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Examining Biophysical and Socio-Demographic Factors across Mandated Tank Users in Urban Australia: A Linking Step towards Achieving Best Practices

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Abstract This study examines biophysical and socio-demographic factors potentially affecting water use patterns of households with mandatory rainwater tanks in South East Queensland (SEQ). The Queensland Development Code (QDC) MP 4.2 promotes the use of rainwater tanks at the domestic level to reduce direct reliance on mains water supply. A sample of 1,134 mandated rainwater tank households were surveyed across SEQ. Results indicated that the majority of participants (78%) had tanks of 5 kL in capacity or larger, with 35% of householders having at least half of roof catchment area connected to their tanks. Also, the majority of participants utilised their rainwater for toilet flushing (97%), clothes washing (94%) and garden irrigation (77%). These biophysical findings indicate a high level of compliance with the QDC MP 4.2 code. Social factors affecting potential yields from mandated rainwater tanks were also examined, to complement the biophysical data obtained. It was found that the majority of tank users were happy to use rainwater as an alternative water supply option for non-potable uses.

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However, most participants reported being unaware of past or present water restrictions to their water supply, highlighting important social implications for total mains water savings. In conclusion, this study presents important biophysical and social descriptions about mandated water users in urban SEQ, as well as providing a foundation for future modelling of actual yields from mandated rainwater tanks to facilitate improved assessment of mains water savings due to the implementation of mandated rainwater tanks.

Keywords Decentralised water supply · Community perceptions · Alternative water · Water restrictions

1 Introduction

The implementation and use of alternative water resources is increasing globally, due to factors such as climate change, agricultural production and population growth, all of which contribute significantly to urban water shortages (Bates et al. 2008; Sharma et al. 2009). This is certainly the case in highly urbanised, water stressed regions of Australia (e.g. Queensland). As a result, future water strategies in many urban cities emphasise a reliance on the sourcing and utilisation of decentralised water systems such as rainwater tanks, greywater systems and groundwater bores (Sydney Water 2008; Queensland Water Commission 2009; Sharma et al. 2010). Decentralised systems allow households to collect, treat and reuse localised water resources for applications where high quality water is not required. The key benefit of these systems is in reducing householders' reliance on mains water and providing water on a fit-for-purpose basis (Tjandraatmadja et al. 2009). While the focus region of this study is South East Queensland (SEQ), the findings are highly relevant to other urbanised regions where decentralised systems are in the process of being integrated with centralised water sources, or have already been incorporated within the traditional urban water grid. This study examines various biophysical and socio-demographic descriptors of those living with mandated decentralised systems, specifically rainwater tanks, in an urban environment, to provide greater insight into aspects of decentralised water acceptance and applications that might affect actual performance of rainwater tanks on-site.

1.1 The Study Region: South East Queensland

SEQ is a relatively small region within the state of Queensland and it is the fastest growing metropolitan area within Australia. SEQ's population is heavily urbanised and is typically concentrated along the coast in Brisbane, Gold Coast and Sunshine Coast (Department of Local Government and Planning 2010). Typically, the region experiences high rainfall in summer due to its sub-tropical climate. However, the region experienced a severe drought from 2002 to 2007, resulting in extreme mandatory water restrictions throughout SEQ. Because of this, the SEQ Water Strategy was developed, in order to maintain water security in the region. This strategy was based on conserving household water, being prepared for ongoing need and managing water efficiently (Queensland Water Commission 2010). SEQ exercises permanent water conservation measures as part of this water management strategy. These measures involve the installation and use of water efficient irrigation fittings, restricted watering timings, and a daily target for personal water use set at 200 l (L) per person per day. The SEQ Water Strategy also provides guidelines for harnessing off-grid supplies by mandating the installation of decentralised water systems for all new residential dwellings and most new industrial and commercial buildings in a revised Queensland Development Code (QDC). This decentralised water was mandated to be used for appropriate non-potable end-uses indoors, as well as outdoor watering (Department of Infrastructure and Planning 2010).

