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Understanding household water-use behaviour in the city of Johannesburg, South Africa

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ABSTRACT

Climate change, population growth and industrial activities continue to threaten water security, especially in the semi-arid regions. Demand management policies are essential in minimising the effects of acute water shortages. Such policies require information on household water consumption patterns and their behavioural practices. This study examines household water consumption behaviour and the adoption of water-efficient appliances in Johannesburg, South Africa. The study uses probit regression models to analyse survey data collected from 889 households during the period November 2017 to February 2018. Results show that while most households do not have water-efficient appliances installed in their homes, they do practise water-efficient behaviour. Older respondents as well as males and lower-income respondents are found to be more likely to practise efficient water-use behaviour. However, biographical variables do not generally influence the adoption of water-efficient appliances. These results are essential for policy-makers when formulating targeted water demand management policies. Thus, policy-makers should focus more on younger people, women and higher-income households when developing campaigns on efficient water-use behaviour.

Key words: Water-efficient appliances, Water policy, Water-use behaviour

HIGHLIGHTS

- Households generally do not have water-efficient appliances installed in their homes.
- Households practise efficient water consumption behaviour.
- Biographical characteristics determine water consumption behaviour.
- Biographic characteristics do not determine the adoption of water-efficient appliances.
- Results inform water demand management policies in South Africa, a water-scarce country.

INTRODUCTION

Water scarcity is one of the most pressing problems across the world. Authorities are commonly faced with the challenge of ensuring that sufficient water resources are available to meet the ever-increasing water demand. Factors like population growth, expansion of business activity and urban development continue to increase the demand for freshwater resources. On the other hand, the supply of water resources is adversely affected by climate change, droughts and pollution. Water scarcity is severe in semi-arid regions, where it becomes even more complex to secure water supplies, especially in the urban areas due to high populations and industrial activities (Fielding *et al.*, 2012; Priyan, 2021).

Households are among the largest consumers of water resources. Therefore, water demand management policies that target reductions in household water consumption are likely to yield positive results. Currently, there is no consensus in the literature in terms of the most effective ways to manage household water demand (Matikinca *et al*., 2020). However, some studies agree that determining household water-use behaviour essentially facilitates a more proactive approach towards water demand management. This exercise would then serve as a foundation for effective interventions and strategies that can bring about substantial and sustained reductions in household water consumption (Jorgensen *et al*., 2009; Shan *et al*., 2015).

In most cases, 'save-water campaigns' are used as tools to promote household water conservation. The literature provides evidence that properly implementing 'save-water campaigns' can bring about positive results. In the city of Cape Town, Booysen *et al*. (2019) found that save-water campaigns reduced household water consumption from 540 to 280 litres/household/day over a period of 36 months. While the reduction noted for Cape Town could also have been due to a severe drought that forced households to conserve water, it should be acknowledged that the targeted campaigns implemented in the city played a huge role. Sustaining reductions in water consumption requires complementary measures which reinforce the behavioural alterations. Developing such measures and implementing targeted water conservation campaigns require authorities to understand the patterns and socio-demographic determinants of household water consumption behaviour.

This study examines household water consumption behaviour and the extent to which households have adopted water-efficient appliances in Johannesburg, South Africa. The study also examines how biographic variables affect water consumption behaviour and the adoption of water-efficient appliances. Analysing water consumption behaviour and the adoption of water-efficient appliances enables policy-makers to implement target initiatives that reduce household water use. There is an increasing need for comprehensive and frequent residential water consumption end-use studies. This is because information on how and where water is used by households is critical for water utility planners (Viljoen, 2015).

Unlike the wet regions of the globe that receive over 1,500 mm of annual rainfall, South Africa is a water-scarce country receiving an average of approximately between 450 and 465 mm of annual rainfall, almost half the world average (Thwala & Edoun, 2018; Ngobeni & Breitenbach, 2021). While the country is naturally water scarce, the constant prevalence of droughts has worsened water security in South Africa. Therefore, all consumers of water resources should adopt effective strategies that reduce water demand. Several studies on household water demand management have been conducted in Cape Town (Viljoen, 2015; Sorensen, 2017; Booysen *et al*., 2019; Matikinca *et al*., 2020). This is mainly because the city recently faced a daring 'Day Zero' where it was expected to run dry. Accordingly, concerted efforts from the academia and other scientific fields were made, emphasising the extent of water scarcity in the city.

Nevertheless, there has not been much research on the same phenomenon in Johannesburg. This is despite the city being the biggest metropolitan in South Africa with about 5.5 million people and it being the economic hub of the country. Johannesburg has historic water challenges due to its location which is at a very high altitude of 1,800 m, away from the largest body of water sources. The high altitude entails that water is pumped more than 300 m higher from the Vaal Dam, the main source of water for the city. Pumping water at that height is an extreme energy-intensive exercise and is hugely affected by the constant electricity shortages in the country. Overall, there are water challenges in Johannesburg and authorities usually adopt water restrictions to manage demand. Efforts to reduce household water demand can improve the city's water security.

HOUSEHOLD WATER CONSERVATION

Household water conservation continues to receive prominence in the literature. This attention dates as far back as the 1980s when Shaw & Maidment (1988) presented the effects of water conservation on daily water use. In modern day, household water conservation is prioritised due to climate change, population growth and industrialisation. The literature contains studies that investigate household water consumption patterns, as a measure to provide evidence on how households relate to water resources (Sing & Turkiya, 2013; Viljoen, 2015; Chen *et al.*, 2019; Virk *et al.*, 2020). On the other hand, several other studies in the literature examine the determinants of household water consumption (Fielding *et al.*, 2012; Newton & Meyer, 2013; Fan *et al.*, 2017; Russell & Knoeri, 2020; Oh *et al.*, 2021). Equally, the role of attitudes, perceptions and water-efficient appliances also continues to receive attention in the literature (Sonnenberg *et al.*, 2011; Willis *et al.*, 2011; Carragher *et al.*, 2012; Dascher *et al.*, 2014; Abu-Bakar *et al.*, 2021). While all these studies focus on understanding households and their role in water conservation, the literature also provides evidence of how water authorities can manage household water consumption (Thwala & Edoun, 2018; Booysen *et al.*, 2019; Matikinca *et al.*, 2020).

