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Water consumption behaviour and the use of technology among households in Durban, South Africa

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ABSTRACT

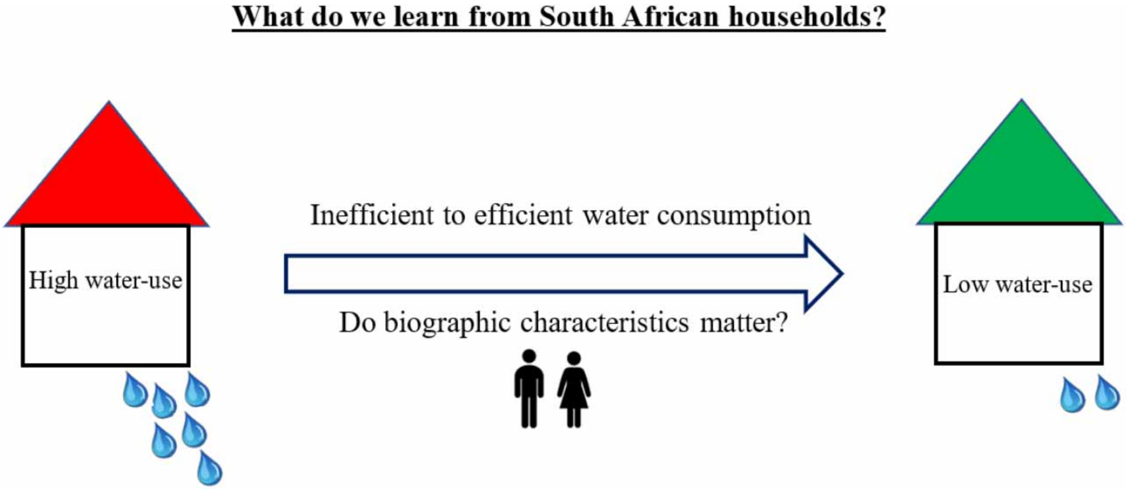
Freshwater resources remain under constant pressure due to population growth, economic development, and changing weather patterns. Water supply utilities generally struggle to keep up with the growing demand for freshwater resources and consequently adopt demand management policies to address supply challenges. As water consumers, households can play a major role in water conservation. This paper examines the impact of biographic characteristics on water consumption behaviour and the adoption of water-efficient technologies in the city of Durban, South Africa. Probit regression models are estimated using survey data collected from 300 household heads sampled across the city. Among other results, the study finds income as the most consistent determinant of water consumption behaviours and the adoption of water-efficient technologies. Furthermore, the level of education was also found to be a consistent determinant of the adoption and installation of water-efficient technologies. These results are significant and serve to guide water utilities when implementing demand management water policies.

Key words: Household water conservation, Water demand management, Water policy, Water utilities

HIGHLIGHTS

- Households generally practice water-efficient consumption.
- Efficient behaviour is more prevalent in the suburbs and township than informal settlements.
- Income level, household size, age, education, and gender are important determinants of water consumption behaviour.
- Different conservation strategies should be adopted for suburbs, townships, and informal settlements.

GRAPHICAL ABSTRACT



INTRODUCTION

Most countries in arid and semi-arid regions are commonly challenged with insufficient freshwater resources. Natural factors such as climate change and geographical conditions as well as human factors like population growth, industrial activity, and inefficient consumption are at the core of freshwater challenges in these regions. About two-thirds of the world's population currently live in water-scarce areas, and an estimated 1.8 billion people are expected to live in countries or regions with absolute water scarcity by 2025 (Nishad & Kumar, 2022). While arid and semi-arid regions are generally prone to severe freshwater challenges, these challenges are worse for developing countries in these regions as they struggle with the accumulative cost of developing new water sources (Huang *et al.*, 2021).

Water-scarce countries with excess freshwater demand ideally adopt demand management policies. Such policies include radical measures like the imposition of water-use restrictions, pressure reduction, tariff increases, and water rationing (Leck & Simon, 2018; Martel & Sutherland, 2019). While these punitive measures can work, some scholars recommend more liberal approaches that nudge consumers towards water conservation (Addo *et al.*, 2018; Koop *et al.*, 2019; Abu-Bakar *et al.*, 2021). The argument is generally that pressure on water resources can be reduced when utilities nudge consumers to practice efficient water consumption behaviour and/or adopt water-saving technologies. Moral suasion is credited for reducing water consumption by almost 50% during a drought in Atlanta (Bernedo *et al.*, 2014), and reducing the average daily water use by about 260 L per household within 36 months during a drought in Cape Town (Booysen *et al.*, 2019; Matikinca *et al.*, 2020).

It is important to appreciate that households are instrumental in the quest for sustainable solutions to water supply challenges. This is essential in urban areas, especially in developing countries where rural–urban migration and urbanisation are challenging potable water supply. While the role of households in water conservation is examined in some major South African cities (Booysen *et al.*, 2019; Matikinca *et al.*, 2020; Murwirapachena, 2021), little is known about households' water-use behaviour in the city of Durban. Although South Africa is a unitary state, different cities in the country have diverse operating environments. Therefore, area-specific interventions are necessary for sustainable water use as the country works towards achieving Sustainable Development Goal (SDG) 6 on access to freshwater resources.

The extent of freshwater challenges in South Africa warrants robust and effective water policies that both protect freshwater resources and govern excessive consumption. Currently, there are no clearly adopted policies that seek to regulate and/or promote efficient water consumption in the country. Current national policies like the Water Supply and Sanitation Policy of 1994, the Free Basic Water Policy of 2001, and the Free Basic Water Policy Implementation Strategy of 2007 emphasise people's right to access water. Thus, a gap exists in policies that seek to govern water consumption levels by households. While there is an increase in the demand for freshwater resources in South Africa, the country is a water-scarce country receiving between 450 and 465 mm of average annual rainfall, almost half the world average (du Plessis *et al.*, 2020; Murwirapachena, 2021). Water consumption in South Africa averages 237 Litres/person/day (L/c/d), a figure higher than the world average of 173 L/c/d (Ngobeni & Breitenbach, 2021). Consequently, the increasing demand for freshwater resources is posing a huge challenge to water utilities in the country. Thus, policies that regulate water consumption are warranted. This is more important considering that different municipalities (deemed Water Service Authorities or WSAs) have the privilege to devise their own policies with very little regulation from the Department of Water and Sanitation (DWS) which acts as the water sector regulator.

The crafting of water consumption policies requires water utilities to appreciate heterogeneity among consumers and how their social and economic characteristics determine consumption patterns. Therefore, this study examines the impact of biographical characteristics on both water consumption behaviour and the adoption of water-saving appliances in Durban, South Africa's third-largest city in terms of population. The study provides practical evidence on household water consumption patterns and the relevance of socio-biographical characteristics in the formulation of water policies within the city and in many other similar environments. To promote sustainable access to improved water services in line with SDG6, there is growth in the number of studies that advance evidence-based water policies. This study contributes to the critical dialogue on the need for evidence-based water policy-making. It essentially emphasises the role of households in achieving SDG6, providing information to policy-makers in environments where natural water scarcity and excessive water demand co-exist.