It is expected that mains water savings of 70 kL/year can be achieved from rainwater tanks in each detached residential dwelling (QDC MP4.2). The guidelines for achieving this target mandate that household rainwater tanks should have a minimum volume of 5,000 l (5 kilolitres), with at least half of the available roof catchment area or 100 m^2 (i.e. whichever is lesser) connected to the tank (QDC MP4.2; DIP 2010). The Code stipulates that if a tank is installed, it is required to be plumbed into toilets, washing machine cold water taps and external taps of detached, single residential households. Gardiner (2009) reported that by 2008, over 300,000 tanks had been installed in SEQ and found that the key drivers for tank installation included conforming to QDC guidelines, government rebates for retrofitting of rainwater tanks, or personal investment due to existing environmental conditions (e.g. peri-urban landscapes). Since the QDC mandate was put into place, approximately 60,000 single detached dwellings in SEQ have been built with rainwater tanks (Australian Bureau of Statistics 2010). However, follow-up research as to whether households are actually using and setting-up their rainwater tanks appropriately, whether they are achieving the stipulated mains water savings, and whether they are correctly maintaining their rainwater tanks are far from conclusive (e.g. Coombes and Kuczera 2003).

1.2 Past Research on Rainwater Tank Yields

Previous studies on domestic rainwater tank yields and savings have found mixed results (e.g. Ghisi 2010; Khastagir and Jayasuriya 2011; Zhang et al. 2010). Coombes and Kuczera (2003) reported that rainwater tanks could yield annual reductions in mains water use from 18 to 144 kL (kL) in Brisbane, depending on the tank size and household occupancy. However, the study was based on pre-drought rainfall data and assumed that rainwater was used for hot water systems, which is not a permitted use of rainwater in SEQ. In comparison, Marsden Jacob Associates (National Water Commission 2007) presented a number of modelled scenarios for Australian urban environments, where they have reported that rainwater tanks could reduce mains water consumptions by 42 kL/household (hh)/year (yr) if the tank was externally plumbed or 71 kL/hh/yr if the tank was plumbed to both external *and* internal water fixtures. Importantly, both these figures were modelled dependent upon a roof catchment area of at least 50% connected to the rainwater tank. Thus, these studies established that for rainwater use to reduce the mains grid water demand, connected roof area, household occupancy, rainfall and tank size were influential factors. It is also important to note that predictions related to potential water savings were limited by the local climatic conditions input into the various rainwater tank simulation models (e.g. pre-drought water use). Therefore, while the findings are interesting, there are a number of biophysical and socio-demographic factors that were not properly controlled or validated in these models and thus, may have affected the actual water savings estimation in these analyses.

Turner and colleagues (2005) also conducted a desktop study which looked at differences in mains water use between households in Sydney with retrofitted efficient showerheads, installation of tap flow regulators and toilet cistern flush arrestors under residential demand management programs and those households without such water-efficient fixtures. The 24,000 single residential homes that engaged in the retrofit programme were randomly selected and paired with non-retrofitters, using a 2-year period of pre-intervention water consumption data. The study found that each retrofitted house used approximately 21 kL/hh/yr less mains water, when compared with the non-retrofitted households. At the State level, the Department of Planning in New South Wales (NSW) responded to drought conditions and water shortages by implementing water demand management strategies and household level installations to minimise centralised water use. This Building Sustainability Index (BASIX) was used as an online mechanism to implement minimum sustainability performance for all new dwellings in NSW. As discussed in Beal and colleagues' (2011a) desktop analysis of potable water savings, the BASIX program used a water use benchmark of approximately 324 kL/hh/year and this was based on the average household water consumption in NSW. To validate whether the BASIX program had been successful, Sydney Water linked BASIX data to quarterly water consumption data of participating households (Sydney Water 2008). Results showed that the BASIX target of 40% reductions was achieved with average water consumption of 192 kL/hh/yr, representing a 40.5% reduction on the BASIX benchmark, during 2007–2008. Interestingly, when the BASIX data were adjusted by using *actual* household occupancy (i.e. not *estimated* household occupancy) obtained from a telephone survey, the average reductions improved to 42%. While in this instance the difference between using estimated and actual household occupancy was not substantial, the analysis demonstrated the importance of knowing actual household occupancy information, in order to confidently estimate the reduction in mains water consumption from households with rainwater tanks. This is particularly important, given the trend for newer residential dwellings to have a higher household occupancy than existing households, in all major cities within Australia (Sydney Water 2008).

