Urban household uptake of Water Sensitive Urban Design source control measures: An exploratory comparative survey across Cape Town and Pretoria, South Africa

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Abstract

Water Sensitive Urban Design (WSUD) presents a process towards the objective of a water-sensitive city. An integrated approach requires community acceptance to implement WSUD at household level. An exploratory comparative survey was conducted amongst 250 households across Cape Town and Pretoria, South Africa, to determine actual uptake of rainwater harvesting, greywater recycling systems and permeable paving, factors affecting uptake, and the perceived effectiveness of assistance to implement WSUD relative to other water demand-side management instruments. Actual uptake of rainwater harvesting and greywater reuse is noticeable amongst water-saving middle-to-high income home owners. Although loglinear analyses suggest that Cape Town's recent drought is unlikely to contribute towards more established levels of uptake, assistance to implement WSUD is nevertheless perceived as the second most effective instrument. Three directions for more systematic research are proposed to better inform the practical implementation of WSUD at household level.

Keywords: Day Zero; Water Sensitive Urban Design; rainwater harvesting; greywater reuse systems; permeable paving; water demand-side management

Introduction

Feldman (2017) describes a 'water-sensitive city' as having minimal adverse effects on water resources and a positive water-energy nexus forming part of a holistic framework involving all aspects of the water system. Such a framework has three principal sets of options, i.e., (1) low-energy approaches for substitution, and (2) regenerating and (3) conserving fresh water (see also Rohr, Cilliers and Fourie [2017]). These innovations should be implemented at neighbourhood or household level alongside traditional infrastructure in order to make these more acceptable and reliable to communities.

Water sensitive urban design (WSUD) presents a process towards the objective of a water-sensitive city. Early conceptions of WSUD were broad, but centred around stormwater management (Beza, Zeunert and Hanson 2019). More recent conceptions regard WSUD as encompassing "all aspects of integrated urban water cycle management, including water supply, sewerage and stormwater management" (Fletcher et al. 2015, 528). Considering that democratic societies favour a bottom-up approach towards development that involves all stakeholders, Carmon and Shamir (2010) point out the importance of civic awareness of and participation in the implementation of WSUD. Several other authors also point out the importance of community acceptance, suggesting that an integrated approach is needed to implement WSUD (Nancarrow, Porter and Leviston 2010; Bell 2015; Sharma et al. 2016; Dobbie, Farrelly and Brown 2017; Rohr, Cilliers and Fourie 2017; Schirmer and Dyer 2018; Beza, Zeunert and Hanson 2019; Toxopeüs, 2019) Donofrio et al. (2009), however, point out that resistance to change, especially from communities, is a challenge facing sustainable development in cities. Considering an integrated approach in which community acceptance and uptake are integral to implement WSUD at household level, we ask what is the current level of WSUD uptake in a developing country context, which factors influence uptake, and what is the perceived effectiveness of assistance to implement WSUD relative to other water demand-side management (DSM) instruments.

While household water conservation has been researched extensively (see, e.g., Dolnicar, Hurlimann and Grün [2012] and Fielding et al. [2012]), research on household uptake of WSUD source control measures is more limited. Mankad and Tapsuwan (2011) review the literature on socio-economic drivers of community acceptance and adoption of decentralised alternative water supply systems, i.e., “the collection, treatment and use of rainwater, stormwater runoff, greywater and black water”. Communities generally appear open to such systems, though acceptance is strongly dependent upon culture, perceived risk, and the level of personal contact with such water. The literature, however, is also criticised for focusing on acceptance based on intentions and hypothetical scenarios instead of actual uptake and the factors influencing uptake. Some exceptions are noted.

Mason, Arwood and Shires (2018) examined seasonal patterns and socio-economic predictors of rainwater and greywater use, and found that Philippine households use rainwater and greywater widely but in seasonal ways, particularly households with more members and less financial resources and access to utilities. Ward et al. (2013) present triangulated results form a literature review and survey on household receptivity to rainwater harvesting in the UK. They too find that households are generally receptive to rainwater harvesting, but that cost and maintenance concerns require improved product development, capacity building, and support. Housebuilders in the UK, however, perceive several barriers to the installation of rainwater harvesting systems in new homes, including institutional and regulatory gaps, absence of incentives, lack of information and technical knowledge, and opposing attitudes from housebuilders themselves (Parsons et al. 2010).

Australia appears more prominent in WSUD research, including research on community responses. Pinto and Maheshwari (2010) found that about half of households in Western Sydney reuse greywater, and that households identify water quality as the most important consideration in greywater reuse for irrigation. Similar to the UK, households are concerned about costs and risks, while there is a need for information to improve “greywater reuse literacy”. Dzidic and Green (2012) used photo-elicitation surveys coupled with interviews, and, similar to the studies cited above, found most respondents felt that different WSUD options were important to have. Yet, respondents were concerned about aesthetics and appearances *vis-à-vis* their neighbours, highlighting the role of norms in community acceptance of WSUD. Schirmer and Dyer (2018) surveyed residents in Canberra about water-sensitive gardening practices, and developed a framework for the identification of factors influencing WSUD uptake, which is discussed in more detail later.

While experimental research may be more common in practice, it appears limited in journals compared to non-experimental research such as cross-sectional surveys. Odom Green et al. (2012) conducted a citizen-based stormwater management study in a suburb along a watershed in Cincinnati, USA. The study involved an education campaign and two successive reverse auctions in which residents could voluntarily bid for the installation of “dispersed stormwater management practices” on their property. A total of 81 rain gardens and 165 rainwater tanks were installed on approximately one-third of 350 local properties, resulting in an estimated 360 m^3 increase in stormwater detention capacity. Participation also appeared to be influenced by norms as many participating properties formed clusters, suggesting that agglomerations may eventually lead to a neighbourhood-wide shift towards more sustainable stormwater management practices.

