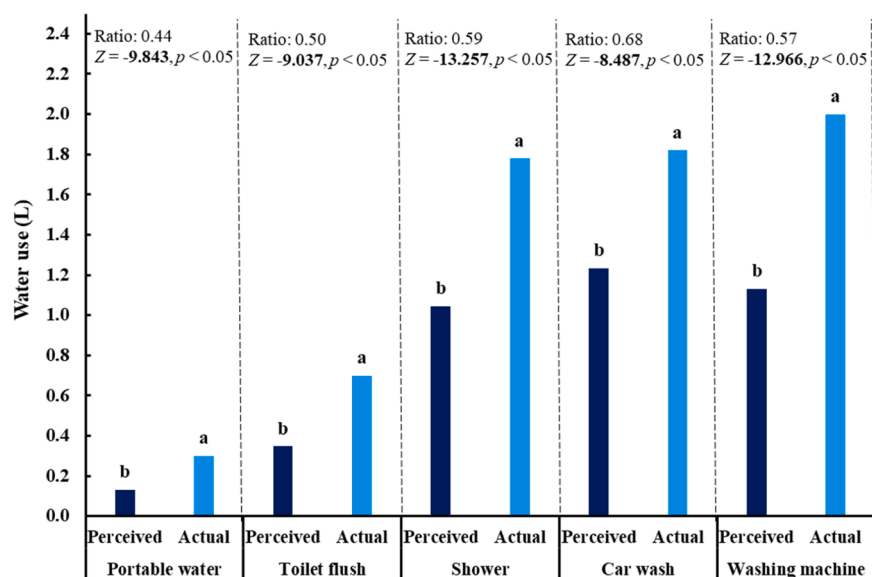


Fig. 5. The estimated mean values for perceived and actual end uses of water. The values in black boxes represent the ratio of perceived to actual end uses of water, and the standardized test statistic (z). In our representation, the use of letters "a" and "b" signifies significant differences between the perception values. Specifically, "a" represents a higher value, and "b" represents a lower value. On the other hand, instances where the same letter is used (i.e., "a-a") indicate non-significant differences between the values being compared.

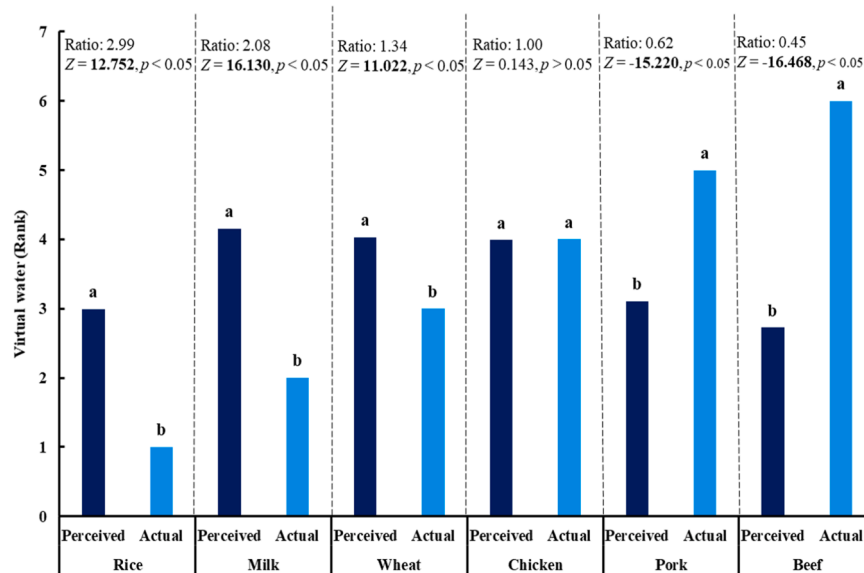


Fig. 6. The estimated mean ranks for perceived and actual virtual water of 6 products. The values in black boxes represent the ratio of perceived to actual virtual water ranks, and the standardized test statistic (z). In our representation, the use of letters "a" and "b" signifies significant differences between the perception values. Specifically, "a" represents a higher value, and "b" represents a lower value. On the other hand, instances where the same letter is used (i.e., "a-a") indicate non-significant differences between the values being compared.

Table 4

The results of a binary logistic regression model analyzing the sociodemographic factors predicting perceived physical and virtual water use.