The BASIX study also highlighted the importance of obtaining accurate details on potential biophysical factors that influence residential water consumption (tank size, dwelling type, rainwater end-uses) that may not be fully taken into account when using generalised Census data. Overall, the context for Sydney Water's work with respect to mandating rainwater tanks in new homes was comparable to the situation taking place in SEQ. Therefore, the BASIX research serves as a methodological model for the research being carried out in the present study. However, the BASIX study did not take into account complementary socio-demographic factors (e.g. attitudes toward water use, risk and threat perceptions) that may also be valuable indicators of rainwater use and mains water savings. The present study addresses these limitations to provide a more rounded understanding of mandated tank users in an urban environment.

1.3 Objectives

The purpose of this study is to examine key factors that might potentially affect water use patterns at identified households with mandatory rainwater tanks in SEQ. A biophysical and socio-demographic survey was developed to identify all key household characteristics that have been identified as potentially influencing rainwater use in past literature. Physical characteristics include tank size, connected roof area, rainwater end-uses, actual household occupancy, garden and property size and type, as well as the types of water appliances and fixtures. Social elements examined are rainwater satisfaction (e.g. colour, odour), water use behaviours and perceptions of water issues in SEQ. As part of this exploratory work, researchers will also attempt to gain an understanding of the installation practices specific to these homes, to ensure that rainwater tanks are set up to the correct standards outlined by the QDC MP 4.2 code. This information is likely to be key in future research examining whether mains water consumption can be reduced as a result of factors such as the correct installation of decentralised systems, or whether socio-demographic factors (e.g., attitudes, behaviours) may also explain water consumption changes. It is anticipated that the outcomes from this study will provide important physical and social information, as well as provide a foundation for subsequent modelling of actual yields from mandated rainwater tanks. This constitutes an important linking step that informs urban water planners and modellers towards the best practices of utilising alternative rainwater sources from domestic rainwater tanks to offset the mains grid water demands.

2 Method

2.1 Study Setting and Time Period

The study setting comprised four local government areas (LGAs) in the target SEQ region: LGA1 and LGA2 were situated north of Brisbane city, LGA3 was located east of the city and LGA4 was south of Brisbane. The 2006 Australian Census described these four LGAs as containing over 40% of SEQ's urban population (Department of Infrastructure and Planning 2009). It is acknowledged that there is some climatic variation across these LGAs which may potentially influence perceptual and actual water consumption behaviour. While this makes for an interesting discussion, the influence of climate variation is not the focus of the present study and therefore will not be discussed further in the present context.

2.2 Participants

A total of 1,134 households from the four LGAs participated in this study, with one person per household participating. The distribution of participants across these LGAs was relatively uniform, with 21% of households from LGA1, 30% from LGA2, 23% from LGA3, and 26% from LGA4. This study received ethical clearance from the relevant Human Research Ethics Committee.

2.3 Measures

A telephone survey was developed to measure key household demographic characteristics, physical property specifications and basic attitudinal and behavioural data.

2.3.1 Demographics and Biophysical Items

This component included items measuring household occupancy (number of adults and children), dwelling structure, property and house size, number of bedrooms per dwelling and number of bathrooms. Several other biophysical measures were also included, to provide an indication of the types of water appliances and fixtures in the house, size of rainwater tanks, estimation of roof connections to the tank (e.g. area connected, number of downpipes), water treatment, number of greywater systems (if any), and whether the tank was connected to a pump.

2.3.2 Social and Behavioural Items

These items were included so as to provide a perspective of water use beyond biophysical and demographic factors. Questions referred to water use habits in the home (e.g. for what purpose is rainwater used), satisfaction with the quality of one's rainwater supply (e.g. taste, colour, odour), knowledge of water restrictions (past or present), and one's perceived level of water usage (i.e. low, medium or high water user). Participants were also asked to cite their main concerns regarding water supplies in SEQ, as well as opinions on the risk of permanent water shortages in SEQ, now or in the future. These questions were included so as to provide an understanding of whether complementary cognitive factors, such as perceptions of threat vulnerability and severity derived from psychological theory (i.e. Rogers 1975, 1983) influenced attitudes toward rainwater use, beyond the influence of purely demographic and biophysical factors.