Research on household uptake of WSUD in a South African urban context is limited. Fisher-Jeffes et al. (2017) considered the viability of rainwater harvesting in the Liesbeek River catchment in Cape Town, and concludes that rainwater harvesting improves water security, prevents flooding, and provides additional benefits. Further research is called for regarding the willingness of different sections of the South African society to harvest rainwater.

Households in informal settlements lacking stormwater infrastructure appear to use partially effective coping measures such as water channels. Uptake of measures such as rainwater harvesting appears limited, especially where dwelling structures are not conducive for water harvesting and municipal water is freely available. Community-based initiatives may have greater potential provided these form part if *in situ* upgrading with support from relevant government and non-government agencies (Adegun 2014).

More exploratory and comparative research is needed about *actual* household uptake of WSUD source control measures in both a developed and developing country context to determine if more systematic research is justified and what such research may involve (see also Gilbertson, Hurlimann and Dolnicar [2011]). The aim of this article is therefore to explore and compare urban household uptake of WSUD source control measures across two South African cities, Cape Town and Pretoria. South Africa is around the 30th driest country in the world, receiving an average 450 mm/a of rainfall compared to a global average of 990 mm/a (Republic of South Africa 2013). Cape Town and Pretoria present two contrasting cases. Cape Town is a more compact city by South African standards with approximately 4 million people (Statistics South Africa 2016), experiencing a coastal winter rainfall climate. Shortly before this study in 2018, Cape Town suffered a major drought that required the city to prepare for ‘Day Zero’ – a stage at which water storage levels would reach 13.5% requiring municipal water supply to be shut down intermittently (Madonsela et al. 2019). Cape Town avoided Day Zero with a collective effort unprecedented in South Africa. Pretoria is a more sprawled city with approximately 3.3 million people (Statistics South Africa 2016), experiencing an inland highlands summer rainfall climate.

We explore household uptake in terms of (1) past, present and future uptake of three WSUD source control measures, i.e., rainwater harvesting, greywater reuse systems and permeable paving, (2) possible factors influencing uptake, and (3) the perceived effectiveness of assistance to implement WSUD relative to other water DSM instruments. Rainwater harvesting, greywater reuse systems, and permeable paving have been linked to WSUD source control measures and water DSM instruments at household level (Vernon and Tiwari 2009; Ahammed 2017), and are some of the more feasible measures for South African urban households (Armitage et al. 2014). These three measures also represent different aspects of integrated urban water cycle management, i.e., water supply, sewerage and stormwater management (Fletcher et al. 2015). We subsequently present our research design, methods and findings, and discuss directions for more systematic research.

Research design and methods

The Water Resources competence area in the South African Council for Scientific and Industrial Research (CSIR) conducted a cross-sectional survey of urban household water use during 2018 across South African metros, which included Cape Town and Pretoria. The CSIR survey aimed to inform the development of more effective water DSM instruments. The Departments of Psychology and Town and Regional Planning at the University of Pretoria (UP) collaborated with the CSIR and introduced the theme of

WSUD. The CSIR team designed a questionnaire on household water use and DSM instruments, after which the UP team included a module of questions on the three WSUD source control measures identified above, i.e., rainwater harvesting, greywater reuse systems and permeable paving. Given the exploratory purpose of the survey, several independent variables hypothesised to influence household water use were included in the questionnaire. The questionnaire was piloted with seven households in Cape Town and 12 in Pretoria after which it was finalised.

Ethical clearance was obtained from the Research Ethics Committees of the CSIR (Ref. 240/2017) and the Faculty of Engineering, Built Environment and Information Technology at UP (Ref. EBIT43/2018). Clearance required informed consent and voluntary participation from household members of 18 years or older, for responses to remain anonymous, and for data to be managed according to institutional policies. No incentives were offered for participation.

CSIR and UP fieldworkers attended rigorous training during which the survey and questionnaire were explained, mock interviews were conducted, and the fieldwork and safety protocols were established. UP fieldworkers included Planning students as part of a project-based learning initiative in which students could use part of the dataset for their final-year research reports. Students were supervised by CSIR and UP team members and each student signed a declaration to abide by the ethical requirements as well as the fieldwork and safety protocols.

The CSIR team liaised with the municipalities of Cape Town and Pretoria and compiled a sample of neighbourhoods in Cape Town and Pretoria stratified by suburb and township[1], with suburbs stratified by income area and level of water consumption. Fieldworkers in teams of two initially surveyed 400 households (200 each in Cape Town and Pretoria) from sampled neighbourhoods using a convenient door-to-door sample across different dwelling types. Fieldworkers interviewed heads of households or the household member considered most capable to answer questions about the household characteristics and water use. The CSIR team conducted quality controls at the end of each day in preparation for the next day of fieldwork.

The CSIR and UP team facilitated a debriefing workshop at the end of the fieldwork during which students shared lessons learnt and were trained to capture the data in Microsoft Excel. Following cross-checks by the UP team, data were exported, cleaned, and analysed using Statistical Package for the Social Sciences, Version 27. Considering the focus on WSUD, findings are based on a subsample of 250 households in freestanding houses and single-storey duplexes that rely on municipal, borehole or bottled water as their main source of potable water – 125 households each from Cape Town and Pretoria, with 90 households from suburbs and 35 from townships. Given the small sample and categorical nature of the data, data were analysed using log-linear analyses, Chi-square and Fisher's exact tests, and Cramér's *V* for effect sizes ($\alpha = 0.05$).

