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What roles do smart sensors play in citizens' water use? From the perspective of household water-saving

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ABSTRACT

Rapid population growth has led to increasing demand for water resources. Studies have shown that the application of new technologies can effectively influence and promote citizens to save water. The application of smart water sensors can effectively monitor household water consumption and feedback the recorded data to citizens promptly, thereby influencing family members' water-saving attitudes and behaviours. For the widespread use of future water sensors in households, it can demonstrate its essential role in three aspects: water use information feedback to reduce water consumption, water information measurement helps to cultivate water conservation awareness, and water use information release as an effective means of behavioural intervention. This research provides some suggestions for the promotion and use of smart sensors in the home and points out the future research directions for the impact of water sensing on household water-saving behaviour.

Key words: household water-saving, smart sensors, water-saving attitudes and behaviour, water use information feedback

HIGHLIGHTS

- The popularisation and use of water sensors can effectively promote citizens to save water.
- Water consumption information recorded by smart water sensors can reduce water consumption and help citizens cultivate water-saving awareness, which is an effective means of behavioural intervention.
- Based on the analysis results, two implementation suggestions are put forward.

INTRODUCTION

It is estimated that by 2050, the world's urban population will grow by 54–66% (Gerland *et al.* 2014). The number of people living in areas facing severe water shortages for at least one month of the year can be as high as 5.7 billion (UN 2021). More and more people will significantly increase the demand for regional water, putting more significant pressure on limited available freshwater (McDonald *et al.* 2011a). In addition, climate and land-use changes will further increase the number of people facing water shortages (McDonald *et al.* 2011b). In this case, building infrastructure to expand the water supply may help to avoid water stress in some cases (Cominola *et al.* 2015). With the continuous advancement of technology, the rapid development of sensors and information and communication technology, social network data analysis and data mining technologies have revealed the new potential for more effective planning (Laspidou 2014; Laspidou *et al.* 2015; Yang *et al.* 2017). The application of these technologies can monitor and inform citizens of the water use status. Realising water-saving by establishing consumer awareness (related projects are grouped under the ICT4WATER cluster – http://ict4water.eu) to influence their behavioural decisions is another way to solve the problem of water scarcity. There are ample evidence that various 'smart' feedback methods are effective in curbing energy use, and the reduction in energy consumption is proven by providing 5% to 20% of real-time energy use data (Gans *et al.* 2013; Houde *et al.* 2013; Vine *et al.* 2013).

The main research purpose of this paper is to study how the real-time feedback data from smart sensors affects household water-saving behaviour, and the main research object is citizens, which is one of the 'new' viewpoints. Most current research is how to realise real-time monitoring, transmission, and control in the water supply system by sensors and controllers. The research on how the installation of sensors affects household water-saving behaviour is not systematic enough. This paper discusses the possible impact of smart sensors on household water-saving from the three dimensions of water feedback, water-saving awareness training, and behavioural intervention. With the rapid increase in the global population and the expansion of water consumption, the proportion of household water consumption is increasing. Exploring the installation of smart sensors in the water system to obtain real-time data to influence the behaviour of water users is another effective way to realise the sustainable development of water resources.

RESEARCH STATUS OF HOME SMART WATER SENSORS

This frontier area of water end-use or water composition analysis has attracted research attention (Nguyen *et al.* 2013a). Scholars have also paid attention to sensor systems' use to monitor household water demand and behaviour changes in daily life (Booysen *et al.* 2019). The combination of sensor technology and the 'data' they generate with advanced machine learning techniques provides many opportunities to enhance outdated methods covering various water management areas (Schimak *et al.* 2010; Usländer *et al.* 2010). The report's research showed that this kind of technology increasingly affects the end-use of citizens in daily life (O'Halloran *et al.* 2012; Nguyen *et al.* 2013a; Di Mauro *et al.* 2019), the final water consumption (Nguyen *et al.* 2013b; Alvisi *et al.* 2019), and changes in water-saving attitudes and behaviour (Fielding *et al.* 2013; Ripunda & Booysen 2019). Many water utilities increasingly attempt to influence consumers' behaviour towards improving water consumption by using communication tools to give information back to users and display their consumption or customised feedback or water-saving tips (Kofinas *et al.* 2018).

Monitoring the quality and amount of water used by citizens is crucial, as it is related to citizens' drinking water safety and water use efficiency. Monitoring is defined as being in a set location and regular mobile phone information to provide data that can be used to define the current situation, determine trends, etc. (Chapman 1996). Traditional monitoring methods are relatively time-consuming, and the accuracy of data monitoring needs to be improved, requiring more extensive and effective monitoring methods (Cloete *et al.* 2016). The emergence of smart sensors has dramatically improved the status of water monitoring. All the data they monitor are processed and analysed intelligently and transmitted to observable devices via wireless networks so that water users can accurately obtain corresponding readings. To use many low-cost sensors that can be inexpensively deployed throughout a home (Apoorva *et al.* 2018), a simple sensor is highly relevant to an actual motion recognition system. It has the advantage of being less invasive of privacy than a visual (or thermal imaging system) imaging system, allowing it to monitor bathroom activities (Chen *et al.* 2018; Susnea *et al.* 2019).