An understanding of household water consumption patterns is essential for developing water-related policies, especially when developing policies that aim to manage water demand by reducing household water consumption. For this reason, household water consumption patterns continue to receive attention in the literature, across the world. This attention is observed more in studies conducted in the context of semi-arid regions. Sing & Turkiya (2013) explored the pattern of domestic water consumption in a semi-arid Indian village, while Viljoen (2015) as well as Meyer *et al.* (2021) analysed household water consumption patterns in South Africa. Other recent studies include Chen *et al.* (2019) which examined water reliability, time spent on water collection and total water consumption among urban households in Nepal, as well as Virk *et al.* (2020) which analysed the status of water availability, consumption and sufficiency in Pakistan. When household water consumption patterns are understood at the local level, policy-makers and managers may be able to develop better initiatives which reduce water consumption. Thus, an understanding of consumption patterns gives policy-makers and managers a new tool to assess planning and environmental policies.

Additionally, water policy-makers require information on the key determinants of household water consumption behaviour. While such determinants tend to vary from place to place, there is a general trend of similar factors affecting household water consumption behaviour across semi-arid regions. Shan *et al.* (2015) report that socio-demographic factors, property characteristics and psychosocial constructs affected household water consumption behaviour in Greece and Poland. The same impact is also found by Fan *et al.* (2017) in Chinese cities. Similar results were reported by Fielding *et al.* (2012) and Newton & Meyer (2013) in studies conducted in Australia. While water demand is generally price inelastic, the literature provides that it is relatively less inelastic for upper socio-economic groups that can afford investing in water-efficient technologies and reduce the quantities consumed. More evidence on the determinants of household water consumption is presented in many other studies in the literature (Wa'el *et al.*, 2016; Russell & Knoeri, 2020; Adil *et al.*, 2021; Oh *et al.*, 2021).

Equally, it is important for water authorities to understand consumer attitudes and perceptions towards water conservation. The literature provides that household water consumption behaviour depends hugely on inter-personal and institutional trust. The former refers to a situation where people save water when they believe that others are also saving water, while the latter is when people save water because they trust the water authority (Jorgensen *et al.*, 2009). Dascher *et al.* (2014) use data from 273 households in Texas and found that household perception is a key issue in water conservation and recommended policy-makers to focus on educational campaigns as part of their water demand management.

If properly implemented, water demand management policies targeting household water consumption can yield favourable results. Booysen *et al.* (2019) found that households in Cape Town reduced average daily water use by about 260 litres/household within 36 months, following official announcements and public engagement with news through social media. Nudging households to save water is reported to be an effective strategy to promote water conservation behaviour (Matikinca *et al.*, 2020). The consensus is that behavioural messages significantly affect water conservation, thus nudging behavioural interventions is an effective mechanism. Many other mechanisms on reducing household water consumption by targeting their behaviour are documented in the literature (Kanakoudis, 2002; Mini *et al.*, 2015; Sorensen, 2017; Thwala & Edoun, 2018). In a study that randomly selected participants, Maduku (2021) reported that conservation campaigns affect consumer's planned and habitual water conservation behaviour, implying that social marketing communications are effective towards water conservation in emerging economies.

Koop *et al.* (2019) suggested that when knowledge transfer is combined with price incentives and water-use restrictions, it can reduce water use by about 10–25%, especially during periods of water scarcity. Other studies suggest even higher water reductions. For example, Bernedo *et al.* (2014) conducted a survey on over 100,000 households during a drought and found that a one-time message that combined technical information, moral suasion and social comparisons reduced consumption by almost 50% after 1 year, and the impact remained observable 6 years later. Thus, targeting household behavioural change is effective but should be tallied with authorities providing water-saving tips (Addo *et al.*, 2019). While larger water reductions are reported in several other studies, Landon *et al.* (2018) conducted an experiment on 5,565 households in Texas, United States and found that normative messages to households reduced water consumption by about 3%. Overall, these and many other studies in the literature emphasise the gains of household water conservation.

Household water conservation behavioural practices can yield even better results if combined with the adoption of water-efficient appliances. Carragher *et al.* (2012) show that the adoption of water-efficient appliances significantly reduced average daily peak hour water consumption in Australia. Similar findings are reported by Willis *et al.* (2013) in a study that provides evidence on the potential savings derived from efficient appliances in Australia. More benefits of adopting water-efficient appliances are documented in Marinoski *et al.* (2018), Fan *et al.* (2019) as well as Abu-Bakar *et al.* (2021). It should be emphasised that if not coupled with green water consumption behaviour, installing water-efficient appliances will not result in the desired water consumption reductions. The literature suggests that people tend to use more water, for example, by taking very long showers after they install an efficient showerhead. Such behaviour offsets the positive contributions of the efficient showerhead. Therefore, promoting household water consumption behaviour and the use of water-efficient appliances is important, especially in a water-scarce country like South Africa.

STUDY SITE

This study was conducted in Johannesburg, the biggest metropolitan in South Africa in terms of population size. Johannesburg is home to about 5.5 million people and is the economic and financial hub of South Africa. In 2018, about 10% of the country's population resided in the city, and 40% of this population was aged between 24 and 44 years (City of Johannesburg, 2020). Between 2008 and 2018, the city's population grew at a yearly average of about 2.9%, almost double the country's average annual population growth of about 1.6% during the same period. Johannesburg has around 1,850,000 households with an average household size of 3. The number of households in the city is growing at an even faster rate than that of the population (City of Johannesburg, 2020). The rapid population growth is due to urbanisation which is a result of the better economic opportunities offered by the city, compared to the other parts of the country. While rapid population growth has its own advantages, for example, a greater market for commodities and more labourers, it comes with many challenges. In many developing countries, rapid population growth can put a strain on service infrastructure, needs and the provision of basic services like water.

Likewise, rapid population coupled with both industrialisation and climate change have resulted in water challenges in Johannesburg. Water services in the city are provided by Johannesburg Water, a company wholly owned by the City of Johannesburg Municipality. Incorporated in November 2000, Johannesburg Water is the sole provider of water within the city, thus making it a natural monopoly. Daily, it supplies about 1,553 ML of potable drinking water, through a water distribution network of 12,069 km, 127 reservoirs and water towers, and 37 water pump stations. The city is divided into seven regions which receive water from Johannesburg Water, as shown in the map of Johannesburg presented in Figure 1.

While all the regions indicated in Figure 1 receive water of the same quality, it is important to note that access to water services varies according to the economic status of each residential area. Like any other South African city, Johannesburg is spatially divided into suburbs, townships and informal settlements, which is also common in many African cities and cities in the developing world. In most cases, households in the suburbs receive better water service packages compared to some households in townships and those in informal settlements. In 2018, about 1,292,571 households in the city accessed piped water inside the dwelling, with 52,365 households accessing water inside the yard, while 118,893 households accessed water from a public tap located within 200 m from their dwelling (City of Johannesburg, 2019). In most cases, households that access water from a public tap are those who reside in informal settlements and some few townships.