[1] 'Suburb' included any former 'white' predominantly residential neighbourhood beyond the central business district within the municipal boundaries that included a noticeable proportion of freestanding houses amongst other housing types. 'Township' included any former 'black' formal settlement within the municipal boundaries that included a noticeable proportion of freestanding houses amongst other housing types.

Findings

Findings are presented in terms of (1) past, present and future uptake of three WSUD source control measures, i.e., rainwater harvesting, greywater reuse systems and permeable paving, (2) possible factors influencing uptake, and (3) the perceived effectiveness of assistance to implement WSUD relative to other water DSM instruments.

Table 1 shows past, present and future uptake of the three WSUD measures. Households were asked to indicate whether they used each of the three measures 'this time last year', 'now', and whether they thought they would use these 'this time next year'. The results in Table 1 indicates the proportion of households using each of the three measures. Chi-square and Fisher's exact tests were conducted to test for significant differences between Cape Town and Pretoria (df = 1). Chi-square tests are based on the likelihood ratio considering the small sample, whereas Fisher's exact test was used where expected counts were < 5.

Table 1 shows that, in total, the proportion of households using any of the three measures increased from 47.6% in the previous year to 48.4% at the time of the survey, and was expected to increase to 53.2% the following year. Thus, almost half of households across Cape Town and Pretoria indicated to have used at least one of the three measures at the time of the survey, and more than half indicated that they would use at least one of the measures the following year. Actual uptake is, however, likely to be lower due to social desirability bias, and some households having interpreted greywater reuse systems to include manual greywater reuse with buckets. In total, significantly larger proportions of households in Cape Town reported past, present and future uptake compared to Pretoria, highlighting the possible effect of Day Zero. Pretoria, however, showed a noticeably higher increase in future uptake, yet, this

Table 1. Past, present and future uptake of Water Sensitive Urban Design source control measures. (Continued on next page.)

Settlement type	WSUD measure	Time period	Cape Town Count	Cape Town %	Pretoria Count	Pretoria %	Total Count	Total %	Significance
Suburb	Rainwater harvesting	Past	44	48.9	16	17.8	60	33.3	$p < 0.001$[a]*
		Present	48	53.3	19	21.1	67	37.2	$p < 0.001$[a]*
		Future	49	54.4	34	37.8	83	46.1	$p = 0.025$[a]*
	Grey-water reuse systems	Past	44	48.9	19	21.1	63	35.0	$p < 0.001$[a]*
		Present	48	53.3	17	18.9	65	36.1	$p < 0.001$[a]*
		Future	52	57.8	27	30.0	79	43.9	$p < 0.001$[a]*
	Permeable paving	Past	4	4.4	15	16.7	19	10.6	$p = 0.006$[a]*
		Present	5	5.6	17	18.9	22	12.2	$p = 0.005$[a]*
		Future	6	6.7	19	21.1	25	13.9	$p = 0.004$[a]*
	Combined	Past	62	68.9	38	42.2	100	55.6	$p < 0.001$[a]*
		Present	66	73.3	37	41.1	103	57.2	$p < 0.001$[a]*
		Future	67	74.4	46	51.1	113	62.8	$p = 0.001$[a]*
Township	Rainwater harvesting	Past	2	5.7	0	0.0	2	2.9	$p = 0.493$[b]
		Present	2	5.7	0	0.0	2	2.9	$p = 0.493$[b]
		Future	7	20.0	0	0.0	7	10.0	$p = 0.011$[b]*
	Grey-water reuse systems	Past	10	28.6	4	11.4	14	20.0	$p = 0.069$[a]
		Present	10	28.6	4	11.4	14	20.0	$p = 0.069$[a]
		Future	10	28.6	5	14.3	15	21.4	$p = 0.244$[a]
	Permeable paving	Past	1	2.9	5	14.3	6	8.6	$p = 0.198$[b]
		Present	1	2.9	5	14.3	6	8.6	$p = 0.198$[b]
		Future	1	2.9	6	17.1	7	10.0	$p = 0.106$[b]
	Combined	Past	10	28.6	9	25.7	19	27.1	$p = 0.788$[a]
		Present	10	28.6	8	22.9	18	25.7	$p = 0.584$[a]
		Future	11	31.4	9	25.7	20	28.6	$p = 0.596$[a]

Notes: [a] Chi-Square Test (Likelihood ratio); [b] Fisher's Exact Test; * Significant at the 0.05 level.

Table 1. Past, present and future uptake of Water Sensitive Urban Design source control measures. (Continued from previous page.)