The rest of this paper is organised into five sections. The 'Household water conservation in the literature' section discusses some literature on household water conservation. The 'Methodology' section discusses the methodology used in the study. The 'Data and descriptive statistics' section provides the data and descriptive statistics. 'Findings' discusses the results of the study. The final section concludes the study.

HOUSEHOLD WATER CONSERVATION IN THE LITERATURE

Water conservation continues to be a topical issue in the literature. A plethora of theories is generally linked to water conservation. While many aspects of water conservation are modelled in the literature, this study draws knowledge from theories that discuss the key determinants of conservation to explain household water conservation. These theories include the utilitarian theory (Bentham, 1789) and the ecological theory by Haeckel in the 1870s. Generally, these theories converge on the assumption that people's environmental beliefs determine their conservation behaviour. Thus, promoting change in people's beliefs is central to achieving sustainable water-use behaviour. The utilitarian theory explains the significance of simultaneously increasing positive human action while reducing actions that harm water resources. It explains the reasons behind people's water consumption patterns. Meanwhile, the ecological theory promotes ecological ethics by encouraging people to be aware of the freshwater requirements of other living species. Thus, human ecological compensation is essential in managing the relationship between local economic development and water security in the arrears where water conservation is crucial. Overall, the utilitarian and ecological theories encourage morally suitable behaviour by households as they seek to maximise their utility in water consumption. As a result, the key assumptions of these theories provide a theoretical basis for this study.

Several empirical studies on water conservation report on the key determinants of household water conservation. Equally, there is a growth of studies that investigate households' water consumption patterns, behaviours, and the adoption of water-saving appliances in the literature. Recent evidence exists that household water conservation is an ideal game-changer in addressing water supply challenges, especially in water-strained regions (Bernedo *et al.*, 2014; Addo *et al.*, 2018; Abu-Bakar *et al.*, 2021). Therefore, campaigns to promote sustainable water consumption perceptions and behaviour among households have increased in practice and are overemphasised in the literature (Koop *et al.*, 2019). Notable gains from positively changing water consumption perceptions, behaviours, and patterns by households are recorded across the world. Prominent references include the city of Cape Town in South Africa where a change in household water-use behaviour saved the city from an anticipated 'Day Zero' (Booysen *et al.*, 2019; Matikinca *et al.*, 2020). In this case, save-water campaigns successfully reduced household water consumption from 540 to 280 litres/household/day within 36 months (Booysen *et al.*, 2019). More evidence of the role of households in water conservation is provided in Nepal, Pakistan, Texas, and Atlanta (Bernedo *et al.*, 2014; Virk *et al.*, 2020).

Apart from changing water consumption perceptions and behaviour, there are now several water-efficient devices that households may adopt to promote conservation. The adoption of efficient technologies in household water use is credited not only with water consumption but also with reducing monthly water costs (Kumarasamy *et al.*, 2017). Town planners in many modern cities now promote the installation of water-saving devices when people build new properties. Some of the noteworthy water-efficient devices that households are commonly encouraged to install include efficient washing machines, efficient showerheads, dual flush toilets, efficient taps, and shower timers (Kumarasamy *et al.*, 2017; Abansi *et al.*, 2018; Murwirapachena, 2021). Installing these water-saving devices may reduce water use by very large proportions. Detailed discussions on the essential benefits of installing water-saving devices are enunciated in many studies in the literature (Marinoski *et al.*, 2018; Fan *et al.*, 2019; Abu-Bakar *et al.*, 2021; Murwirapachena, 2021).

However, it should be emphasised that the installation of water-saving devices alone cannot be sufficient. To achieve meaningful gains, the installation of water-saving devices should be coupled with the adoption of water-efficient behaviour. In the absence of water-efficient behaviour, water-saving devices may even lead to excessive water use and higher monthly water bills. Offsetting behavioural responses where households use more water after installing water-saving devices are underscored in the literature (Jorgensen *et al.*, 2009). Key examples of offsetting behaviour that are generally mentioned in the literature include people extending the time they spend in the shower after installing water-efficient showerheads. Such behaviour reverses the expected gains of the showerhead. Thus, the installation of water-saving devices should be followed by the adoption of efficient water-use behaviour if positive results are to be achieved. After all, there can be a disruption of sufficient water supply and increases in water provision costs if there is no change in water behaviour.

Nudging households to install water-saving devices and adopt efficient water-use behaviour should fast become the common water policy focus in arid and semi-arid regions. In the past, even currently in the developing world, water management policies have been largely focused on using pricing reforms as an instrument to induce water conservation. However, it should be realised that the usefulness of pricing reforms as an instrument for water management heavily depends on the price elasticity of water demand (Arbués *et al.*, 2010). Generally, water is a low-involving product and a necessity, implying that its demand is price-inelastic (Bruno & Jessoe, 2021; Flores Arévalo *et al.*, 2021; Jiang *et al.*, 2022). Thus, people's response to water tariff increases is not usually sufficient to meet the expected consumption reduction targets. This is usually the case in most developing countries

(Nauges & Whittington, 2010). Consequently, using pricing reforms becomes a substantially ineffective instrument to water consumption behaviour (Booysen *et al.*, 2019; Matikinca *et al.*, 2020). Studies like Koop *et al.* (2019) suggest price incentives nudge efficient water consumption as opposed to increasing water tariffs. Our study joins the emerging studies that emphasise the role of changing household water-use behaviour and the installation of water-efficient devices. The study provides more evidence on water consumption behaviour and the adoption of water-efficient devices in a typical South African metropolitan.

STUDY SITE

This study was conducted in the city of Durban, the economic capital of the KwaZulu-Natal (KZN) province in eastern South Africa. In terms of population statistics, the city is South Africa's third largest after Johannesburg and Cape Town. It is within the jurisdiction of the eThekwini Metropolitan Municipality, which is one of South Africa's eight metropolitan municipalities[1]. According to the Cooperative Governance and Traditional Affairs (COGTA, 2020), the municipality had a total population of about 4 million people and an average annual growth rate of 1.2% in 2019. The annual population growth rate in the municipality is like the provincial growth rate, but lower than the national average of 1.5% (COGTA, 2020). About 51% of the population is female, with racial distributions being 74% (Blacks), 18% (Indians), 6% Whites, and 2% (Coloureds) (Statistics South Africa, 2016, as cited in COGTA, 2020).