Generally, the average water consumption in South Africa is 237 litres/person/day (l/c/d), which is higher than the world average of about 173 l/c/d (Ngobeni & Breitenbach, 2021). In a report prepared for the Water Research Commission, du Plessis *et al.* (2020) breaks down the estimated water consumption according to the level of service and the number of persons per household. Thus, a family of four utilising a full house connection with

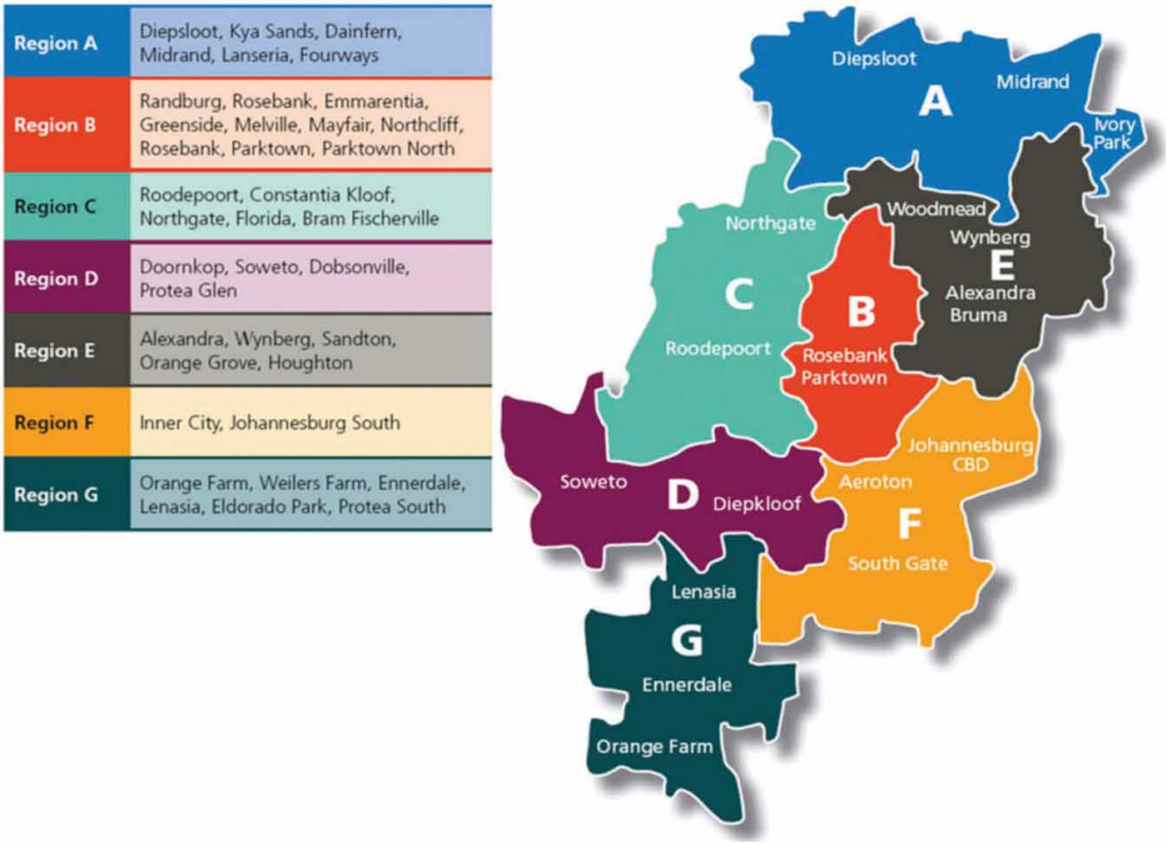

Fig. 1 | Map of Johannesburg showing the seven regions of the city. *Source*: Chirisa & Matamanda (2019).

outdoor water use consumes about 221 l/c/d. Households that mostly fit this category are those in the suburbs where outdoor water use includes gardening and swimming pools. In townships, most households only use water for indoor activities. According to du Plessis *et al.* (2020), a family of four utilising a full house connection without outdoor water use consumes 143 l/c/d, while a family of four with a simple yard connection consumes about 46 l/c/d. However, for households in informal settlements, peri-urban areas and rural areas who mostly access water services through standpipes, consumption is about 22 l/c/d, regardless of the household size (du Plessis *et al.*, 2020). Thus, consumption for such households is below the minimum volume of 25 l/c/d recommended by the government through the free basic water policy of 2001.

Like other South African cities, Johannesburg constantly experiences water challenges and frequently imposes water consumption restrictions. Water challenges experienced in the city are very much linked to South Africa being a water-scarce country, climate change which exposes the country to constant droughts, industrialisation, population growth and human activities like pollution which affect water quality. Equally, energy challenges have drastically affected water provision in the recent past. The electricity–water nexus has seen load-shedding interrupting water supply, especially in areas where water needs to be pumped into supply towers or directly into the network. While all these challenges affect water provision in Johannesburg, the main challenge for the city is that it is located at a high altitude of 1,800 m, away from the largest body of water source. Historically, cities were traditionally built closer to large sources of water. However, Johannesburg came into existence because of the rich deposits of gold that were found on the Highveld. Thus, it is expensive and an engineering nightmare to get water to Johannesburg. Water needs to be pumped more than 300 m higher to get it to Johannesburg from the Vaal Dam, the main source of water for the city. This is an extreme energy-intensive exercise which is also affected by the constant electricity shortages in the country.

METHODOLOGY AND EMPIRICAL MODEL SPECIFICATION

The survey data collected in the study are analysed in two parts. First, descriptive statistics are used to show how well households in the sample adopted water-efficient appliances and the extent to which they practise efficient water-use behaviours. Descriptive statistics are credited in the literature for assisting researchers to organise their data in a reasonable and readable manner, thus making it easy to identify patterns in the data. In this context, the study uses descriptive statistics to summarise the distribution of key observations from the survey data. While descriptive statistics may be considered to have little science, they are important in this context because they give clear patterns and frequencies of the examined water consumption behavioural practices as well as the adoption of water-efficient appliances.

Secondly, the study scientifically examines the relationship between the observed responses on water-use behavioural practices and biographical variables, as well as the observed responses on the adoption of water-efficient appliances and biographical variables. This is done to establish the impact of selected biographical characteristics on water-use behavioural practices and, separately, on the adoption of efficient water appliances. Such information is essential when formulating water demand management policies that aim to reduce household water consumption. To do this, the study uses probit regression models.