2.4 Procedure

This survey was conducted using the Computer Assisted Telephone Interviewing (CATI) approach. CATI is a telephone surveying technique in which the survey is conducted by an interviewer and the call takes place via a computer. Respondents' answers are recorded through direct insertion into data collation software.

Participants whose home address matched a valid telephone number were contacted during July and August 2010. Before commencing the survey, participants were asked several screening questions. Those without rainwater tanks, tenants of houses, owners or tenants of apartments/units, and those living in areas where recycled water was connected to the house for non-potable uses were not included in the sample, to minimise bias in the data. After the initial screening questions, surveys were administered and took approximately 10 min to complete. Data were collected and stored in a locked Excel file for further analysis.

2.5 Data Analysis

The number of participants recruited for this survey was based on proportional stratified random sampling with a maximum error rate of +/− 6.8% at the 95% confidence level. This gives an indication of the probability that a margin of error around the reported scores would include the "true" score. Along with the confidence level (i.e. the amount of uncertainty the analysis will tolerate, which in this case is 5%), the sample size for a survey helps to determine the magnitude of the margin of error. A larger sample size produces a smaller margin of error, all else remaining equal; thus the large sample size used in the present study is desirable.

Data were analysed using descriptive and correlational methodology, where appropriate, as well as thematic analyses (i.e. responses categorised based on content similarity) for open-ended qualitative questions. Means, standard deviations and sample proportions were calculated for the total sample, as well as for each region.

3 Results

3.1 Basic Compliance Criteria

Under the QDC MP 4.2, the acceptable solution for achieving up to 70 kL/hh/yr is the use of a 5 kL mandated rainwater tank, plumbed internally for toilet flushing, cold tap washing machine, as well as at least one external tap, and connected to at least half of the available roof catchment area or 100 m^2 (i.e. whichever lesser). In this study, it was important to assess whether homes met the basic compliance criteria before commencing future research on mains water saving from mandated rainwater tanks.

3.1.1 Tank Volumes

Results showed that of the 1,134 respondents, the volume of rainwater tanks at their premises varied moderately from the standard 5,000 l tank requirement. Approximately 8% of homes had a tank below the minimum tank size required (i.e. 5 kL), however the majority of homes (78%) were compliant and owned a tank with a volume of 5 kL or more. Interestingly, 14% of homeowners did not know the size of their rainwater tank. The outcomes were relatively comparable between the four LGAs, ranging from 75% (LGA4) to 81% (LGA1) compliance in having a tank volume of at least 5 kL. A Chi-square test for independence indicated no significant association between LGA and tank volume, χ^2=(15, 1134)=15.25, p=.43, Cramer's V=.07.

3.1.2 Roof Connection

The estimated proportion of connected roof catchment areas was also gathered in this study, an important component of the QDC MP 4.2. It was found 35% of householders estimated that the roof connection area for their rainwater tank met the required proportion of roof area (>50%) as per QDC guidelines. A minor proportion (11%) of respondents reported not knowing what percentage of their roof area was connected to the tank. Once again, a Chi-square test for independence indicated no significant association between LGA and proportion of roof connection, χ^2=(12, 1134)=11.90, p=.45, Cramer's V=.06.

3.1.3 Rainwater End Uses

With respect to rainwater end-use application, participants were allowed to give multiple responses and it was found that a high proportion of householders used rainwater for toilet flushing (97%), clothes washing (94%), garden irrigation (77%), car washing (54%) and swimming pool top-up (26%). Interestingly, more people reported using rainwater for indoor applications, in comparison to those using rainwater for outdoor end-uses. When the rainwater use data were further analysed according to specific LGAs (see Fig. 1), a Chi-square test for independence indicated significant association between LGA and garden irrigation, χ^2=(3, 1134)=9.88, p=.02, Cramer's V=.09; and a significant association between LGA and swimming pool top-up, χ^2=(3, 1134)=26.99, p<.001, Cramer's V=.15. It can be seen that compared to the other three LGAs, LGA4 revealed distinct rainwater use patterns geared more toward outdoor applications and this is reflected in the medium effect sizes computed (Cramer's V). This finding may be explained in terms of single detached dwellings located within LGA4 region having a larger block of land that may permit and encourage a greater outdoor living culture, such as a gardening area and a swimming pool. However, it is also important to reiterate here that local climatic conditions were not accounted for in this survey, therefore, these uses for rainwater may be a product of not only lifestyle, but also climate variation.