Settlement type	WSUD measure	Time period	Cape Town Count	Cape Town %	Pretoria Count	Pretoria %	Total Count	Total %	Significance
Total	Rainwater harvesting	Past	46	36.8	16	12.8	62	24.8	$p < 0.001$[a]*
		Present	50	40.0	19	15.2	69	27.6	$p < 0.001$[a]*
		Future	56	44.8	34	27.2	90	36.0	$p = 0.004$[a]*
	Grey-water reuse systems	Past	54	43.2	23	18.4	77	30.8	$p < 0.001$[a]*
		Present	58	46.4	21	16.8	79	31.6	$p < 0.001$[a]*
		Future	62	49.6	32	25.6	94	37.6	$p < 0.001$[a]*
	Permeable paving	Past	5	4.0	20	16.0	25	10.0	$p = 0.001$[a]*
		Present	6	4.8	22	17.6	28	11.2	$p = 0.001$[a]*
		Future	7	5.6	25	20.0	32	12.8	$p < 0.001$[a]*
	Combined	Past	72	57.6	47	37.6	119	47.6	$p = 0.001$[a]*
		Present	76	60.8	45	36.0	121	48.4	$p < 0.001$[a]*
		Future	78	62.4	55	44.0	133	53.2	$p = 0.003$[a]*

Notes: [a] Chi-Square Test (Likelihood ratio); [b] Fisher's Exact Test; * Significant at the 0.05 level.

increase is from a lower basis compared to Cape Town. In total, the order of present uptake ranges from greywater reuse systems (31.6%) to rainwater harvesting (27.6%) to permeable paving (11.2%). Significantly larger proportions of households in Cape Town used rainwater harvesting and greywater reuse systems, whereas a significantly larger proportion of households in Pretoria, where properties are generally larger, used permeable paving.

Uptake is foremost in suburbs, as more than double the proportion of households in total reported past, present and future uptake compared to the proportion of households in townships. Moreover, while uptake in suburbs increases over time, uptake in townships actually decreases over time (see also Adegun [2014]). Significantly larger proportions of suburban households in Cape Town reported combined past, present and future uptake compared to Pretoria, again highlighting the possible effect of Day Zero. Apart from future uptake of rainwater harvesting, there are no significant differences in uptake by township households between Cape Town and Pretoria. Any effect of Day Zero is clearly limited to suburbs.

The findings therefore suggest noticeable levels of uptake of rainwater harvesting and greywater reuse systems, or at least manual greywater reuse, amongst suburban households in freestanding houses. The level of uptake signals the need for more systematic research using larger samples for multivariate analyses. While Day Zero appeared to effect uptake given the differences between Cape Town and Pretoria, uptake is limited to suburbs, suggesting that uptake in a South African context is, *inter alia*, driven by settlement type and factors associated with suburban settlements, notably economic enablers such as income. It should be noted that the South African government policy of free basic services that requires all municipalities to supply a substantial quantity of free water to poorer households probably plays a role, in the absence of which uptake in townships may arguably be higher.

Table 2 shows possible factors influencing uptake in suburbs. Variables hypothesised to predict uptake were clustered into three sets, i.e., ‘contextual/physical’, ‘behavioural/ situational’, and ‘socio-demographic’ (see also Schirmer and Dyer [2018]). ‘Uptake’ here is whether households used any of the three measures presently. Findings are limited to suburbs to control for differences between settlement type and because the subsample for townships was too small for separate bivariate analyses. Table 2 first shows results from log-linear analyses to determine any significant three-way effects (city × predictor × uptake), followed by Chi-square and Fisher’s exact tests for significant differences between predictor categories, and effect sizes for each predictor using Cramér’s *V*. For each log-linear analysis, all expected counts were > 1 and more than 20% of expected counts were > 5. The likelihood ratio of each model was $\chi^2(0) = 0$, $p = 1$. Chi-square tests are also based on the likelihood ratio considering the small sample, whereas Fisher’s exact test was used where expected counts were < 5 (df = 1).

Table 2 first shows that none of the log-linear analyses yielded any significant three-way effects, thus, there are no significant differences between Cape Town and Pretoria in terms of the effect any of the predictors had on uptake. Although current uptake of all three measures combined is significantly higher in Cape Town suburbs (73.3%) compared to Pretoria suburbs (41.1%) (see Table 1), the effect of Day Zero appears to be an immediate response by households to drastic measures, rather than a mediator of factors that may contribute to more established levels of uptake. Scenarios such as Day Zero should probably not be seen as a primary driver of uptake – assistance to implement WSUD at household level is likely to remain important.

Table 2. Predictors of Water Sensitive Urban Design uptake within suburbs. (Continued on next page.)

Predictor set	Predictor	Log-linear Analysis (Likelihood ratio)	City	Chi-Square Test (Likelihood ratio) Fisher's Exact Test	Cramér's *V*
Contextual / Physical	Source of water	$\chi^2(1, 180) = 0.269, p = 0.604$	Cape Town	N = 90; $p = 0.378$[b]	0.106
			Pretoria	$\chi^2(1, 90) = 0.202, p = 0.653$[a]	0.047
			Total	$\chi^2(1, 180) = 1.980, p = 0.159$[a]	0.106
	Size of stand	$\chi^2(1, 118) = 2.690, p = 0.101$	Cape Town	N = 53; $p = 0.298$[b]	0.183
			Pretoria	$\chi^2(1, 65) = 0.980, p = 0.322$[a]	0.122
			Total	$\chi^2(1, 118) = 2.283, p = 0.131$[a]	0.139
	Size of house	$\chi^2(1, 106) = 1.433, p = 0.231$	Cape Town	N = 47; $p = 1.000$[b]	0.040
			Pretoria	$\chi^2(1, 59) = 2.262, p = 0.133$[a]	0.190
			Total	$\chi^2(1, 106) = 0.672, p = 0.413$[a]	0.079
Behavioural / Situational	Existing water-saving behaviour	$\chi^2(2, 180) = 0.280, p = 0.861$	Cape Town	$\chi^2(2, 90) = 11.516, p = 0.003$[a]*	0.378*
			Pretoria	$\chi^2(2, 90) = 17.363, p < 0.001$[a]*	0.416*
			Total	$\chi^2(2, 180) = 31.464, p < 0.001$[a]*	0.413*
	Announcements of water restrictions	$\chi^2(1, 106) = 0.091, p = 0.763$	Cape Town	N = 71; $p = 0.463$[b]	0.099
			Pretoria	N = 35; $p = 0.238$[b]	0.201
			Total	$\chi^2(1, 106) = 2.733, p = 0.098$[a]	0.165
	Enforcements of water restrictions	$\chi^2(1, 105) = 0.057, p = 0.811$	Cape Town	$\chi^2(1, 71) = 0.004, p = 0.949$[a]	0.008
			Pretoria	N = 34; $p = 1.000$[b]	0.060
			Total	$\chi^2(1, 105) = 0.004, p = 0.950$[a]	0.006