Probit models assume that the probability of a positive outcome is determined by the standard normal cumulative distribution function. The origin of probit analysis can be traced to the work of Bliss (1934) which was in connection with bioassay. Probit fits maximum likelihood models with dichotomous dependent variables coded as 0 or 1. The basic mathematical formulation of a probit model is as follows:

$$\Pr(y_i \neq 0 | x_j = \Phi(x_j \beta)) \quad (1)$$

where Pr is the probability of the dependent variable; y_i is the dependent variable which in the context of this study is the dummy for efficient water consumption behavioural practices of the surveyed respondents; x_j is the explanatory variable which in the context of this study entails the selected biographical characteristics of the respondents; Φ is the standard cumulative normal and β is the coefficient of each biographical characteristics of the respondents.

In this study, behavioural responses were coded in a 4-point Likert scale, ranging from 'never', 'once in a while', 'always' to 'not applicable'. If respondents indicated 'never', it meant they practised efficient water-use behaviour. Therefore, the study converts these responses into binary so that they can fit a probit model. A dummy binary variable is deduced by coding 1 all responses for 'never', and 0 otherwise. The created dummy variable is then regressed against selected biographical variables. This procedure is done for all the 11 behavioural questions asked to respondents; thus, 11 models are estimated. Thus, the following probit model is estimated for each water consumption behavioural practice:

$$y_i = \alpha + \beta_1 \mathrm{HHS}_i + \beta_2 \mathrm{GENDER}_i + \beta_3 \mathrm{RACE}_i + \beta_4 \mathrm{STATUS}_i + \beta_5 \mathrm{EDU}_i + \beta_6 \mathrm{AGE}_i + \beta_7 \mathrm{INCOME}_i + \varepsilon_i \quad (2)$$

where HHS_i is the household size for respondent i; GENDER_i is the gender for respondent i; RACE_i is the racial group of respondent i; STATUS_i is the marital status of respondent i; EDU_i is the level of education for respondent i; AGE_i is the age of respondent i; INCOME_i is the average monthly household income for respondent i; α is the constant; β_1–β_7 are the coefficients of the selected biographic variables and ε_i is the standard error. The socio-biographic variables used as explanatory variables in this study have also been used in other similar studies (Jorgensen *et al.*, 2009; Fielding *et al.*, 2012; Fan *et al.*, 2017; Shan *et al.*, 2015).

It is acknowledged that variables such as the type of access to water supply (i.e., whether a household accesses water inside the dwelling, in the yard or from a community tap), and the mode of charging for water services may be important variables in similar estimations. However, in the context of this study, all surveyed respondents accessed water services from a tap inside the dwelling; thus, there is no variability and modelling access type would not have been necessary. Furthermore, water services for all surveyed respondents were charged using the increasing block tariff (IBT) structure, where the property value is used to establish indigent households that may receive free basic water services. The income levels of respondents may be used as a reasonable proxy for respondents that received free basic water services and those that paid for water services. Since all respondents paid for water services using the IBT, which is the common water pricing structure across South African municipalities, it was considered not necessary to include the mode of charging as a variable in the estimated models.

The same procedure taken for household water consumption behavioural practices is also used for the adoption of water-efficient appliances. In terms of the latter, responses on the ownership of water-efficient appliances were coded in a 4-point Likert scale which ranged from 'yes', 'no', 'not applicable' to 'not sure'. Thus, a dummy variable was created where 1 was allocated to a 'No' response, and 0 otherwise. The dummy binary variable was then regressed against the same biographical variables mentioned in Equation (2) using probit regression models. Six models were separately estimated, each for the responses obtained on the ownership of each water-efficient appliance. This was done with the aim to elicit the relationship between the biographical characteristics of respondents and the non-ownership of water-efficient appliances.

DATA AND DESCRIPTIVE STATISTICS

The study is based on data collected from 889 heads of households in Johannesburg during the period November 2017 to February 2018. Survey instruments were prepared in English, and enumerators conversant in both

English and local languages were trained to collect data. The questionnaire had three sections. The first section presented a choice experiment, while the second section asked for daily water-use behavioural practices and the adoption of water-efficient appliances. The third section asked for biographical information. This study reports only on the data collected in the second and third sections of the questionnaire. Due to budget constraints, surveys were conducted in selected residential areas, namely Soweto, Ennerdale, Lenasia, Midrand, Randburg, Roodepoort and Sandton. These areas represent both suburbs and townships, capturing the spatial dynamics and all regions of the city. The convenient sampling technique was used to select respondents in each residential area. This technique was necessary because it is usually very difficult accessing respondents, especially in affluent areas. Since we had initially stratified our survey areas into suburbs and townships, there was minimum bias even after using a convenient sampling technique. The descriptive statistics for the biographic data of the sample are given in Table 1.

The average household size of the sample was four, while the average age was 43 years. These two statistics are much closer to the actual demographic statistics of the city presented. Male respondents were more than female respondents with respective proportions of 55 and 45%. The racial distribution of the sample shows that most of the respondents were Blacks (84%) followed by Whites (9%), then Indians (5%) and Coloureds (2%). These statistics are also consistent with the city's racial distribution, as well as that of the country. Most respondents in the sample were married (53%), while 44% were single and 3% indicated other marital statuses. In terms of education, most of the respondents completed high school (67%), while 15% had post-high school certificates and 11% had diplomas. Finally, a larger number of the respondents earned between R5,000 and R10,000 per month (44%), while 38% earned less than R5,000 per month and a very tiny fraction earned above R20,000

Table 1 | Descriptive statistics ($N = 889$).

		Mean/frequency
Household size		4
Age		43
Gender (%)	Male	55
	Female	45
Race (%)	Black	84
	White	9
	Indian/Asian	5
	Coloured	2
Marital status (%)	Single	44
	Married	53
	Others	3
Education level (%)	Primary school	2
	High school	67
	Post school certificate	15
	Diploma	11
	Postgraduate	3
Monthly income (%)	<R5,000	38
	R5,000–R10,000	44
	R10,000–R20,000	17
	R20,000–R40,000	1

per month. These biographical statistics show a diverse sample which represents the different groups of residents. As such, empirical results from the study will be deemed more inclusive.

To understand the use of water-efficient appliances, respondents were asked seven questions where they were expected to indicate whether they currently installed specified water-efficient appliances. More specifically, respondents were asked to indicate whether they currently have water collection tanks, cistern displacement devices, water-flow regulators, efficient showerheads, efficient toilet cisterns, dishwashers and efficient garden devices. These questions contained 4-point Likert scale responses ranging from 'yes', 'no', 'not applicable' to 'not sure'. The frequency distribution of the responses is given in Figure 2.