3.1.4 Use of Other Decentralised Water Systems

Since all single detached dwellings within SEQ are required to supply their own 70 kL/hh/yr of alternative water resources under the QDC Part MP 4.2, there was a possibility that some households may be using supplementary water sources other than rainwater. Therefore, participants were asked if they were using other water sources, such as greywater, wastewater or stormwater on the property. Results showed that only 7% of respondents reported having a greywater treatment system installed at their premises. Most other householders (90%) were

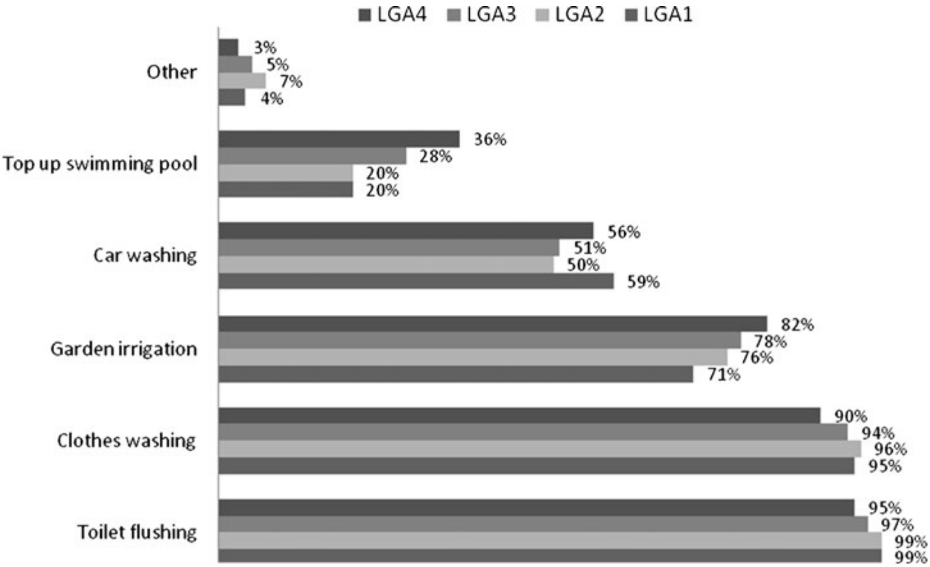

Fig. 1 Detailed analysis of percentage distributions for common end-uses of rainwater among specific LGAs

found to solely depend on the supply from rainwater tanks to meet the water savings target. The remaining 3% of households were not sure whether their premises were reticulated with greywater or any other alternative water systems. A detailed LGA-by-LGA analysis did not reveal any significant differences beyond those already reported regarding the use of other decentralised systems.

3.1.5 Use of Water-Efficient Fittings and Appliances

In addition to important biophysical characteristics of tank installation, it was also necessary to understand and identify any other synergistic factors that may contribute to the overall water savings from mandated rainwater tanks. In SEQ, local councils introduced a rebate scheme from 2006 to 2008 that promoted potable water savings via the installation of domestic water efficient fittings and appliances such as shower roses, taps and washing machines (Gardiner et al. 2008). In this study, a check was carried out as to whether the surveyed householders had installed these 'WaterWise' fittings as a way of saving mains water. Once again, participants were allowed to select more than one fitting/appliance. Results showed that most householders reported having domestic water-efficient fittings or appliances installed at their premises. Overall, a high proportion of respondents (91%) reported having low-flow shower roses installed, followed by a water-efficient washing machine (79%), water-efficient dishwasher (74%), and water-efficient irrigation system (25%). These results did not significantly vary across the four LGAs.