The 2016 Community Survey conducted by Statistics South Africa (Stats SA) revealed that the municipality had approximately 1.13 million households. About 81.5% of these households live in formal dwellings, while 13.3% live in informal dwellings, and 4.3% live in traditional dwellings (Statistics South Africa, 2016). The average household size in the municipality was 3.3 in 2016, which was like the national average (COGTA, 2020). Furthermore, about 42.1% of the households are female-headed, while approximately 3001 households were headed by children younger than 18 years. Regarding access to water, the 2016 Community Survey reported that 98.3% of households accessed water from a regional or local service provider, thus about 20% higher than the provincial average (83.35%) and about 10% higher than the national average (86.2%). Of these statistics, about 60% of households had access to piped water inside the house. According to COGTA (2020) there were water supply backlogs of 20,345 consumer units in 2019, estimated to take about 5–10 years to address based on current funding levels. The map of the eThekwini Municipality showing its different spatial regions is presented in Figure 1.

The eThekwini Municipality is spatially divided into the North, Central, South, and Outer West regions. The Northern region covers about 26% of the municipal area, while the Outer West region covers about 34% of the municipal area (COGTA, 2020). On the other hand, the Central region covers about 28% of the municipal area, while the Southern region covers about 20% of the municipal area. Generally, very little is known about the current level of household water consumption behaviour, water consumption patterns, adoption of water-saving devices, and general water conservation in the municipality. This is usually the case in many South African municipalities and in other developing countries. In South Africa, statistics are mostly available at national level. On average, the water consumption level in South Africa is 237 L/c/d, which is higher than the world average of about 173 L/c/d (Ngobeni & Breitenbach, 2021). Du Plessis *et al.* (2020) breaks down the estimated water consumption in South Africa according to the level of service and the number of persons per household. In this regard, a family of four utilising a full-house connection with outdoor water use consumes about 221 L/c/d. This is the case with high-income households with outdoor facilities like swimming pools and gardens.

[1] South Africa has 278 municipalities which are categorised as eight metropolitans, 44 districts, and 226 local municipalities.

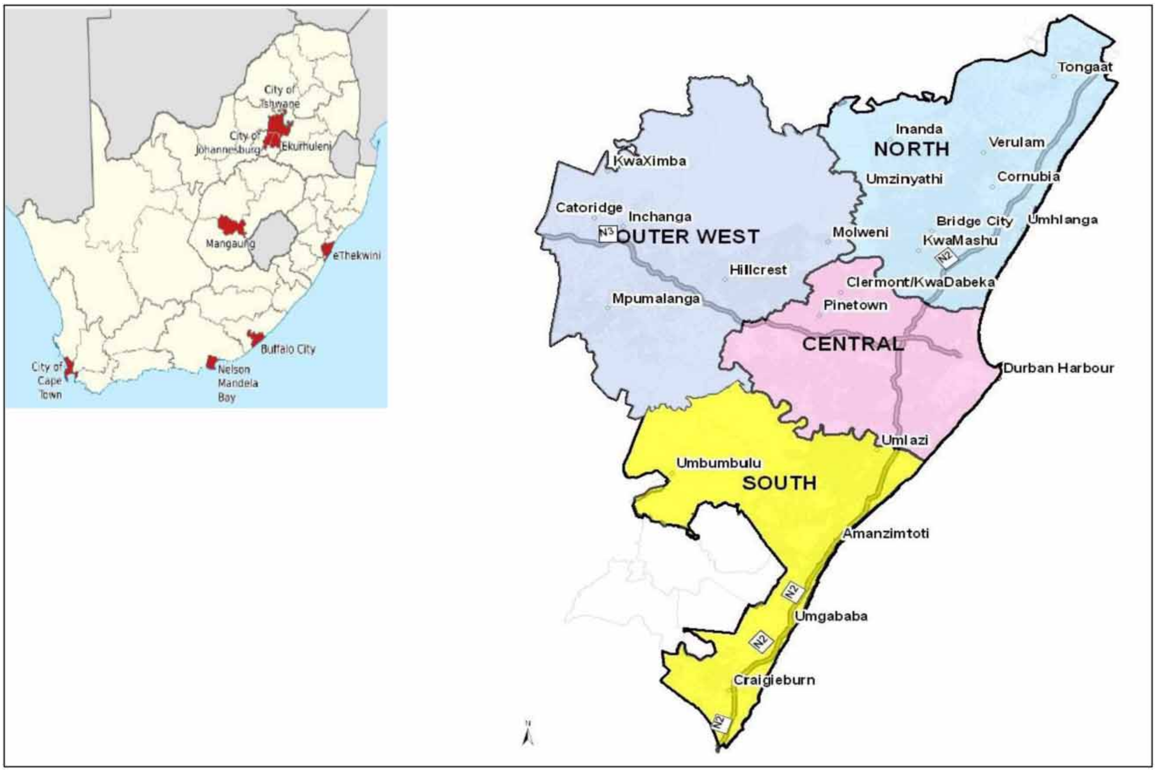


Fig. 1 | Map showing the spatial regions of eThekwini Municipality. *Source*: eThekwini Municipality (2014).

Low- to middle-income households who normally use water for indoor purposes generally consume averages between 22 and 143 L/c/d (du Plessis *et al*., 2020).

Like other South African cities, Durban constantly experiences water challenges and frequently imposes water consumption restrictions. Water challenges in the city are linked to the reality that South Africa is a water-scarce country where annual rainfall is almost half of the world average (Murwirapachena, 2021). Apart from this, the city is usually affected by extreme weather events like droughts and floods which in most cases affect the water supply (Ndlovu & Demlie, 2020; Bond & Galvin, 2022). Droughts in the city usually see dam levels going below normal, while floods like those reported in April 2022 destroyed water supply resources and infrastructure. Furthermore, energy challenges in South Africa also have negative effects on the water supply in the country. South Africa currently has major electricity generation challenges which have led to load-shedding (Akpeji *et al*., 2020). In essence, load-shedding generally interrupts the water supply, especially when water is pumped into supply towers or directly into the network (Murwirapachena, 2021). Against this backdrop, water challenges in Durban make the city an ideal case study for household water conservation.

METHODOLOGY

Methodological approach and research design

The study adopted a quantitative research approach where survey data were collected from heads of households around the city of Durban. A quantitative research approach uses statistical analyses through a process that quantifies response categories and has quantifiable outcomes in the form of discrete and non-discrete numerical values (Leavy, 2022). The literature provides several research designs for the quantitative research approach (Saunders *et al*., 2016; Abutabenjeh & Jaradat, 2018; Leavy, 2022). This study adopted a descriptive design to establish the impact of biographical characteristics on water consumption behaviour and the adoption of efficient technology in the city of Durban. According to Saunders *et al*. (2016), a descriptive research design is one that aims to systematically obtain information that describes a phenomenon, through an observation, a survey, or a case study. In this study, a survey was adopted to collect cross-sectional data that addresses the established aim of the study.