The modal response for all seven questions was 'no', indicating that most households in the sample did not have the mentioned water-efficient appliances installed in their homes. Although this revelation is alarming, it is real considering that most households in the sample belonged to the low- to middle-income households. This is also in line with the Living Standards Measure (LSM) index for Johannesburg which is predominantly 1–5, thus low- to middle-income households. The revelation that households did not use water-efficient appliances confirms findings from Sonnenberg *et al.* (2011) in a study conducted on households from Pretoria.

While income can easily be given as a convenient excuse for not installing water-efficient appliances, it is important to emphasise that some of the efficient appliances mentioned in this study are not expensive both to purchase and install. As such, respondents were asked to indicate the most likely reason from a given list of possible reasons. Though several reasons may be noted, respondents were asked to choose between 'I cannot afford', 'I did not know about them', 'I have no infrastructure to connect them', 'They are not important to me' and 'Others'. Figure 3 presents the frequency distribution of responses from the participants.

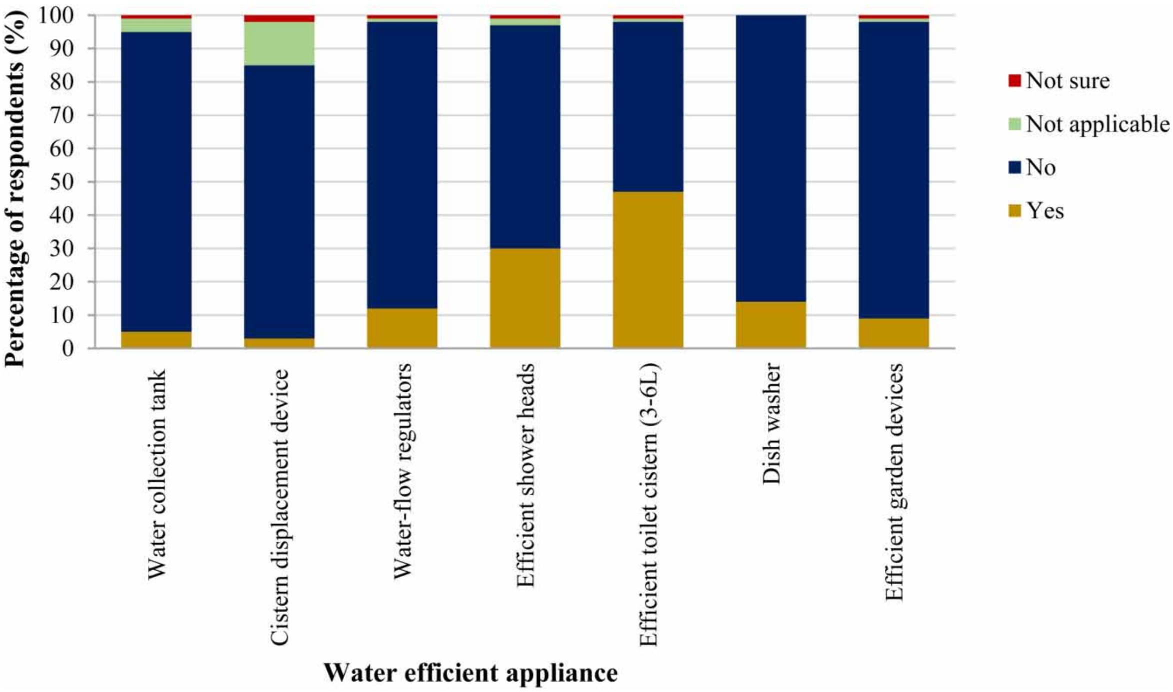

Fig. 2 | Frequency distribution of responses to having water-efficient appliances ($N = 889$).

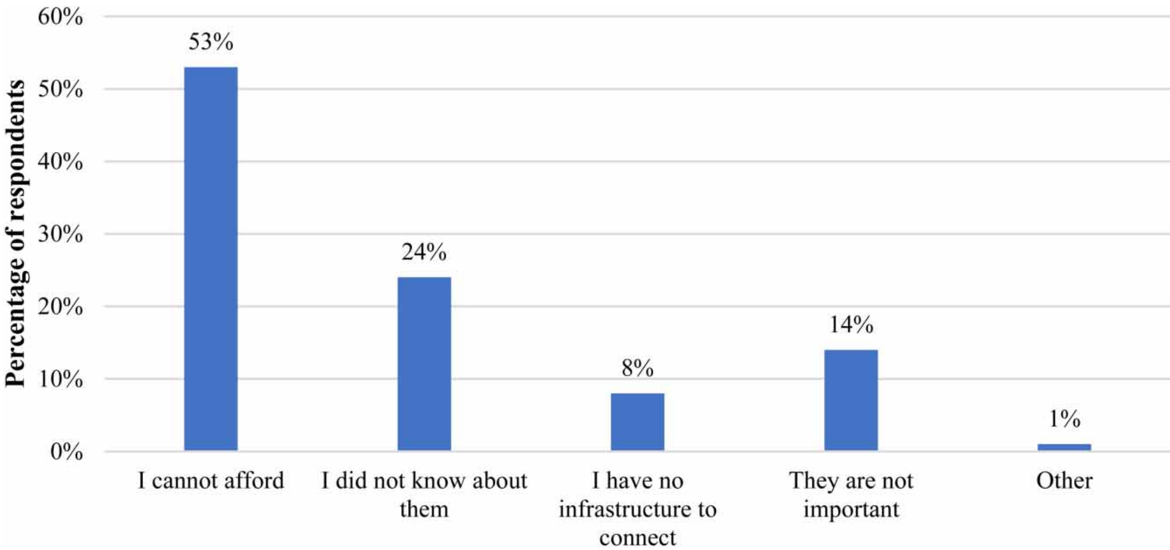

Fig. 3 | Reasons for not installing water-saving appliances ($N = 889$).

As expected *a priori*, the main reason for most of the respondents (53%) not installing water-efficient appliances is because they cannot afford the appliances. This can be a reasonable finding which is consistent with the income characteristics of the sample and the LSM index of the city which reflects predominantly low- to middle-income households. Interestingly, 24% of the respondents indicated that they did not know about the water-efficient appliances. Under normal circumstances, this is expected since water is generally a low-involvement product where people do not think about it if it is available and is in good quality. However, in places like Johannesburg with frequent water challenges, households would be expected to have some information about water-saving appliances. While 8% of the respondents indicated that they did not have the infrastructure to connect the appliances, it is concerning that 14% of the respondents think water-efficient appliances are not important. This warrants the need for intensified water conservation campaigns to provide conservation knowledge among households. The recommendation to intensify water conservation campaigns is also suggested by Dascher *et al*. (2014) who recommend policy to focus on educational campaigns as part of demand-side management of water resources.