Notes: [a] Chi-Square Test (Likelihood ratio); [b] Fisher's Exact Test; * Significant at the 0.05 level.

Table 2. Predictors of Water Sensitive Urban Design uptake within suburbs. (Continued from previous page.)

Predictor set	Predictor	Log-linear Analysis (Likelihood ratio)	City	Chi-Square Test (Likelihood ratio) Fisher's Exact Test	Cramér's *V*
Socio-demographic	Income area	$\chi^2(2, 180) = 0.443$, $p = 0.801$	Cape Town	$\chi^2(2, 90) = 2.513$, $p = 0.285$[a]	0.174
			Pretoria	$\chi^2(2, 90) = 2.266$, $p = 0.322$[a]	0.158
			Total	$\chi^2(2, 180) = 13.567$, $p = 0.001$[a]*	0.274*
	Household size	$\chi^2(2, 177) = 4.415$, $p = 0.110$	Cape Town	$\chi^2(2, 90) = 0.680$, $p = 0.712$[a]	0.087
			Pretoria	$\chi^2(2, 87) = 9.037$, $p = 0.011$[a]*	0.322*
			Total	$\chi^2(2, 177) = 3.203$, $p = 0.202$[a]	0.133
	Highest level of education in household	$\chi^2(2, 170) = 0.228$, $p = 0.892$	Cape Town	$\chi^2(2, 84) = 1.600$, $p = 0.449$[a]	0.141
			Pretoria	$\chi^2(2, 86) = 0.416$, $p = 0.812$[a]	0.070
			Total	$\chi^2(2, 170) = 1.202$, $p = 0.548$[a]	0.084
	Age of head of household	$\chi^2(2, 162) = 2.177$, $p = 0.337$	Cape Town	$\chi^2(2, 81) = 2.817$, $p = 0.244$[a]	0.181
			Pretoria	$\chi^2(2, 81) = 2.000$, $p = 0.368$[a]	0.153
			Total	$\chi^2(2, 162) = 3.155$, $p = 0.207$[a]	0.139
	Ownership status	$\chi^2(1, 171) = 0.019$, $p = 0.890$	Cape Town	N = 85; $p = 0.137$[b]	0.177
			Pretoria	N = 86; $p = 0.177$[b]	0.169
			Total	$\chi^2(1, 171) = 4.570$, $p = 0.033$[a]*	0.164*

Notes: [a] Chi-Square Test (Likelihood ratio); [b] Fisher's Exact Test; * Significant at the 0.05 level.

In the bivariate analyses, only three predictors had a significant effect on uptake in total (Cape Town and Pretoria combined), i.e., (1) existing water-saving behaviour, (2) income, and (3) home ownership. Respondents were asked to report water-saving measures, including constant flow regulators, smart metering, water-saving shower heads, dual flush toilets, eco-settings on appliances, timed sprinklers, and manual greywater reuse. In total, a significantly larger proportion of households that used one or two (66.7%) or three or more (71%) of the water-saving measures above also used at least one WSUD measure, as opposed to households that used none of the water-saving measures (20.9%), but used at least one WSUD measure. Existing water-saving behaviour had the strongest effect on uptake (Cramér's $V = 0.413$; $p < 0.001$), which corresponds with studies highlighting the influence of pro-environmental behaviour (see, e.g., Fielding et al. [2012], Schirmer and Dyer [2018], and Amodeo and Francis [2019]). A significantly larger proportion of households in mixed (middle to high) income suburbs (67.6%) used at least one WSUD measure as opposed to households in middle (37.5%) or high (57.9%) income suburbs. While income appears to be a significant predictor of uptake, households in the uppermost income bracket are probably more reluctant to install unappealing rainwater harvesting tanks or retrofitted plumbing. Consequently, income had a weak to moderate effect (Cramér's $V = 0.274$; $p = 0.001$). Lastly, a significantly larger proportion of households who own the house (60.3%) used at least one WSUD measure as opposed to households who rent (35%) (see also Pinto and Maheshwari [2010], and Owusu and Teye [2015]), although the effect of ownership is weak (Cramér's $V = 0.164$; $p = 0.032$). Contrary to other studies (Fielding et al. 2012; Baiyegunhi 2015; Schirmer and Dyer 2018), age and education were not significant predictors. The lack of prediction by contextual/physical factors suggest that it may be challenging to guide WSUD at household level in the absence of more systematic research to examine the possible effect of such factors more carefully.