Study sample and sample size

Data for the study were collected from 300 participants who were heads of households around the city of Durban during the period from December 2020 to April 2021. The simple random sampling technique was used to select household heads in various areas around the city. Using the Raosoft® sample size calculator, the minimum recommended sample size for a total population of 1.13 million households was 271 households given a 90% confidence level, a 5% error margin, and a 50% response distribution (http://www.raosoft.com/samplesize.html). Therefore, 300 participants were deemed sufficient to produce robust results. However, residential areas in the city of Durban are spatially divided into suburbs, townships, and informal settlements (Parikh *et al*., 2020; Mottiar, 2021). While the quality of water consumed in these different areas may be the same, the water service packages received is different, with suburbs having better water service packages compared to townships and informal settlements, respectively (Parikh *et al*., 2020; Odili & Sutherland, 2021). As a result, data for the survey were collected from these three different areas. More precisely, 100 responses were collected from suburbs (Morningside, Musgrave, and La Lucia), another 100 from townships (Umlazi, Ntuzuma, and Chatsworth), and the final 100 from informal settlements (Bhambayi, Mayville, and Chesterville). Thus, data were equally drawn from the suburbs (100 participants), townships (100 participants), and informal settlements (100 participants). This distribution gave a fair representation of the spatial dynamics within the city and was expected to produce reliable results and inferences.

Sampling technique

The stratified random probability sampling technique was adopted to select survey participants. This sampling technique entails dividing the entire population into different subgroups or strata then participants are randomly selected, proportionally from each stratum (Nguyen *et al*., 2021). Using the stratified random probability sampling technique gives a sample that is extremely descriptive of the population, making the statistical conclusions from the data collected robust (Berndt, 2020). Therefore, this study stratified households in the city of Durban into subgroups based on the type of the residential area, namely, suburbs, townships, and informal settlements. Subsequently, participants were randomly selected from each stratum. Categorising respondents based on the type of their residential area is proxy to categorising them based on their income levels. This is essential because the income level is usually reported to have a direct correlation with the ability to buy water-saving appliances and other technologies.

Data collection procedure

Ethical clearance was obtained from the Durban University of Technology and all ethical considerations were upheld throughout the study. A questionnaire developed in the English language was used to collect survey data. Since the most spoken language in the city of Durban is isiZulu, the questionnaire was translated to participants who were not conversant in the English language. This questionnaire was pretested through a pilot study that was conducted on 15 participants from the target sample. Feedback from the pilot study was used to improve the questionnaire as questions that were not clear to the piloted respondents were edited and some new information added to improve the suitability of questions. Prior to data collection, potential participants were provided with a letter of information which detailed the aim of the research as well the rights of participants. More importantly, participants were informed that participation was voluntary, and that they could withdraw participation at any time without prejudice. Subsequently, those who agreed to participate signed an informed consent, indicating that they were sufficiently informed about the survey and their rights. In collecting data, the researchers self-administered the questionnaire, and this allowed them to clarify questions which appeared ambiguous to participants. The survey was conducted during the COVID-19 pandemic and South Africa had strict health protocols which aimed at reducing the prevalence of the virus. Therefore, all government health protocols were observed during data collection. For example, masks which covered the mouth and nose were correctly worn, social distance was maintained, and the researchers carried a bottle of hand sanitiser which they used to sanitise their hands before and after meeting each participant.

Data analysis

To establish the role of households in water conservation, the study used both descriptive and inferential statistics. Probit regression models were estimated to establish the marginal effects of biographic characteristics on both water-efficient behaviour and the adoption of water-saving technologies. Probit regression models give a binary dependent variable (for example, YES or NO outcome), and assume that the probability of a positive outcome is determined by the standard normal cumulative distribution function (Aldrich & Nelson, 1984). Thus, it fits the maximum likelihood model with a dichotomous dependent variable coded as 0 or 1. Generally, a probit model transforms data to a representable manner that can be viewed as a linear function (Aldrich & Nelson, 1984). Its basic mathematical formulation is given as:

$$\Pr(y_i \neq 0|x_j = \Phi(x_j\beta) \tag{1}$$

where Pr is the probability of the dependent variable; y_i is the dependent variable which in the context of this study represents the dummies for the dichotomous water conservation variables; x_j is the explanatory variable which in this study entails the selected biographic characteristics chosen as possible determinants of water conservation behaviour and the adoption of water-saving technologies; Φ is the standard cumulative normal; and β is the coefficient of each selected determinant. Thus, each probit model estimated in the study will ascertain variables that are statistically significant in determining household water conservation. Following Murwirapachena (2021) who also regressed water consumption behaviour and the adoption of water-saving technologies against biographic characteristics in the city of Johannesburg, South Africa, this study modifies the basic probit model expressed in Equation (1) as follows:

$$y_i = \beta_0 + \beta_1 GEN_i + B_2 AGE_i + \beta_3 EDU_i + \beta_4 OWN_i + \beta_5 SIZE_i + \beta_6 INC_i + \varepsilon \tag{2}$$

where y_i is the binary outcome of practicing water-efficient behaviour, GEN_i is the gender of each respondent; AGE_i is the age of each respondent; EDU_i is the education level of each respondent; OWN_i is whether the respondent owns the property they reside in or they are tenants; $SIZE_i$ is the average household size for each respondent; INC_i is the average income for each household; β_0 is the constant; β_1 to β_6 are coefficients; and ε is the standard error.

Equation (2) was estimated in two parts. First, it was estimated to establish the impact of biographic variables on water consumption behaviour. More precisely, six water consumption behaviours were established and each was regressed against the biographic characteristics of respondents. The water consumption behaviours regressed were 'run tap while brushing teeth, ignore water leaks, run tap while washing dishes, run tap while rinsing cutlery, run tap to defrost food, and ignore a dripping tap'. More specifically, the regression models examined the probability of selecting 'NEVER' given the biographical variables of each respondent. The second set of probit models was estimated to establish the impact of biographic characteristics on the adoption of water-saving technologies. In this regard, two models were estimated, the first one on 'ownership of water-efficient appliances, and the second on installation of water-efficient technologies'. The two regression models examined the probability of selecting 'YES' given the biographical variables of each respondent. The approach adopted in this study was also used in other similar studies (see Shan *et al.*, 2015; Fan *et al.*, 2017, 2019; Murwirapachena, 2021).

Probit regression modelling was deemed appropriate in the context of this study for several reasons. For example, unlike logit models, probit models are more sensitive to outliers which makes them ideal in the context of this study where sample is heterogeneous. Furthermore, probit models can overcome the challenges of linear probability models because their predicted probabilities are always between 0 and 1. Thus, probit models provide the likelihood of an item falling into one of a range of categories by estimating the probability that observation with specific features will belong to a particular category (Aldrich & Nelson, 1984). Such estimation cannot be provided by linear and logit models which generally give the odds of success of an item as a function of independent variables. The main objective of this study is to establish the probability of a participant adopting efficient water consumption behaviour and/or technology given their biographical characteristics. Thus, probit modelling was ideal in achieving this objective. Equally, many advantages of probit regression modelling over linear and logit models have seen the former adopted in many studies which examine the determinants of household water use (see Murwirapachena, 2021; Karaaslan *et al.*, 2022; Ibáñez-Rueda *et al.*, 2022). However, while probit models are preferred in the context of this study, the study does not argue that they are always superior to logit models. The choice of model is usually determined by the objectives and nature of data. As a result, some similar studies adopt logit models (Liao *et al.*, 2019; Lazaric *et al.*, 2020; Amoah *et al.*, 2021).