In terms of households' daily water-use behavioural practices, respondents were asked 11 behavioural questions using a 4-point Likert scale which ranged from 'never', 'once in a while', 'always' to 'not applicable'. If respondents indicated 'never', it showed that they were practising efficient water-use behaviour. On the other hand, if respondents indicated 'always', it suggested that they were not practising efficient water-use behaviour. The frequency distribution of responses is presented in Figure 4.

Figure 4 shows that inefficient water-use behaviour is only reported in the first question (take bath instead of shower) where 44% of the respondents indicated that they 'always' take a bath instead of a shower, while only 27% will 'never' take a bath ahead of a shower. Although a bath is mostly considered inefficient relative to taking a shower, this is only true if households fill 'bigger-sized' bathtubs. In cases where water is collected in buckets, taking a bath becomes efficient, relative to taking showers. This can be true considering the earlier revelation that 67% of the respondents indicated that they do not have efficient showerheads installed. Furthermore, it could also be argued that the reason for households always taking a bath could be that they do not have showers

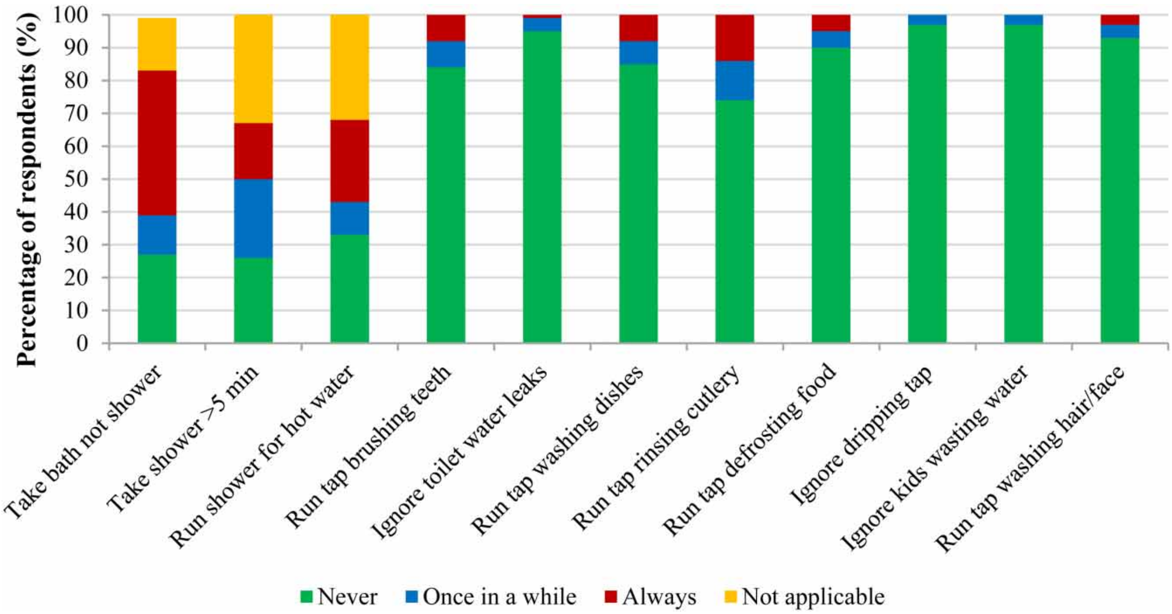

Fig. 4 | Household daily water-use behavioural practices ($N = 889$).

installed in their houses; hence, they use mostly buckets to collect bathwater. Nevertheless, it is clear in the diagram that the surveyed households are generally water-efficient in their daily water-use behavioural practices. The revelation that the sampled households in Johannesburg generally practise efficient water-use behaviour is also confirmed in similar studies conducted in other South African cities, for example, in Pretoria (Thwala & Edoun, 2018) and in Cape Town (Viljoen, 2015; Booysen *et al*., 2019; Matikinca *et al*., 2020). Based on these revelations, it can be argued that South African households generally practise water-efficient behaviour in their daily activities.

EMPIRICAL MODELLING RESULTS

Several studies in the literature examine the impact of biographical characteristics on water consumption behaviour. Examples include Fielding *et al*. (2012) in Australia, Shan *et al*. (2015) in Greece and Poland, Viljoen (2015) in Cape Town, Fan *et al*. (2017) in China, Russell & Knoeri (2020) in the United Kingdom and Shahangian *et al.* (2021) in Iran. Understanding the relationship between the biographical characteristics of households and their water consumption behaviour is essential for policy-makers when developing water demand management policies. Therefore, this study estimates the impact of biographical characteristics on household water-use behavioural practices using the probit model as an estimation tool. As mentioned earlier, a dummy binary variable was deduced from the responses, where all responses that were 'never' were coded 1, and 0 otherwise. Subsequently, probit models were estimated to examine the probability of selecting 'never' given the biographical variables of each respondent. The conversion of Likert scale responses to a binary dummy variable was done for all the 11 behavioural practices, and a probit model was estimated for each. Estimation results for the probit models are presented in Table 2.

Results in Table 2 are interpreted in terms of the statistical significance and sign of the coefficients of biographical variables under each model (i.e., under each behavioural practice). Since 11 models were estimated, we

Table 2 | Probit modelling of the relationship between biographical variables and water consumption behavioural practices.