Table 3 shows the perceived effectiveness of different water DSM instruments, including assistance to implement WSUD. Respondents were asked to rank each of the seven instruments in Table 3 from most to least effective in causing their household to reduce municipal water use. After excluding cases with missing or duplicate rankings, rankings were grouped into three categories, i.e., 'most effective' (if ranked amongst the first three), 'neither effective nor ineffective' (if ranked fourth), and 'least effective' (if ranked amongst the last three). Percentages in Table 3 are for instruments ranked 'most effective', and instruments are sorted from the largest to smallest total percentage (Cape Town and Pretoria combined). Chi-square tests based on the likelihood ratio determined significant differences between Cape Town and Pretoria. All expected counts were $\geq$ 0.9 and more than 20% of expected counts in each test were > 5 (df = 2).

Assistance to implement water-saving measures (constant flow regulators, smart metering, water-saving shower heads, etc.) were perceived as most effective to reduce municipal water use in total (Cape Town and Pretoria combined), followed by assistance to implement WSUD measures (rainwater harvesting, greywater reuse systems and permeable paving), and tax incentives for reducing water use, with no significant differences between Cape Town and Pretoria. Clearly, households thought that constructive rather than punitive instruments would be more effective. A significantly larger proportion of households in Cape Town (52.4%), however, thought general water restrictions to be more effective compared to Pretoria (42.5%), highlighting the role of water restrictions as part of Day Zero. The first, second and third most effective instruments were also ranked similarly across suburbs and townships. In fact, suburban households in Cape Town thought assistance to implement

Table 3. Proportion of households ranking different water demand-side management instruments as most effective. (Continued on next page.)

Settlement type	Municipal water demand-side management instrument	Cape Town		Pretoria		Total		Significance
		Count	%	Count	%	Count	%	
Suburb	Assistance to implement water-saving measures	25	56.8	44	77.2	69	68.3	$p = 0.024$*
	Assistance to implement water-sensitive design measures	27	61.4	36	63.2	63	62.4	$p = 0.968$
	Tax incentives for reducing or limiting water use	24	54.5	34	59.6	58	57.4	$p = 0.833$
	General water restrictions	23	52.3	24	42.1	47	46.5	$p = 0.054$
	Fines for increasing use or using water above a certain quantity	13	29.5	17	29.8	30	29.7	$p = 0.019$*
	Water rate increases	11	25.0	13	22.8	24	23.8	$p = 0.599$
	Naming and shaming of our neighbourhood for increasing use or using water above a certain quantity	9	20.5	4	7.0	13	12.9	$p = 0.124$
Township	Assistance to implement water-saving measures	15	78.9	17	73.9	32	76.2	$p = 0.884$
	Assistance to implement water-sensitive design measures	14	73.7	16	69.6	30	71.4	$p = 0.953$
	Tax incentives for reducing or limiting water use	12	63.2	12	52.2	24	57.1	$p = 0.444$
	General water restrictions	10	52.6	10	43.5	20	47.6	$p = 0.425$
	Water rate increases	1	5.3	7	30.4	8	19.0	$p = 0.090$
	Fines for increasing use or using water above a certain quantity	3	15.8	4	17.4	7	16.7	$p = 0.976$
	Naming and shaming of our neighbourhood for increasing use or using water above a certain quantity	2	10.5	3	13.0	5	11.9	$p = 0.729$

Notes: * Significant at the 0.05 level.

Table 3. Proportion of households ranking different water demand-side management instruments as most effective. (Continued from previous page.)

Settlement type	Municipal water demand-side management instrument	Cape Town		Pretoria		Total		Significance
		Count	%	Count	%	Count	%	
Total	Assistance to implement water-saving measures	40	63.5	61	76.3	101	70.6	$p = 0.059$
	Assistance to implement water-sensitive design measures	41	65.1	52	65.0	93	65.0	$p = 0.978$
	Tax incentives for reducing or limiting water use	36	57.1	46	57.5	82	57.3	$p = 0.973$
	General water restrictions	33	52.4	34	42.5	67	46.9	$p = 0.023$*
	Fines for increasing use or using water above a certain quantity	16	25.4	21	26.3	37	25.9	$p = 0.062$
	Water rate increases	12	19.0	20	25.0	32	22.4	$p = 0.472$
	Naming and shaming of our neighbourhood for increasing use or using water above a certain quantity	11	17.5	7	8.8	18	12.6	$p = 0.299$

Notes: * Significant at the 0.05 level.

WSUD to be most effective. Many suburban households in Cape Town may already have implemented several water-saving measures in response to Day Zero, and probably saw WSUD as the next step towards better use of water.

Directions for more systematic research

Considering the findings, we propose three directions for more systemic research on household uptake of WSUD. We propose research to specifically augment the literature on WSUD and to better inform the practical *implementation* of WSUD source control measures at household level. Table 4 outlines the three directions in terms of important theoretical and methodological considerations for social research in the built environment (see, e.g., Du Toit and Mouton [2013]).

There are several theoretical frameworks for studying pro-environmental behaviour (Kollmuss and Agyeman 2002). We propose two validated frameworks to shape the first two directions. These include the Theory of Planned Behaviour (TPB) (Ajzen 2011) (see Figure 1), and the Values, Awareness, Identity and Life-style (VAIL) framework (Schirmer and Dyer 2018) (see Figure 2).