Variables	Perceptions of water use in 5 activities OR (95 % CI)	Perceptions of embedded virtual water in 6 products OR (95 % CI)
Gender_0 vs. Gender_1 ^a	3.913 (2.273, 6.736)	1.308 (0.857, 1.997)
Age	0.990 (0.973, 1.007)	1.004 (0.990, 1.019)
Edu_0 vs. Edu_3 ^b	0.474 (0.064, 3.488)	0.750 (0.141, 4.007)
Edu_1 vs. Edu_3	0.220 (0.080, 0.604)	1.413 (0.647, 3.085)
Edu_2 vs. Edu_3	0.813 (0.365, 1.811)	1.171 (0.600, 2.284)
Inc_1 vs. Inc_3 ^c	1.561 (0.767, 3.177)	1.233 (0.679, 2.238)
Inc_2 vs. Inc_3	0.371 (0.194, 0.712)	1.321 (0.787, 2.218)
Famsize_1 vs. Famsize_5 ^d	0.204 (0.055, 0.749)	0.418 (0.158, 1.103)
Famsize_2 vs. Famsize_5	0.653 (0.241, 1.768)	0.946 (0.392, 2.287)
Famsize_3 vs. Famsize_5	1.207 (0.516, 2.822)	0.484 (0.234, 1.002)
Famsize_4 vs. Famsize_5	0.509 (0.232, 1.120)	0.949 (0.497, 1.813)
Nagelkerke R ²	0.198	0.040

Significant results were shown in bold font.

^a female group was treated as Gender_1.

^b graduate school education was treated as Edu_3.

^c high-income group was treated as Inc_3.

^d family size of 5 or more was treated as Famsize_5.

members). On the other hand, for virtual water, the odds of individuals having a family size of 3 (Famsize_3, OR = 0.484; 95 % CI: 0.234, 1.002) accurately perceiving virtual water was 48.4 % of the odds of the family size of 5 members or more. This suggests that being from a 3-member family is associated with a lower likelihood of accurately estimating virtual water contents of products compared to larger families. Furthermore, water use perception was significantly influenced by other variables including gender, education level and annual income. For the gender factor, the OR of 3.913 (95 % CI: 2.273, 6.736) suggests that females (coded as 1) were 3.913 times more likely to have a perception of water use that differs from males (coded as 0). This means that females had a higher likelihood of inaccurately estimating water use compared to males. Based on education level, the odds of having an

accurate perception of water use for respondents with high school education was 22 % of the odds of those with graduate education level. This suggests that individuals with a high school education are less likely to provide accurate estimations of water use compared to those with a graduate school education. In terms of annual income, individuals belonging to the middle-income category were 37.1 % more likely to accurately estimate water use compared to the high-income group. In other words, the middle-income group has a lower likelihood of providing an accurate estimation of their water use.

Compared to the results in the first step model, the inclusion of the water price, environmental attitudes and water-saving behaviour variables to form the second step model did not have any significant impact on the results of the sociodemographic variables (Table 5). While the environmental attitudes were significant predictors of water use and virtual water perception, water-saving behaviour only significantly predicted water use perception, and water price was not a significant predictor of both perceptions. The results of environmental attitudes showed that individuals with higher environmental attitudes are approximately 4.844 and 2.946 times more likely to accurately estimate their water use and virtual water content of products respectively compared to those with lower environmental attitudes. This suggests that as environmental attitudes increase, the likelihood of accurate perception of water consumption also increases. This is so because individuals with stronger environmental attitudes are more likely to have a better understanding of their own water usage patterns, hence reflecting a positive relationship between environmental attitudes and accurate perception of water use and virtual water content. Furthermore, the odds ratio of 0.094 indicates that for each unit increase in water-saving behavior, the odds of perceiving water use accurately (as opposed to underestimating or overestimating it) decrease by approximately 90.6 % ($1 - 0.094 = 0.906$, or 90.6 %). In other words, individuals who engage in more water-saving behaviors are less likely to perceive water use accurately. The possibility of this lies in the fact that individuals who are actively focused on water-saving behaviours may prioritize their attention on their own conservation efforts rather than objectively observing or estimating water use. This heightened focus on their own actions might lead to an underestimation or overestimation of water use by neglecting likely external factors. In addition, individuals who are motivated to engage in water-saving behaviours may already

Table 5

The results of a binary logistic regression model analyzing the multi-angle factors predicting perceived physical and virtual water use.