	Bath instead of shower	Shower >5 min	Run shower for hot water	Run tap brushing teeth	Ignore toilet leaks	Run tap washing dishes	Run tap rinsing cutlery	Run tap defrosting food	Ignore dripping tap	Ignore kids wasting water	Run tap washing hair/face
Household size	−0.056	−0.106**	−0.088**	0.053	−0.045	0.158**	0.074	0.066	0.036	0.036	0.057
	[0.045]	[0.048]	[0.046]	[0.057]	[0.083]	[0.075]	[0.053]	[0.094]	[0.143]	[0.083]	[0.081]
Gender	−0.154	0.185	0.250*	−0.036	0.162	−0.037	−0.407***	−0.579**	−0.140	−0.491*	−0.539*
	[0.142]	[0.148]	[0.141]	[0.174]	[0.284]	[0.222]	[0.169]	[0.302]	[0.565]	[0.277]	[0.292]
Race	0.152	−0.018	−0.224*	0.148	omitted	−0.039	−0.040	omitted	−0.948*	−0.113	−0.214
	[0.126]	[0.133]	[0.139]	[0.164]		[0.195]	[0.141]		[0.550]	[0.196]	[0.195]
Marital status	0.372***	0.287*	0.100	0.262	0.492	0.395*	0.170	0.412	1.048	0.155	0.245
	[0.149]	[0.157]	[0.150]	[0.188]	[0.330]	[0.237]	[0.175]	[0.349]	[1.359]	[0.292]	[0.314]
Education	0.068	0.018	−0.041	−0.085	−0.065	−0.100	−0.214***	0.186	0.013	0.048	−0.191
	[0.076]	[0.081]	[0.079]	[0.089]	[0.141]	[0.107]	[0.082]	[0.188]	[0.280]	[0.150]	[0.126]
Age	0.024***	0.033***	0.028***	0.009	0.003	−0.020**	0.007	0.044***	0.054	0.024*	0.039***
	[0.006]	[0.006]	[0.006]	[0.008]	[0.013]	[0.010]	[0.008]	[0.017]	[0.042]	[0.014]	[0.016]
Income	−0.182*	−0.337***	−0.262***	−0.675***	−0.112	−0.163	−0.159	−0.250	0.132	−0.268	−0.243
	[0.105]	[0.113]	[0.107]	[0.138]	[0.212]	[0.173]	[0.119]	[0.227]	[0.414]	[0.193]	[0.196]
_cons	−1.657***	−1.658***	−0.840*	1.655***	1.488	1.964***	1.953***	0.029	0.275	1.725**	2.026**
	[0.483]	[0.504]	[0.483]	[0.595]	[0.978]	[0.724]	[0.556]	[1.042]	[1.933]	[0.898]	[0.930]
LL	− 236.1	− 209.4	− 231.3	− 145.1	− 46.5	− 84.1	− 162.0	− 45.0	− 13.0	− 57.6	− 54.6
Prob. $> \chi^2$	0.000	0.000	0.000	0.000	0.420	0.058	0.001	0.001	0.225	0.074	0.001
Pseudo R^2	0.099	0.017	0.130	0.136	0.061	0.075	0.073	0.202	0.266	0.101	0.189
Observations	403	403	403	403	371	403	403	371	403	403	403

Notes: ***, ** and * indicate statistical significance at 1, 5 and 10% levels, respectively. Standard errors are in parentheses.

track the number of times each biographic variable was statistically significant, thus the number of models where each biographic variable was statistically significant. Subsequently, variables are listed in a descending order, that is, the one with the most times of statistical significance is given first, and the one with the least times is given last. Results show that the age of respondents was statistically significant in 7 out of the 11 models, followed by gender which was significant 5 times, then level of income (4 times), household size and marital status (both 3 times), race (2 times) and education (once).

The results imply that age is a persistent determinant of household water consumption behaviour. Its impact was statistically significant at 1% across five models, at 5% in one model and at 10% in another model. The sign of the coefficient of age is mostly positive except in one model (run tap washing dishes) which has a negative coefficient that is significant at 5%. A positive coefficient in this context means that older respondents were likely to choose 'never', relative to younger respondents. Thus, the higher the age, the more likely it is for respondent to practise water-efficient behaviour. Nevertheless, this is contrary in terms of 'running a tap when washing dishes' where results indicate that younger people are likely never to do that.

Gender is another important determinant of water-use behaviour, being statistically significant five times. Except for the model 'run shower for hot water', the coefficient for gender is negative. This implies that male respondents were more likely to choose 'never' compared to female respondents, suggesting that male respondents are more conscious about water conservation than female respondents. This is concerning considering that in South Africa, women spend more time using water resources as they are usually responsible for the home economics. The implication of this revelation is that while water conservation awareness campaigns should target all South African, more emphasis should be given to women.

Being statistically significant in four models, the level of income had negative coefficients, implying that lower-income respondents were likely to choose 'never', relative to higher-income respondents. This can be true because of the price elasticity of water demand whose value is usually higher among low-income earners. Thus, when low-income households get a chance to save water, they do so with the intention to also save money. Differently, the level of education and race were found to be less important in water consumption behaviour. *A priori*, education was expected to be a significant determinant of water consumption behaviour. Thus, more educated individuals were expected to be more conscious of water conservation. Findings in this study would be interpreted to warrant that the South African education system should include elements of environmental consciousness.

To understand the exact impact of each biographic variable on the behavioural practices, average marginal effects were estimated after each probit model. A margin is a statistic based on a fitted model in which some of or all the covariates are fixed (Williams, 2012). In the context of this study, marginal effects are changes in the response for change in a covariate, which is reported as a derivative. Contextually, a marginal effect of 0.3 is interpreted to mean that the dependent variable increases with the independent variable at a rate such that, if the rate were constant, the dependent variable would increase by 0.3 if the independent variable increased by 1. The average marginal effects of all covariates for the behavioural water consumption practices were estimated and the results are presented in Supplementary Material, Appendix 1.

Marginal effect estimates for household size were statistically significant under three models, ranging from −0,031 to 0.017. In terms of gender, the estimates were significant for five models, ranging from −0,091 to 0.082. Race and education were significant in only one model each, with respective marginal effects of −0.073 and −0.047, while marital status reported significant marginal effects under three models where the estimates ranged from 0.044 to 0.124. For age, estimates were significant in seven models, ranging from −0.002 (which was the only negative estimate) to 0.010. Finally, income reported significant estimates for the first four models only, with estimates ranging from −0.134 to −0.061. These results imply that water consumption behavioural practices change with biographic variables. Thus, biographic characteristics are key determinants of water consumption behaviour.

Further to the water consumption behavioural practices, the study examined the relationship between 'non-installation' of water-saving appliances and the biographical variables of respondents. As explained earlier, a dummy variable was created where 1 was allocated to a 'no' response, and 0 otherwise. The 'no' response was preferred because it was the modal response for all questions on the adoption of water-saving appliances. The dummy binary variable was then regressed against biographical variables using probit models, and results are presented in Table 3.

Results in Table 3 show education and income levels being statistically significant under 2 of the 6 models. Except for marital status, which was statistically insignificant across all 6 models, the rest of the biographic variables were significant at most once. Based on the frequency of each variable's statistical significance, these results can be interpreted to mean that generally, biographic variables were not consistent determinants of the ownership of water-efficient appliances. However, it is important to also emphasise that the level of education had negative coefficients under efficient showerhead and smaller cistern, implying that less educated respondents were more likely to answer 'no' to the ownership of these appliances relative to more educated respondents. For the same appliances, statistically significant negative coefficients were also reported for the income variable, implying that relatively low-income respondents were likely to say that they do not own these appliances compared to respondents with more income. Findings for both education and income were consistent with *a priori*

Table 3 | Relationship between biographical variables and non-adoption of efficient appliances.