The TPB is widely used to study pro-environmental behaviour, especially water conservation (see, e.g., Fielding et al [2012]), and is shown to have stronger predictive power than other theories of pro-environmental behaviour (Chao 2012). In short, if a person has a positive attitude towards a behaviour, e.g., to harvest rainwater, and feels both pressured (subjective norm) and able (perceived behavioural control) to do so, the person is likely to form a strong intention and to harvest rainwater in future. The roles of attitude, norm and control in household water conservation are well-established (Parsons et al. 2010; Pinto and Maheshwari 2010; Dzidic and Green 2012; Ward et al. 2013; Feldman 2017). 'Control' alone is useful to predict household participation in at-source stormwater management (Brown et al. 2016). Although not part of the original

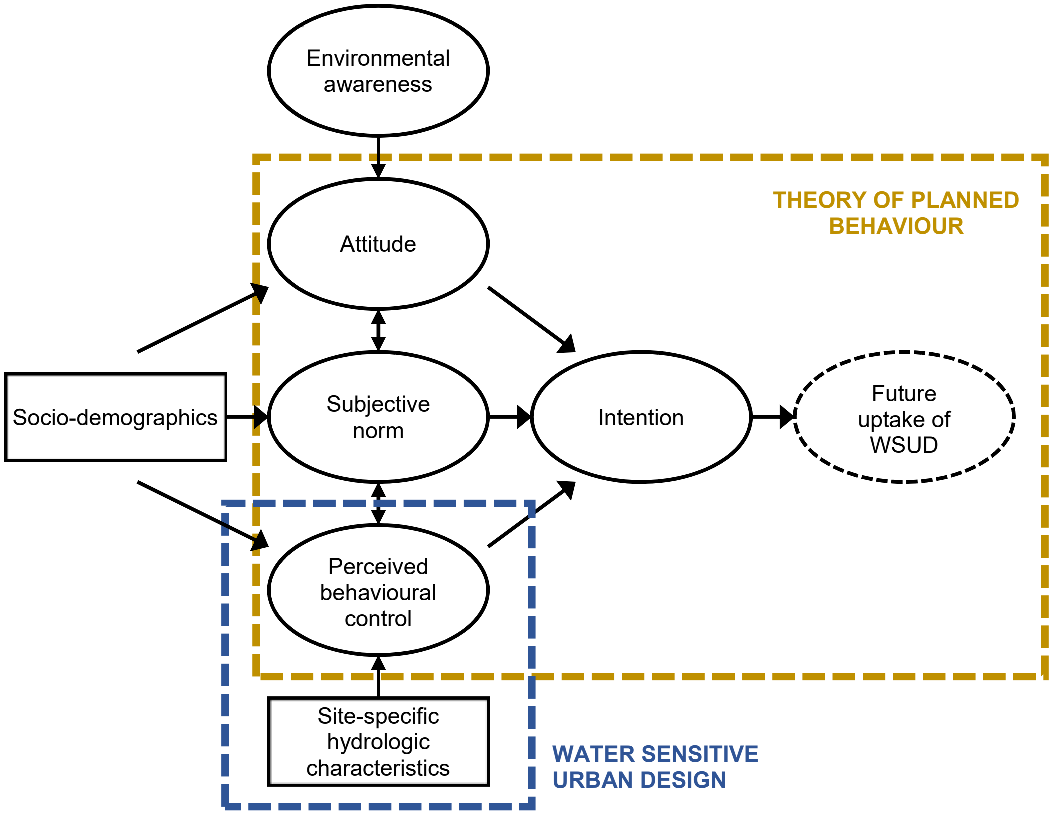
Table 4. Directions for more systematic research on household uptake of Water Sensitive Urban Design source control measures.

Considerations	Direction		
	1	**2**	**3**
Theoretical framework	Theory of Planned Behaviour (TPB)	Values, Awareness, Identity and Lifestyle (VAIL) framework	
Mode of reasoning	Deductive (theory-testing)	Deductive (theory-testing)	Inductive (theory-generating)
Main research question	*What is the effect of control (e.g., physical) factors relative to attitudinal and normative factors on household uptake of WSUD, and what are the implications for the implementation of WSUD at household level?*	*What is the relative effect of values, awareness (of, e.g., physical factors), identity, and lifestyle factors on household uptake of WSUD, and what are the implications for the implementation of WSUD at household level?*	*What unique combinations of factors appear to contribute to exemplary cases of household uptake of WSUD within a given context, and how can planners and designers better facilitate WSUD at household level within that context?*
Research purpose	Descriptive, explanatory	Descriptive, explanatory	Exploring exemplary cases of uptake, formulating practical planning and design recommendations
Methodological paradigm	Post-positivist	Post-positivist	Critical realist / Pragmatic
Methodological approach	Quantitative	Quantitative	Qualitative
Research design (and core logic)	Survey (generalisation)	Survey (generalisation)	Case study (contextualisation) Grounded theory (induction)

TPB, we suggest including socio-demographics to better understand differences between households and how such differences effect household ability to adopt WSUD (see also Nancarrow, Porter and Leviston [2010]). In a study of more than 3000 Australians, Dolnicar, Hurlimann and Grün (2012) point out that water conservation is foremost influenced by “a high level of pro-environmental behaviour” (environmental awareness in general) and “pro-actively seeking out information about water” (control) (see also Kollmuss and Agyeman [2002]). We therefore suggest including environmental awareness as a separate construct to differentiate between householders’ environmental awareness and attitudes toward specific WSUD measures. The New Ecological Paradigm scale offers a widely used measure for environmental awareness in terms of “pro-ecological” worldview (Dunlap et al. 2000).