Variables	Perceptions of water use in 5 activities OR (95 % CI)	Perceptions of embedded virtual water in 6 products OR (95 % CI)
Gender_0 vs. gender_1	3.997 (2.256, 7.084)	1.329 (0.862, 2.049)
Age	0.991 (0.973, 1.009)	1.005 (0.990, 1.021)
Edu_0 vs. Edu_3	0.623 (0.077, 5.043)	0.701 (0.123, 4.000)
Edu_1 vs. Edu_3	0.213 (0.074, 0.615)	1.188 (0.529, 2.665)
Edu_2 vs. Edu_3	0.672 (0.282, 1.606)	0.943 (0.466, 1.906)
Inc_1 vs. Inc_3	1.200 (0.570, 2.529)	1.206 (0.640, 2.271)
Inc_2 vs. Inc_3	0.329 (0.168, 0.646)	1.333 (0.786, 2.260)
Famsize_1 vs. Famsize_5	0.186 (0.049, 0.702)	0.385 (0.141, 1.054)
Famsize_2 vs. Famsize_5	0.748 (0.269, 2.078)	0.857 (0.350, 2.099)
Famsize_3 vs. Famsize_5	1.036 (0.426, 2.517)	0.449 (0.211, 0.952)
Famsize_4 vs. Famsize_5	0.493 (0.221, 1.097)	0.976 (0.507, 1.880)
Waterprc_1 vs. Waterprc_5 ^a	1.002 (0.271, 3.708)	1.942 (0.737, 5.116)
Waterprc_2 vs. Waterprc_5	1.153 (0.200, 6.641)	0.618 (0.159, 2.408)
Waterprc_3 vs. Waterprc_5	2.550 (0.493, 13.193)	4.148 (0.913, 18.847)
Waterprc_4 vs. Waterprc_5	1.645 (0.164, 16.499)	1.497 (0.271, 8.281)
Environmental attitudes	4.844 (1.244, 18.858)	2.946 (0.975, 8.901)
Water-saving behaviour	0.094 (0.015, 0.581)	0.418 (0.099, 1.767)
Nagelkerke R ²	0.232	0.074

Significant results were shown in bold font.

^a water price of ₦2 & above was treated as Waterprc_5.

hold a belief or expectation that they are making a significant difference in reducing water consumption. This confirmation bias could influence their perception and lead them to interpret water use in a way that aligns with their preconceived notions.

In summary, while majority of the factors (gender, education level, annual income, family size, environmental attitudes and water-saving behaviour) played a significant role in influencing the perceptions of water use, their influence on virtual water perceptions were largely insignificant. Age and water price had no significant influence on both water use and virtual water perceptions. It is challenging to make an accurate estimation of virtual water. To address the prevalent misunderstandings about virtual water among the public, it is necessary to implement focused educational initiatives at district and school levels. These programs should aim at enhancing public awareness and understanding of virtual water (Attari, 2014; Liu et al., 2022).

4. Discussion

The results of this study provide valuable insights into the socio-demographic characteristics of the respondents, their reaction to water conservation actions, perceptions of water use and virtual water, and the factors influencing these perceptions. In terms of sociodemographic analysis, the majority of respondents were female, and the age distribution was skewed towards younger and older age groups. Most respondents had undergraduate degrees as their highest educational attainment, and the predominant level of income fell within the middle-income group. Occupation-wise, the majority of respondents worked in the tertiary industry, indicating a diverse representation of professions. These sociodemographic factors can potentially influence individuals' knowledge, attitudes, and behaviors related to water use and virtual water (Arbués et al., 2003). The study also explored the respondents' water-saving behaviors and environmental attitudes. The findings

suggest that, on average, respondents exhibited a tendency to engage in water-saving behaviors at a moderate level, indicating some level of awareness and effort to conserve water. However, the adherence to water-saving behaviors was not strong. In terms of environmental attitudes, the respondents showed a relatively strong inclination towards environmental concerns and positive attitudes towards environmental issues. This suggests a higher level of support for environmental protection and sustainable practices among the respondents. However, it is worth noting that the respondents were more pro-environmental than water-saving, indicating potential variations in priorities and motivations when it comes to different aspects of sustainability.

The perception of "Water Conservation Actions" revealed interesting patterns in respondents' recommendations for themselves and others. The majority of respondents recommended curtailment actions for themselves and others, which involve reducing or limiting water usage. In contrast, efficiency actions, which focus on maximizing the efficient use of water, were less commonly recommended. This preference for curtailment actions may be influenced by the perceived costs associated with efficiency actions, such as the purchase of water-saving appliances. These findings align with previous research highlighting the influence of cost considerations on individuals' water conservation recommendations (Attari, 2014).