	No collection tank	No cistern displacement	No water-flow regulator	No efficient showerhead	No smaller cistern	No dishwasher
Household size	0.132* [0.074]	0.077 [0.076]	0.058 [0.103]	0.009 [0.050]	0.035 [0.045]	−0.045 [0.106]
Gender	−0.183 [0.202]	−0.314 [0.218]	−0.111 [0.295]	−0.041 [0.157]	−0.318** [0.141]	0.315 [0.374]
Race	0.396 [0.348]	0.449 [0.374]	Omitted	−0.077 [0.137]	−0.044 [0.132]	−0.491*** [0.200]
Marital status	−0.051 [0.213]	−0.335 [0.266]	0.100 [0.305]	−0.077 [0.165]	0.084 [0.149]	0.105 [0.408]
Education	−0.066 [0.110]	−0.172 [0.113]	−0.061 [0.155]	−0.186** [0.080]	−0.193*** [0.075]	0.020 [0.181]
Age	0.001 [0.009]	−0.007 [0.009]	−0.014 [0.013]	0.011 [0.007]	0.019*** [0.006]	0.010 [0.017]
Income	0.102 [0.152]	0.236 [0.166]	−0.148 [0.230]	−0.268*** [0.114]	−0.207** [0.105]	−0.238 [0.233]
_cons	0.877 [0.771]	2.319*** [0.835]	2.894*** [1.086]	1.913*** [0.539]	1.013** [0.482]	2.318** [1.097]
LL	− 95.5	− 86.4	− 41.1	− 182.5	− 234.8	− 34.8
Prob $> \chi^2$	0.419	0.042	0.865	0.000	0.000	0.254
Pseudo R^2	0.036	0.077	0.030	0.071	0.081	0.114
Observations	403	403	371	403	403	403

Notes: ***, ** and * indicate significance at 1, 5 and 10% levels, respectively. Standard errors are in parentheses.

expectations. Overall, the frequency of statistical significance of biographic variables under all models suggest that these variables are generally not the main determinants of the ownership of water-efficient appliances. This is also confirmed by statistically significant intercepts across all models, except for the 'collection tank' model.

To understand the actual impact of each biographical variable on the non-adoption of water-efficient appliances, average marginal effects were estimated after each probit model. Estimates for the average marginal effects of all covariates for the non-adoption of water-efficient appliances are presented in Supplementary Material, Appendix 2. Estimates for household size, gender, race and age were statistically significant only once, ranging from −0.106 to 0.016. While marital status reported no significant estimates, education and income had significant estimates under two models. The estimates for education and income ranged from −0.069 to −0.047. Overall, these results suggest that while some impact of biographic characteristics is noted on the non-adoption of water-efficient appliances, biographic characteristics are generally not key determinants of the non-adoption of water-efficient appliances.

In summary, five important points emerged from the results. First, older respondents were more likely to practise water-efficient behaviour than younger respondents. Secondly, male respondents were more conscious about water conservation than female respondents. Thirdly, lower-income respondents were more likely to practise water-efficient behaviour than higher-income respondents. Fourthly, the education level and the race of respondents were less important determinants of water consumption behaviour. Finally, biographical variables were generally not important determinants of the ownership of water-efficient appliances. While Shan *et al.* (2015) acknowledge that the theorised association between biographical variables and engagement in water-saving behaviours is ambiguous, results in this study are consistent with findings in similar studies. For example, a similar impact was reported for age in Fielding *et al.* (2012), Makki *et al.* (2015) and Abu-Bakar *et al.* (2021), while the impact of income is consistent with findings in Fielding *et al.* (2012), Shan *et al.* (2015) and Russell & Knoeri (2020). Thus, although high income enables the acquisition of efficient appliances, water savings may be negated by a reluctance to modify habits. Overall, findings in this study contribute to the growing literature on the impact of biographical variables on household water conservation, thus providing background information to be considered by water policy-makers.

CONCLUSION

This study examined household water-use behavioural practices and the adoption of water-efficient appliances among 889 households in the city of Johannesburg. Probit models were used to examine the impact of biographic characteristics on water-use behaviours and the adoption of water-efficient appliances. Three key findings were reported. First, the study found that most households do not have water-efficient appliances installed in their homes. While most respondents suggested that they could not install the appliances because they cannot afford them, several respondents suggested that they had no knowledge of the appliances.

Secondly, the study found age to be the most consistent determinant of water-use behaviour, followed by gender, income, household size and marital status, in that order. Characteristics such as race and education were reported to be less consistent determinants of water-use behaviour. In terms of age, older respondents were found to be more likely to practise efficient water-use behaviour than younger respondents. Also, male respondents were more likely to practise efficient water-use behaviours than females, while low-income respondents were more likely to practise efficient water-use behaviours relative to high-income respondents. Thirdly, biographic variables were generally found not to be consistent determinants of the ownership of water-efficient appliances. Some significance was noted in education and income, but the frequency of this significance was outweighed by the times these variables were insignificant.

The implication of these results is that there is need for intensified water conservation campaigns that provide enough knowledge on efficient appliances among households. Thus, policy-makers should focus on educational campaigns as part of their demand-side management of water resources. When developing and implementing campaigns on water-use behaviour and efficient water appliances, more focus should be given to women and younger people. This is warranted because women were reported to be more likely to practise less efficient water-use behaviour compared to men. Equally, prioritising women in such campaigns is likely to yield positive results because they spend more time doing activities that use water resources in a homestead. Furthermore, the campaigns should target younger people because age proved to be a significant determinant of water consumption behaviour, where older people were found to be more likely to practise water-efficient behaviour than relatively younger people. Finally, the revelation that education is not an important determinant of behaviour is quite alarming. This warrants that the South African education system should include environmental sustainability topics in fundamental subjects. Educated people should be environmentally conscious.

Future research on water consumption behaviour in South Africa may use longitudinal data to examine whether the impact of biographical variables on water consumption behaviour varies over time, based on the availability or unavailability of sufficient water resources. The current study uses cross-sectional data collected during a period of water shortages. Although studies like Bernedo *et al.* (2014) provide evidence that consumption behaviour extends across time, such a relationship is worth exploring in the context of South Africa as it aids in the crafting of policies with long-term impacts. Another important aspect worth exploring is the nexus between household water consumption behaviour and the availability of electricity. Results from such analyses will shed light, especially in South Africa where the economy has a double challenge of water and electricity shortages.

DATA AVAILABILITY STATEMENT

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

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