DATA AND DESCRIPTIVE STATISTICS

As described in the previous section, data were collected from 300 participants and was equally drawn from the various spatial areas of the city, namely, suburbs (100 participants), townships (100 participants), and informal settlements (100 participants). This distribution gave a fair representation of the spatial dynamics within the city. The descriptive statistics of the data collected are presented in Table 1.

The average household size in the sample was four members which was slightly above the national average of 3.34 (Statistics South Africa, 2021). Informal settlements reported the least average age of 37 years, while townships had the highest average age of 41 years, implying that relatively younger people stayed in the informal settlements compared to townships and suburbs, respectively. More females participated in the survey for all strata, except for the informal settlements where males were more than females. Most of the participants were Blacks which is a true reflection of the actual population dynamics in the city and in South Africa (Statistics South Africa, 2021). Furthermore, most respondents owned the properties they lived in, and all participants from the townships and suburbs accessed potable water services inside the house, while only 34% of participants from the informal settlements accessed water services in their yard. This is generally the case in South Africa where households in the suburbs and townships have improved access to water services (du Plessis *et al.*, 2020; Murwirapachena, 2021; Ngobeni & Breitenbach, 2021). Furthermore, all respondents in the suburbs owned water-efficient appliances and had them installed in their properties. However, no participant owned or had water-efficient technologies installed in the informal settlements. These descriptive statistics shed light on the data and give intuitions on the behaviour of the sampled participants.

Table 1 | Descriptive statistics ($N = 300$).

		Suburbs	Townships	Informal settlements	All areas combined
Household size		4	5	4	4
Age		39	41	37	39
Gender (%)	*Male*	40	49	53	47
Race (%)	*Black*	19	58	100	59
	White	69	11	–	27
	Indian/Asian	8	31	–	13
	Coloured	4	–		1
Education level (%)	*No formal education*	–	1	8	3
	Primary school	1	7	17	9
	High school	3	17	50	23
	Certificate	21	35	17	24
	Diploma/Degree	26	27	8	20
	Postgraduate	49	13	–	21
Property ownership (%)	*Owner*	81	85	55	74
	Tenant	16	10	30	19
	Other	3	5	15	7
Access to water (%)	*Inside dwelling*	100	100	–	67
	In the yard	–	–	34	11
	Community tap	–	–	66	22
Monthly income (%)	*< R3 000*	–	–	22	7
	R3 001–R6 000	–	1	47	16
	R6 001–R9 000	–	14	31	15
	R9 001–R20 000	9	52	–	20
	> R20 000	91	33	–	42
Appliance ownership (%)	*Yes*	100	59	–	53
	No	–	41	100	47
Installation of water-saving equipment (%)	*Yes*	100	77	–	59
	No	–	23	100	41
N		100	100	100	300

In addition to the above, participants were asked to describe the quality of their potable water and 36% indicated that their water quality was excellent, 26% indicated it was good, 24% suggested it was poor, and 14% indicating bad. Thus, 38% of the sampled participants were not satisfied with the quality of their potable water. Most participants also complained about the time taken by the municipality to fix water leaks, while those from informal settlements further indicated that community taps were fewer and cause people to wait longer in queues to get water. Equally, some people in the informal settlements walk long distances to access community taps. This is generally the case in most informal settlements across South Africa because most of these settlements exist on land that is not serviced and would therefore not have infrastructure for basic service delivery (Murwirapachena, 2022).

Furthermore, the households' daily water-use behavioural practices were elicited. Ten behavioural questions were asked using a Likert scale with four options (i.e., Never, Occasionally, Always, and Not applicable). Selecting the option 'Never' implied that participants were extremely water-conserving in their daily consumption behaviours, while selecting 'Always' suggested that their behaviour was wasteful. Figure 2 shows the frequency distributions of response on the 10 behavioural questions.

Except for the first three questions where the modal response was 'Occasionally', Figure 2 shows that the sampled participants practiced efficient water consumption behaviours. Thus, participants were conscious to water-conserving behavioural practices which are applauded in the literature (Bernedo *et al.*, 2014; Hasan *et al.*, 2021). Water-conserving behaviour is essential especially in Durban and South Africa at large, where rising population growth, climate change and economic development are pressuring the limited water resources. These responses are consistent with those reported in the city of Johannesburg by Murwirapachena (2021) and confirms that South Africans in the major cities generally practice efficient water consumption behaviours. In addition, it is important to note that several participants indicated 'Not applicable' in nine of the 10 questions. This was expected considering that the sample included participants from the informal settlements who do not have water infrastructure that warrants such behaviour. In that case, participants would choose 'Not applicable'. Nevertheless, it can be summarised that the sampled participants generally practiced water-efficient behaviour in their daily consumption activities.

FINDINGS

The aim of this study was to examine the impact of biographic characteristics on water consumption behaviour and the adoption of water-saving technologies. Several other studies in the literature examine the impact of biographical characteristics on water consumption behaviour (Russell & Knoeri, 2020; Dean *et al.*, 2021; Martinez & Maia, 2021). The common biographical characteristics that are usually examined include gender, age, education level, household size, and income levels (Araya *et al.*, 2020; Cauberghe *et al.*, 2021; Lameck *et al.*, 2021). Thus, this study maintains consistency with other studies by examining the impact of gender, age,