The study also investigated the actual versus perceived water use and virtual water embedded in various products. The results showed that, on average, the respondents significantly underestimated their actual water use across all five activities examined. This systematic discrepancy suggests a lack of understanding of the relative magnitude of water use among the respondents. Similar findings have been reported in previous studies, indicating a common tendency for water users to underestimate their water consumption (Beal et al., 2013; Liu et al., 2022). These findings highlight the importance of raising awareness and providing accurate information about water use to bridge the perception-reality gap (Dietz, 2014). Regarding the perception of virtual water, the respondents' rankings of virtual water content in different products revealed interesting discrepancies between perceived and actual ranks. The respondents had limited awareness of the water footprint associated with different products, particularly in relation to livestock products. This lack of awareness suggests a need for educational initiatives to enhance public understanding of virtual water and its implications for sustainable consumption.

Based on a comparison of the two-step binary regression models, the predictors better explained variations in water use perception when compared to virtual water perception. The results reveal that family size has a significant influence on both water use and virtual water perceptions. Specifically, individuals from smaller families were less likely to accurately estimate water use and virtual water content compared to those from larger families. Gender, education level, and annual income were significant predictors of water use perception. Females were more likely to have inaccurate perceptions of water use, individuals with a high school education level were less likely to provide accurate estimations of water use compared to those with a graduate education level, and individuals in the middle-income group had a lower likelihood of accurately estimating water use compared to the high-income group. Environmental attitudes significantly influenced both water use and virtual water perceptions, indicating that individuals with stronger environmental attitudes were more likely to accurately perceive water consumption. Water-saving behavior was only a significant predictor of water use perception, suggesting that individuals who engage in more water-saving behaviors were less likely to accurately perceive water use. Majority of the findings are in line with reports from Liu et al. (2022) and Attari (2014). These findings highlight the complex interplay between individual characteristics, attitudes, and behaviors in shaping water use and virtual water perceptions.

4.1. Managerial implications

The findings of this study have several implications for water management in Daegu city:

- i. The study reveals a lack of understanding and awareness among respondents regarding their actual water use and the virtual water content of various products. This highlights the need for educational initiatives to enhance public knowledge about water consumption and its environmental implications. Water management authorities can develop awareness campaigns and educational programs to inform the public about water-saving practices, the water footprint of different products, and the importance of sustainable water management.
- ii. The study identifies specific demographic factors, such as family size, gender, education level, and annual income that influence water use perception. Water management strategies can be tailored to target these specific groups to address their misconceptions and promote accurate perceptions of water use. For example, targeting individuals from smaller families with educational programs that highlight the importance of individual water-saving actions can be effective in reducing overall water consumption.
- iii. The study demonstrates that individuals with stronger environmental attitudes are more likely to accurately perceive water consumption. This suggests that fostering pro-environmental attitudes and values can contribute to more sustainable water management practices. Water management authorities can collaborate with environmental agencies and community groups to promote environmental awareness and values through campaigns, workshops, and public engagement activities.
- iv. The study also indicates that water-saving behavior is associated with lesser perceptions of water use. Therefore, implementing behavior change programs that incorporate systematic and measurable monitoring and assessment are essential for shifting perceptions toward a greater degree of accuracy.
- v. The findings also emphasize the lack of awareness regarding the virtual water content of different products. Water management authorities can collaborate with relevant stakeholders, such as agricultural producers, retailers, to promote product labeling and certification schemes that provide information about the water footprint of products. Clear labeling and certification can enable consumers to make informed choices, encouraging the purchase of water-efficient products. Drawing upon a sufficient understanding of virtual water, the utilization of a virtual water strategy has the potential to serve as a policy tool for conserving local water usage and consequently mitigating water scarcity (Zhao et al., 2015).

4.2. Theoretical contributions

The theoretical contributions of this study encompass insights into the influence of sociodemographic factors, the perception-reality gap in water use, and the significance of pro-environmental attitudes in the realm of sustainability and resource management:

- i. Understanding Sociodemographic Factors: The study illuminates how certain sociodemographic characteristics can significantly shape individuals' perceptions and behaviors related to water use and virtual water. Understanding these influences is crucial in developing targeted interventions and policies. For instance, knowing that respondents were skewed towards younger and older age groups sheds light on generational differences in attitudes and behaviors towards water conservation. In addition, the finding that family size influences perception suggests that household dynamics play a role in shaping how individuals

perceive their water usage. This theoretical insight can help tailor educational campaigns and initiatives that resonate with specific demographic groups, ensuring more effective engagement and impact.