Terms such as 'smart water network', 'smart water supply system', 'smart water system', or 'smart water network' have been widely spread (Li *et al.* 2020). Using smart components such as sensors, controllers and data centres into the water use system can realise real-time monitoring, transmission, and control of water for decision-makers, a more cost-effective and sustainable solution (Sonaje & Joshi 2015). For example, smart meters provide essential information for constructing individual consumer behaviour models (Laniak *et al.* 2013; Hilty *et al.* 2014; Cominola *et al.* 2019). Some current research cases have introduced sensors to household smart water systems to monitor water consumption and detect water leakage in water pipes to solve and manage water use problems appropriately, as shown in Table 1. A significant gap in the current literature is the relative lack of different dimensions to explore smart sensors' impact on implementing water-saving behaviours of citizens in water use and failure to form a research system. Nevertheless, it also explained the role of smart sensors in one aspect, showing its impact on citizens' water behaviour. There is a lack of research on smart sensors influencing behavioural decision-making paths and architecture. This article analyses the current application status of existing sensors, determines the application prospects of smart sensors, and establishes a more systematic research framework for smart sensors' impact on citizens' water-saving behaviours to inspire future research in their implementation.

PROMOTING THE USE OF HOME SMART WATER SENSORS

This study believes that the effective combination of smart sensors and water-saving behaviours should be based on smart sensors' ability to collect data. The analysis framework should be constructed from three aspects: water feedback, water-saving awareness, and behavioural interventions. It mainly shows how the installation of home sensors can achieve the impact of household water-saving and puts forward suggestions for future research directions on smart sensors. The specific research framework is shown in Figure 1.

Table 1 | Workflow and effect of some smart water systems

Application types of smart sensors	Effect	References
Intelligent measurement and network for real-time information sharing and integration with sustainable water distribution infrastructure	The data fed back by the sensor is transmitted to the data management layer and the display layer through the network, and the water consumption information is recorded. Detect leaks and provide the basis for behavioural decision-making based on the results of data analysis	Kartakis *et al.* (2015), Li *et al.* (2020)
A combination of the water meter and data logger technology is used to capture information about water consumption	The main purpose is to record water consumption, feed it back to customers, understand household water consumption patterns, and promote water use behaviour changes through actual water use information	Boyle *et al.* (2013), Günther *et al.* (2015)
WaterWiSe is an intelligent water system platform that provides integrated measurement and analysis to improve system management and operation	The main purpose is to find water leaks and reduce repair and maintenance time	Allen *et al.* (2011)
Smart sensors and blockchain water-saving technology are incorporated into household water-saving	By calculating blockchain technology and the recording of smart sensors, reasonable rewards and punishments can be provided to promote household water conservation	Thakur *et al.* (2021), Yang *et al.* (2019)
Intelligent water system combining IoT & cloud computing with information & communication technology	Quickly locate the leak location based on the difference between the actual water consumption and the total consumption; through data feedback, the cloud control and management application will update the water control plan	Yasin *et al.* (2021); Alshattnawi (2017)

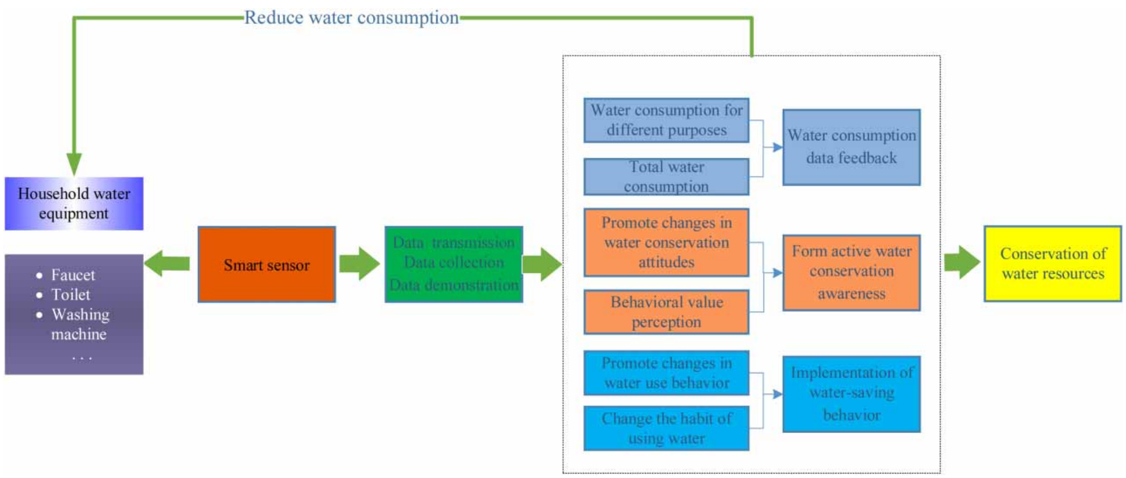

Figure 1 | The research framework of the impact of sensor uses on water-saving behaviour of citizens.