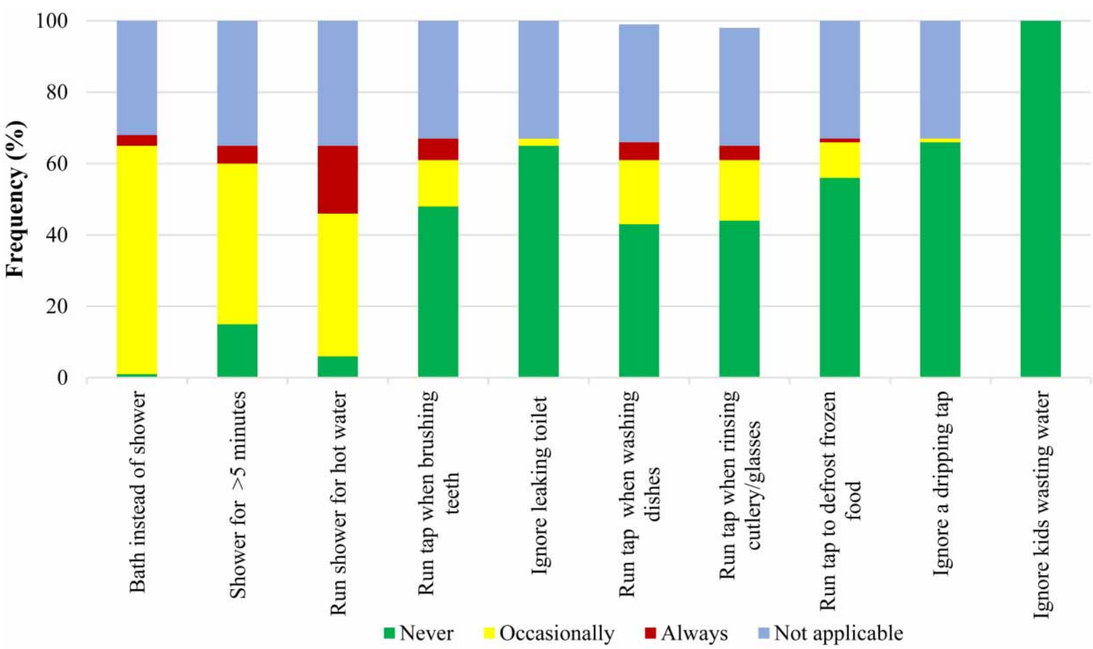


Fig. 2 | Responses on respondents' daily water behaviour.

education level, home ownership, household size, and income levels on both water consumption behaviours and the adoption of water-efficient technologies. This is essential because some evidence exists that the impact of biographic characteristics on water consumption behaviours varies from one place to the other (Araya *et al.*, 2020; Cauberghe *et al.*, 2021; Dean *et al.*, 2021; Lameck *et al.*, 2021; Martinez & Maia, 2021).

Probit regression models were used to estimate the individual impact of the selected biographical characteristics on water consumption behaviours and the adoption of water-efficient technologies. Prior to these estimations, correlation tests were run to establish whether the problem of multicollinearity existed among the explanatory variables. If multicollinearity exists among explanatory variables, estimation results will be unreliable due to problems that exist when fitting the models (Gujarati & Porter, 2021). Therefore, a Pearson correlation test was used to measure the strength and direction of association among the explanatory variables. The Pearson correlation test was preferred because some of the biographic variables were continuous. Correlation values range from 0 to 1, where a correlation value of 0 implies no association between variables, while a correlation value of 1 implies a very strong association (Gujarati & Porter, 2021). Thus, the strength of association of variables increases as the correlation value approaches 1. Results from the correlation test are presented in Table 2.

In addition to the six biographical variables mentioned earlier, two other variables were included in the correlation test as possible determinants of water consumption behaviours (i.e., area type and access type). The correlation coefficients in Table 2 are generally very small, except for those between 'area type and income', 'access type and income', as well as 'access type and area type' which all have absolute coefficients greater than 0.8. This implies that closer relationships exist between these variables. Thus, modelling them together as explanatory will produce spurious relationships that can have an impact on the reliability of results (Gujarati & Porter, 2021). Therefore, 'income' was used as a proxy for 'area type' and 'access type'. This is consistent with reality where people commonly reside in different areas depending on their income levels (Parikh *et al.*, 2020; Mottiar, 2021). Thus, the probit regression models estimated in the study had six biographical characteristics as explanatory variables.

The impact of biographic characteristics on water consumption behaviour

As indicated earlier, probit regression modelling requires a binary dependent variable (Aldrich & Nelson, 1984). However, in this study participants were asked 10 water consumption behavioural questions using a 4-point Likert scale with the options 'Never, Occasionally, Always, and Not applicable'. Participants who chose 'Never' were considered to be performing efficient water consumption behaviours. Therefore, we follow Murwirapachena (2021) and deduced a dummy binary variable from the Likert scale responses, where all 'Never'

Table 2 | Pearson correlation matrices for the possible explanatory variables.

	Gender	Age	Edu	Ownership	Household size	Income	Area type	Access type
Gender	1.000							
Age	0.009	1.000						
Edu	0.132	−0.044	1.000					
Ownership	0.057	−0.307	−0.127	1.000				
Household size	0.105	0.153	0.112	−0.128	1.000			
Income	0.083	0.150	0.607	−0.271	0.248	1.000		
Area type	− 0.106	−0.100	−0.657	0.252	−0.184	−0.861	1.000	
Access type	− 0.067	−0.178	−0.558	0.271	−0.258	−0.827	0.817	1.000

responses were coded 1, and 0 otherwise. This was done for all the 10 behavioural questions. However, out of the 10 behavioural questions, only questions where 'Never' was the modal response were selected for further analysis. There was a behavioural question where all respondents indicated 'Never'. This question was excluded from further analysis because it had no variability in responses, and regression analysis would have been pointless. In this backdrop, only six of the 10 behavioural questions were analysed further. Thus, probit regression models were estimated for each of the six behavioural questions using the generated dummy variable as the dependent variable. In this context, the regression models examined the probability of selecting 'Never' given the biographical variables of each respondent. Results for each model are presented in Table 3.

The results in Table 3 are read based on the statistical significance and the sign of the coefficient of each biographical variable in each model. Statistically significant relationships exist when the *p*-value is less than 0.001 (i.e., significance at 1%), or *p*-value is greater than 0.001 but less than 0.005 (i.e., significance at 5%) or *p*-value is greater than 0.005 but less than 0.010 (i.e., significance at 10%). On the other hand, a negative coefficient implies that there is a negative relationship between a given biographical characteristics and the given water consumption behavioural practice. Thus, a positive coefficient implies otherwise.

The results show income as the most consistent variable which is statistically significant at 1% across all consumption behavioural models. The coefficient is consistently positive across all models. Results on the relationship between the level of income and water consumption behavioural practices imply that households with higher income levels were likely to practice water-efficient behaviours in their daily water consumption activities. This revelation is consistent with findings from similar studies, Addo *et al.* (2018) and Moglia *et al.* (2018) in Australia, Barnett *et al.* (2020) in Northern Utah (United States), and Murwirapachena (2021) in Johannesburg (South Africa) which also report a positive relationship between income and efficient water consumption behaviour.

Household size has the second greatest number of significant coefficients across all models. The variable has positive coefficients which are statistically significant in three models. It is statistically significant at 5% in the first model and at 1% in the other two models, implying that households with more members are more likely to practice efficient water consumption behaviour in their daily consumption activities. Generally, households with many members can reduce water consumption by sharing activities like washing laundry and dishes (Alarcón *et al.*, 2019). Members in larger households generally share resources such as bathroom, so people take short showers to allow others to quickly get their turns (Barnett *et al.*, 2020). The behaviours by larger households which are reported in the literature support the results of positive relationships between household size and water-efficient water consumption.

Age and the level of education are statistically significant in two models, both with positive coefficients. This implies that out of the six models, age and education were only important in two models. The results separately suggest that relatively educated people were likely not to ignore water leaks and dripping taps, while relatively older people were likely not to run the tap when brushing teeth and ignore water leaks. These results are consistent with findings from other studies in the literature which also report age and education to have a positive impact on water consumption behavioural practice (Ehret *et al.*, 2021; Onyenankeya *et al.*, 2021).