- ii. Perception-Reality Gap in Water Use: Uncovering the perception-reality gap, where individuals consistently underestimate their actual water use, contributes to the theoretical understanding of cognitive biases and perceptual inaccuracies. This aligns with existing research in behavioral economics and psychology, highlighting how individuals may have skewed perceptions of their resource consumption (Leviston and Uren, 2020). This insight is vital for policymakers and communication strategists aiming to design effective awareness campaigns that bridge this gap, correcting misperceptions and encouraging more accurate assessments of personal water use.
- iii. Value of Pro-Environmental Attitudes: Highlighting the value of pro-environmental attitudes in shaping accurate water consumption perceptions aligns with theories of planned behavior and social norms. It underscores the importance of nurturing positive attitudes towards environmental stewardship. Theoretical frameworks like the Theory of Planned Behavior posit that attitudes significantly influence behavioral intentions and actions (Ajzen, 2020). Therefore, fostering pro-environmental attitudes through targeted interventions could lead to more sustainable water usage behaviors.

4.3. Study limitations

There are some limitations to this study that should be acknowledged. Similar to Beal et al. (2013), the data used in this study relied on individual survey respondents rather than aggregating responses from all household members. In other words, the perceived water usage level was determined by considering the average of responses from individual survey participants, rather than using a collective response from all members of a household. However, this limitation was predetermined from the planning stage of the study as it was not within the study scope to ascertain the combined beliefs, attitudes, and perceptions of households. In addition, the study was restricted to only one major city in South Korea. Larger samples covering the whole country would provide a broader view on the research topic and should be considered in further studies.

5. Conclusions

Demand-oriented water management is gaining attention due to factors such as population growth, urbanization, and the resulting strain on water resources. Unlike traditional supply-oriented approaches, demand-oriented strategies focus on understanding and managing water consumption patterns, promoting conservation, efficiency, and behavioral changes. This approach aligns with principles of integrated water resource management and sustainable development, aiming to balance competing demands while considering social, economic, and environmental factors. Effective water demand management should be based on a comprehensive understanding of public perceptions regarding water use. By comprehending how the public perceives water use, water managers can tailor their communication and educational initiatives to address misconceptions, promote awareness, and encourage sustainable water practices. Public perception influences attitudes, beliefs, and willingness to adopt water-saving behaviors, making it essential to engage the public and provide accurate information about the value, scarcity, and environmental implications of water resources. By aligning water management strategies with public perception, policymakers can foster a sense of ownership and collective responsibility, leading to more effective water demand management and the conservation of this vital resource.

This study attempted to shed some light on understanding the

public's knowledge of water use through online and offline surveys, taking Daegu city as a case study. Our findings showed that Daegu indigenes generally underestimated water use and had no knowledge of the virtual water embedded in daily-consumed agricultural products. In combination with existing studies from the United States of America and China, we can conclude that misconception of water use could likely be a common issue at both the national and sub-national levels. The findings also identified specific sociodemographic factors that influence water use and virtual water perceptions, such as family size, gender, education level, annual income, environmental attitudes, and water-saving behaviour; suggesting the importance of targeted interventions tailored to different demographic groups to effectively address their challenges and promote sustainable water management practices.

This analysis of perceptions of water use was conducted at a sub-national level, specifically in Daegu city, to understand the context-specific factors influencing water management and conservation behaviors in an urban context. By focusing on a specific city, the study can capture the unique sociodemographic characteristics and local water management policies that may shape residents' perceptions and behaviors related to water use. While the results of this study are specific to Daegu city, they can still provide valuable insights and lessons for other cities around the world. The findings highlight the necessity for tailored interventions, education, and collaboration among stakeholders in promoting sustainable water management practices. Therefore, other cities can adapt and apply similar strategies, taking into account their own local contexts, to effectively address water conservation challenges and promote responsible water use among their residents.

CRedit authorship contribution statement

Golden Odey conceived and designed the research, analyzed the data, and wrote the paper. **Bashir Adelodun** analyzed the data and wrote the paper. **Seulgi Lee** contributed analysis tools and data sourcing. **Qudus Adeyi** contributed analysis tools and data sourcing. **Kyung Sook Choi** provided funding and analyzed the data.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.envsci.2023.103629](https://doi.org/10.1016/j.envsci.2023.103629).

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