Water use of information feedback can reduce water consumption

A study of final water consumption helps water planners and consumers determine where and when households use water, thereby reducing water consumption (Loh & Coghlan 2003; Stewart *et al.* 2010; Makki *et al.* 2013). Therefore, it is very important to promote the widespread use of household sensors and install sensors in key locations for household water use (such as sinks, toilets, showers, and water appliances). When water starts to flow through the sensor, the sensor starts to measure the amount of water used and transmits the detected data to integrated systems such as the billing system, consumption system, and smart water system. Finally, the relevant information is displayed on the user's platform (e.g., laptop, smartphone, or tablet), the real-time water consumption information is reflected, and the corresponding water fee. Simultaneously, when the data reach the prescribed water consumption limit, an over-use alert is sent to household users via phone or e-mail (Soh *et al.* 2018; Pérez-Padillo *et al.* 2020). The feedback of information enables water users to make wise choices based on their drinking habits and participate in water management activities (Li *et al.* 2020) and can also help them save water and reduce some water bills (Sønderlund *et al.* 2016).

Water information measurement can help citizens cultivate water conservation awareness

The lack of awareness of citizens will seriously hinder water-saving work (Kotze 2018), and when individuals hold positive behaviours and the external environment presents favourable conditions, the attitude of users can be modified more effectively to support water-saving behaviour (Guagnano *et al.* 1995). In particular, smart meters themselves are technologies that promote behaviour change and water-saving attitudes through tailored feedback (Fielding *et al.* 2013). Although citizens are increasingly aware of the need to save water, many studies have shown that family members' awareness of water use is not consistent with actual behaviour (Millock & Nauges 2010; Beal *et al.* 2013), and their awareness of water saving is not healthy enough to drive water users to implement water-saving behaviours effectively. More importantly, citizens' perceptions of water use attitudes come from self-reports, which do not incorporate actual water consumption. The provision of water consumption measurement data can reflect the end-use of household water, to change citizens' attitudes towards water conservation (Stewart *et al.* 2010). Therefore, water information measurement based on smart water sensors can provide water users with water flow data for different purposes and improve their understanding of domestic water use. Only when water users genuinely appreciate the information fed back from actual data can they better cultivate their water-saving awareness, thereby changing their water consumption attitudes and perceptions from self-reports and promoting the efficient implementation of water-saving behaviours.

Water use information release is a practical implementation of behavioural intervention

A behavioural intervention can effectively stimulate water-saving behaviours (Koop *et al.* 2019), and data feedback from smart water meters is an effective behavioural intervention (Visser *et al.* 2021). We need to explore further what role the use of sensor technology plays in the change or evolution of water use behaviour. One study believes that if technological innovations are put into use better than existing technologies, the behaviour of water users will change rapidly (Ripunda & Booysen 2019). The main implementation path is to monitor each household user's water consumption in real time based on the installed smart water meter and publish the historical weekly or monthly data simply and intuitively (such as bar graphs, line graphs, etc.) through posters or information platforms. By displaying the before and after differences in household water consumption and regularly carrying out specific water-saving publicity in the community, we can intervene in the water use behaviour of every water user, arouse the public's awareness of water conservation, and achieve the purpose of saving water and strengthening water resources protection. This purpose is also consistent with the purpose of World Water Day.

RECOMMENDATIONS

The entry of smart water sensors into the home is a challenge for intelligent water detection. At present, some studies only install smart sensors in some public areas such as schools (Ripunda & Booysen 2019; Visser *et al.* 2021). Most of them only use smart water meters to measure total water consumption (Cardell-Oliver *et al.* 2016), and the recorded data are relatively simple. Therefore, based on the above discussion, the following suggestions are put forward, as far as possible, to use the smart water sensors to measure the water consumption and the water flow for different purposes to the greatest extent.

To ensure the privacy of family members and not affect the family's appearance, multiple miniature smart sensors are installed on the primary water nodes of the family. An integrated system is established based on a microsensor network. It is connected with a billing system and a metering system using a common platform, transmitting information such as total water consumption, water consumption for different purposes, and real-time water charges to family members, gradually influencing the water consumption habits and behaviours of family members through the feedback information.

The water sector or the water supply company can establish a comprehensive platform to centrally release water consumption information, which mainly includes the total water consumption of the community in a fixed period, the total water supply of the water supply company, the sewage discharge volume, etc. However, considering personal or household data confidentiality, the platform can set up independent household accounts, requiring family members to access household water data through specific accounts and passwords. The water sector or the water supply company needs to obtain the type of information most suitable for their needs from the water users (such as water consumption for different purposes, peak consumption, comparative analysis results, and information that can intervene in the water use behaviour of household members). Based on this information, a tailor-made report can be created and uploaded to a separate account or sent directly to water users by e-mail or information push. At the same time, the water sector or the water supply company can also promote water-saving-related information on the platform, transfer water-saving knowledge, arouse the awareness of water-saving of every family member, and implement correct water-saving behaviours.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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