Gender has a positive coefficient that is statistically significant at 10% in one model. The variable was dummy coded to reflect 1 if male and 0 otherwise. Thus, the negative coefficient means that males were more likely not to run a tap when rinsing cutlery. This is concerning given that females generally spend more time doing house chores than males, yet results indicate that males are more conscious to water-efficient behaviour when rinsing dishes and cutlery. Differently, home ownership is revealed to be an unimportant determinant of water consumption behaviour. However, the intercepts which are consistently negative and statistically significant across all models suggest that apart from the biographical variables, other factors which cause inefficient water consumption behaviours exist.

Table 3 | The relationship between consumption behaviour and biographic characteristics.

	Run tap to brush teeth	Ignore water leaks	Run tap to wash dishes	Run tap to rinse cutlery	Run tap to defrost	Ignore drip tap
Gender	−0.261 [0.172]	0.226 [0.271]	−0.210 [0.170]	−0.295* [0.172]	−0.050 [0.182]	0.090 [0.327]
Age	0.027*** [0.010]	0.038** [0.020]	0.005 [0.010]	0.005 [0.010]	0.010 [0.011]	0.011 [0.022]
Education	0.116 [0.078]	0.325*** [0.126]	−0.055 [0.079]	−0.061 [0.079]	0.093 [0.082]	0.313** [0.148]
Home ownership	−0.152 [0.153]	−0.064 (0.231)	−0.022 [0.153]	−0.021 [0.154]	−0.001 [0.167]	−0.152 [0.261]
Household size	0.094** [0.050]	−0.036 [0.078]	0.127*** [0.050]	0.142*** [0.050]	0.071 [0.053]	0.087 [0.092]
Income	0.528*** [0.093]	1.363*** [0.178]	0.675*** [0.101]	0.695*** [0.102]	0.805*** [0.105]	1.841*** [0.277]
_cons	−3.446*** [0.666]	−7.194*** [1.278]	−2.990*** [0.676]	−2.951*** [0.681]	−3.913*** [0.742]	−7.715*** [1.501]
LL	−151.1	−54.5	−152.7	−150.5	−121.9	−38.5
χ^2	113.2	280.8	105.0	110.0	167.7	307.6
Prob $> \chi^2$	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R^2	0.272	0.721	0.256	0.267	0.407	0.800
Observations	300	300	300	300	300	300

Note: ***, ** and * = statistical significance at 1%, 5%, 10% level, respectively. Standard errors are shown in parenthesis.

While estimates presented in Table 3 show the relationship between water consumption behavioural practices and biographic characteristics, it is important to understand the exact impact of each biographic variable on the given behavioural practice. Such information is obtained from the estimation of average marginal effects. Williams (2012) explains a margin as a statistic based on a fitted model in which some of or all the covariates are fixed. In most cases, marginal effects are changes in response to a change in a covariate, which is reported as a derivative. For example, a marginal effect of 0.4 means that the dependent variable increases with the independent variable at a rate such that, if the rate was constant, the dependent variable would increase by 0.4 if the independent variable increased by 1. In this study, the average marginal effects of all covariates for efficient water consumption behaviours were estimated and results are presented in Supplementary material, Appendix 1.

The statistical significances of the margins were consistent with those reported earlier in Table 3. Thus, income has the most statistically significant margins, followed by household size, age and education, and gender in that order. Equally, the signs of the statistically significant margins are like those reported earlier in Table 3. The least absolute significant marginal effect is 0.004 reported for 'age' in Model 2 (i.e., ignore leaks), while the largest is 0.196 reported for 'income' in Model 4 (i.e., run tap to rinse cutlery). In terms of the least absolute significant marginal effect, this result means that the probability of not ignoring water leaks increases with age at a rate such that, if the rate was constant, the probability of not ignoring water leaks would increase by 0.004 if age increased by 1. For the largest absolute significant marginal effect of 0.196 reported, it means that the probability of not running the tap while rinsing cutlery increases with income levels at a rate such that, if the rate was constant, the probability of not running the tap while rinsing cutlery would increase by 0.196 if income levels increased by 1. Generally, it is observed from the results that the level of income has the largest marginal effects on behavioural practices. This is observed across all models.

In the context of water supply utilities with no clearly defined and known water consumption policies, these results are important when such utilities undertake activities that aim to reduce household water consumption. The major implication is that cities like Durban with consistent water shortages and excessive water demand can be able to know which population groups to target when undertaking roadshows and other household water conservation campaigns. Currently, the city continuously appeals to households to reduce water consumption through the adoption of efficient behaviour (eThekwini Municipality, 2021). Like in many other South African cities, Durban continuously struggles to meet rising water demand. Generally, the average water consumption in South Africa is 237 L/c/d, a figure which is extremely higher than the world average of about 173 L/c/d (Du Plessis *et al*., 2020; Murwirapachena, 2021; Ngobeni & Breitenbach, 2021). This generally implies that serious efforts should be used to enforce and nudge households to practice efficient water consumption behaviour. Thus, having clear and specific information such as the impact of each socio-biographic characteristic on water consumption behaviour is critical when developing policies and undertaking campaigns that seek to promote efficient water consumption by households.

The impact of biographic characteristics on the adoption of water-saving technology

The study also examined the impact of biographical variables on the ownership and installation of water-saving appliances. Respondents were asked two dichotomous (Yes or No) questions on the ownership of water-saving appliances and the installation of such appliances. About 53% of the respondents indicated that they owned water-saving appliances such as efficient washing machines and dish washers, while 59% had water-efficient equipment installed in their homes. For each of these two questions, a binary variable was captured where a 'Yes' response was coded 1, and 0 otherwise. Probit regression models were then estimated to examine the relationship between the biographic characteristics of respondents with ownership and installation of water-efficient technologies, respectively and results are presented in Table 4.

Table 4 | The relationship between biographical characteristics and using efficient appliances.

	Ownership of efficient appliances	Installation of efficient technologies
Gender	0.196 [0.225]	0.059 [0.244]
Age	0.001 [0.013]	0.005 [0.015]
Education	0.429*** [0.103]	0.303*** [0.106]
Home ownership	−0.078 [0.220]	0.056 [0.228]
Household size	0.074 [0.067]	0.151** [0.074]
Income	1.106*** [0.146]	1.240*** [0.155]
_cons	−6.605*** [1.060]	−6.654*** [1.097]
LL	−80.4	−67.7
χ^2	253.9	270.7
Prob > χ^2	0.000	0.000
Pseudo R^2	0.612	0.667
Observations	300	300

Note: ***, ** and * = statistical significance at 1%, 5%, 10% level, respectively. Standard errors are shown in parenthesis.