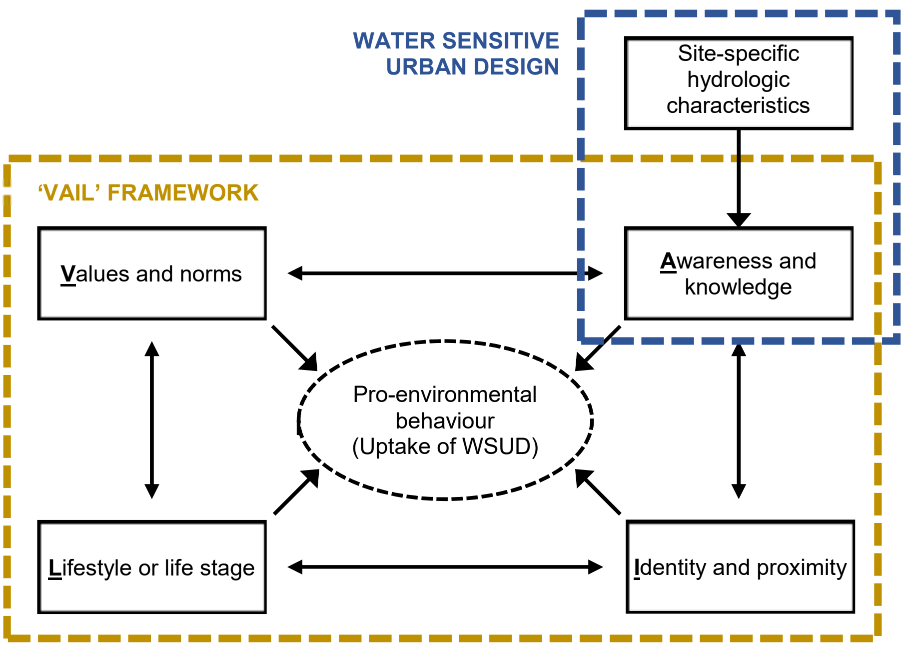
The VAIL framework is more flexible and was developed to identify contextual factors influencing pro-environmental behaviour in relation to WSUD. Considering a study’s local context, factors can be identified in four domains, i.e., pro-environmental values and norms (environmental awareness), awareness and knowledge of environmental problems and possible solutions (control), proximity and placed-based identity, and life-stage or life-style (socio-demographics) (Schirmer and Dyer 2018). In a study in Canberra, Australia, Schirmer and Dyer identified 22 ‘VAIL’ factors relevant to the local context and surveyed more than 3300 residents to predict water-friendly gardening practices. The factors explained a significant amount of variance, highlighting further possibilities for facilitating water-friendly gardening practices.

Figure 1. Application of the Theory of Planned Behaviour



Note: Adapted from Ajzen (2011).

Figure 2. Application of the Values, Awareness, Identity and Lifestyle framework



Note: Adapted from Schirmer and Dyer (2018).

Situational or contextual factors, particularly the characteristics of a physical setting, can significantly enable or disable pro-environmental behaviour (Corraliza and Berenguer 2000; Steg and Vlek 2009). Both the TPB and VAIL framework are useful in that regard since the constructs of ‘control’ (in the TPB) and ‘awareness and knowledge’ (in the VAIL framework) can be operationalised to focus on householders’ ability to adopt WSUD in relation to physical factors. As depicted in Figures 1 and 2, these constructs can incorporate physical factors relevant to the implementation of WSUD, in particular site-specific hydrological properties such as roof coverage, but also other factors such as settlement and dwelling type. A better understanding of how such factors influence householders’ ability to adopt WSUD may lead to planners and designers being better able to facilitate WSUD at household level, e.g., site planning that better facilitates permeable paving, and architectural design that better facilitates rainwater harvesting and greywater recycling. The main research question for the first two directions is therefore about the relative effect of physical factors on household uptake of WSUD, and what the implications are for the implementation of WSUD at household level. Research in these two directions is meant to describe and explain the effects of different factors by means of quantitative surveys that enable generalisations.

While research on household uptake of WSUD appears limited, qualitative and participatory forms of research are arguably more so. Fisher-Jeffes, Carden and Armitage (2017) point out the importance of balancing WSUD with issues of equity in a developing country, and educating and encouraging residents in both formal and informal areas to be more water-sensitive. Madonsela et al. (2019) in turn state that it is crucial for cities like Cape Town to ask what ‘water sensitivity’ means considering poverty, inequality, lack of services and context-specific challenges. For the third direction we propose grounded theory research that asks *what unique combinations of* *factors appear to contribute to exemplary cases of household uptake of WSUD in both formal and informal contexts, and how can planners and designers better facilitate household uptake in such contexts?* Research in this direction is meant to be more explorative and participatory in terms of formulating practical and context-specific water-sensitive planning and design recommendations that are informed by in-depth qualitative case studies of specific households and communities.

Conclusion

Considering an integrated approach in which community acceptance and uptake are integral to implement WSUD source control measures at household level, we conducted an exploratory comparative household survey across Cape Town and Pretoria to determine actual uptake of rainwater harvesting, greywater recycling systems and permeable paving, factors affecting uptake, and the perceived effectiveness of assistance to implement WSUD relative to other water DSM instruments. With noticeable levels of rainwater harvesting and greywater recycling, particularly amongst water-saving middle-to-high income home owners, and with assistance to implement WSUD perceived as the second most effective water DSM instrument, we discussed directions for more systematic quantitative theory-testing and qualitative theory-generating research to better understand household behaviour and the practical implementation of WSUD source control measures at household level. The implementation of WSUD, however, requires stronger institutional arrangements and cooperation between water managers and urban planners (Gober et al. 2013), and education and empowerment of communities to enhance a collective effort towards water-sensitive cities (Benton-Short and Keeley 2017). These themes also require further research.

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