Table 4 shows education and income as consistent determinants of both ownership and installation of water-saving appliances and technologies. These two variables are statistically significant at 1% in both models. In addition, household size is also an important determinant of the installation of water-efficient technologies, with a positive coefficient which implies that larger-sized households are more likely to install water-efficient technologies. Generally, the results are consistent with other studies in the literature which also report the same biographical characteristics as important determinants of water consumption behaviours (Millock & Nauges, 2010; Sparkman & Walton, 2017; Quesnel *et al*., 2020; Murwirapachena, 2021). Furthermore, the actual impact of biographical variables on the ownership and installation of water-saving appliances was examined using the marginal effects approach explained earlier in this section and results are presented in Supplementary material, Appendix 2.

The statistical significance of the margins reported education and income as consistently significant across the two models, while household size had a significant margin in the second model only. The sizes of the statistically significant margins were largely closer to each other for each variable, across the models. Thus, the results are interpreted to mean that the probability of owning water-efficient appliances increases with the level of education at a rate such that, if the rate was constant, the probability would increase by 0.063 if the level of education increased by 1. Furthermore, the probability of owning water-efficient appliances increased with the level of income at a rate such that, if the rate was constant, the probability would increase by 0.163 if the level of education increased by 1. Almost the same impact is reported for Model 2 which additionally shows that the probability of installing efficient appliances increases with the household size at a rate such that, if the rate was constant, the probability would increase by 0.019 if the household size increased by 1. The impact of biographical characteristics reported in this study are in line with those reported in similar studies (Aslam *et al*., 2021; Murwirapachena, 2021; Shahangian *et al*., 2021). It is evident that biographic characteristics are generally significant determinants of the adoption of water-saving appliances.

Since education and income are major determinants in the adoption of water-efficient technologies, it implies that water policy-makers should essentially subsidise water-efficient technologies for low-income households. This is important since low-income households constitute a very large population group in the city. Over a million people in Durban live below the food-poverty line and the intensity of poverty according to the 2016 Community Survey conducted by Statistics South Africa is above 40% (Statistics South Africa, 2016; COGTA, 2020). These statistics have been worse in the post COVID-19 era where the city continues to record high levels of unemployment, respectively hovering around 28.4 and 21.8% in the first and third quarter of 2022 (Statistics South Africa, 2022). Considering these unfavourable economic conditions and the revelation that inefficient behaviour is common among low-income households, it is imperative for policy-makers to subsidise water-efficient technologies for poor households. Currently in Durban, households occupying properties valued at less than R350,000 (about US$19,200) are exempted from paying for water services in line with the country's Free Basic Water Policy of 2001. This same property targeting approach can be used by the municipality to install water-efficient technologies in properties occupied by indigent and low-income households. While this may be a costly exercise, the long run return is huge since there is no direct substitute for water, especially in water-scarce environments like Durban.

CONCLUSION

In line with SDG6, most water utilities across the globe seek to promote sustainable access to improved water services for all. As such, various policies are adopted to promote both water supply sustainability and improved access. Due to high water scarcity levels, especially in arid and semi-arid regions, demand management water policies have been instrumental in addressing the pressure exerted on freshwater resources by rising demand due to population growth, industrialisation, and changing weather patterns. Demand management water policies generally emphasise the role of water consumers in conservation. Consequently, it is ideal for water supply utilities to understand the characteristics of water consumers and how they influence their propensity to adopt water-efficient consumption behaviours.

Some semi-arid countries (South Africa included) do not have clearly pronounced national and synchronised local policies on household water conservation. In most cases, different municipalities adopt different approaches to demand management. Such approaches would in some instances become more radical during periods of drought and/or extreme water scarcity. Adopted approaches would sometimes include water-saving tips usually published on municipal websites and other public places as well as an increase in water tariffs which is a common tool for water demand management. While tariffs can be useful in managing water demand, the price elasticity of water demand is generally low (i.e., water has relatively inelastic demand) making the gains from increased water tariffs extremely marginal.

South African municipalities should generally embrace the culture of nudging and/or enforcing households water conservation policies outside of increasing water tariffs. Such policies should be crafted and implemented even during times when water scarcity is at its lowest, as opposed to rushed intermittent restrictions during times of extreme water shortages. Thus, sustainable policies should be developed and households conscientized of the benefits of practicing sustainable water consumption behaviours. This is important in South Africa where water is generally a low-involving product that is usually ignored if it is available in good quality. To be effective, such policies should be tailored to suit the different demographic characteristics of households which are generally diverse in the context of South Africa.

This study provided practical evidence on household water consumption patterns and the relevance of socio-biographical characteristics in the formulation of water policies within the city of Durban. Using survey data collected from household heads, the study observed that households generally practice water-efficient behaviours in their daily consumption activities. However, efficient water-use behaviour was more prevalent in the suburbs and township compared to the informal settlements where residents did not have enabling water infrastructure. Access to water services in informal settlements is generally through community taps which imply difficulties in promoting efficient consumption. The study further observed the level of income as the most consistent determinant of water consumption behaviour, followed by household size, age and education, and gender, respectively. Generally, higher income households, larger-sized households, educated people, older people, and males were more likely to practice water-efficient behaviours and adopt water-saving technologies.

Key implications of findings from the study include the reality that the municipality should have clearly pronounced household water conservation policies which go beyond the use of water tariffs to manage consumption. An understanding of water consumption behaviours and patterns within the city is warranted. Such an understanding would then allow for the crafting and implementation of relevant household water conservation policies. More importantly, policies adopted in the city should be tailor made to suit the diverse population and spatial distributions of the city. This is important because water consumption patterns vary across suburbs, townships, and informal settlements. The revelation that less sustainable water consumption behaviours were among low-income households, smaller-sized households, relatively younger residents, less-educated residents, and female residents imply the need to devise policies that target these population groups. Thus, water demand management policies should be designed to nudge these population groups towards water consumption efficiency. The city should further devise policies that improve the design of community taps in informal settlements because excessive water wastage is commonly observed around community taps in the informal settlements. Therefore, 'push buttons' taps and/or 'self-closing' taps are recommended to control and prevent the continuous flow of water even after individuals have finished water collection.

While socio-biographic characteristics are essential in formulating water demand management policies, it is important to note that they are not always sufficient in capturing the water consumption behaviour of households. Policy variables can also play a role in pushing households towards sustainable water consumption behaviour. Apart from punitive measures that include water rationing and tariff increases which are usually adopted in the city of Durban, moral suasion can nudge households towards efficient consumption behaviour. One weakness of our study is that it could not include policy and moral suasion variables in the estimated models. This was because there are no clearly pronounced moral suasion policies in the city of Durban except for the water-saving tips that are usually published on the municipality's website. Therefore, the study recommends future research to also incorporate policy variables when estimating the determinants of household water consumption behaviour. Adding such variables will increase knowledge essential for water policy formulation. Furthermore, nuances such as households' attitude towards water conservation, their awareness levels, and methods of exercising controls on water consumption activities at home can also be explored in future research. Establishing such critical information will benefit water policy-makers, especially in the context of less developing countries where water is a less involved product that people usually ignore if it is reliably available and in good quality.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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