3.2 Physical House and Householder Characteristics

3.2.1 Housing Type

The physical house and householder characteristics of interest included the type of house, number of bedrooms and bathrooms within the house, as well as the occupancy rate within each household (i.e. number of adults, adolescents and children). Most participants reported living in a single storey dwelling, constituting 73% of the households, followed by 26% in double storey dwellings. The majority of homes were reported as comprising 4 bedrooms (56%) or 3 bedrooms (23%), with two bathrooms (81%). When these groupings were analysed for their distributions at the LGA level, a large variability was visible across the four LGAs. Homes in LGA1 and LGA2 were primarily single-story dwellings with four bedrooms and two bathrooms. Comparatively, homes in LGA3 and LGA4 comprised single- and double-story dwellings, with 3–4 bedrooms and 2–3 bathrooms. While in the present study these findings are merely used as descriptors of housing type, the differing dwelling characteristics have important implications for potential variability that may be seen across households with respect to their rainwater consumption and mains water savings, such as those discussed in Coombes and Kuczera (2003).

3.2.2 Household Occupancy

Household occupancy is one of the most important factors that might affect the water use patterns of each household, as discussed in the BASIX report (Sydney Water 2008). These family characteristics were grouped into categories that allowed a direct comparison with relevant 2006 ABS census district data (Table 1). Results showed that most families fell into the either couple (two-adult) families with children or couple families without children, with some variations across the four LGAs. When family characteristics were compared to the 2006 ABS census district data (2010), it was found that respondents in this survey were less representative of 'one-parent families' and over-representative of 'other/non-traditional family' structures.

3.3 Householder Attitudes and Behaviours

Apart from identifying key biophysical and demographic descriptors that may impact on the final water savings from mandated rainwater tanks, the present study also looked to understand community perceptions towards water usage and savings at the individual household level. This included measuring householders' attitudes, behaviours and perceptions toward their own water use pattern, awareness of water restrictions and other possible threats on the reliability of mains water supply.

Table 1 Comparison of family characteristics between survey respondents across the four LGAs, compared with 2006 ABS census district data (ABS 2010)

Family Characteristics	Present study*					2006 ABS census data				
	LGA1 (%)	LGA2 (%)	LGA3 (%)	LGA4 (%)	Total (%)	LGA1 (%)	LGA2 (%)	LGA3 (%)	LGA4 (%)	Total (%)
Couple families with children	41.7	51.2	46.4	43.2	46.0	42.9	52.4	48.1	40.6	43.6
Couple families without children	47.8	37.0	39.8	45.2	42.0	39.5	33.4	39.1	41.0	39.2
One parent families	8.3	8.1	8.2	7.5	8.0	16.6	13.2	12.0	16.9	15.9
Other families	2.2	3.7	5.6	4.0	3.9	0.9	1.0	0.7	1.5	1.3
Average household occupancy (person/household)	3.2	3.2	3.2	3.3	–	3.0	3.0	2.9	3.2	–

3.3.1 Self-Rated (Subjective) Water Consumption

Results showed that when participants were asked to rate their own water usage level, most householders rated themselves as medium (53%) or low water users (33%), rather than high water users (10%). A detailed distribution analysis across the four LGAs revealed that there were some variations across the 4 LGAs in perceptions of water use, however, a Chi-square test for independence indicated no significant association between LGA and self-rated water consumption, χ^2=(9, 1134)=13.25, p=.15, Cramer's V=.06.

Further analyses examined the inter-relationship between self-perceptions of water consumption and external end-uses for rainwater (Fig. 2). Interestingly, those who perceived themselves as high water users were less likely to use water for external applications around the home, compared to those who perceived themselves as low and medium water users. Those who believed themselves to be medium water users were most likely to use their rainwater for outdoor end-uses.

3.3.2 Knowledge of Water Restrictions

When participants were asked whether they were aware of any past, present or future water restrictions affecting their LGA, results showed that most householders (61%) were not aware of any form of water restrictions that applied to them at all (e.g. irrigation restrictions, recommended personal water consumption targets). Approximately 32% of householders were aware of water restrictions that applied in the past and only 20% of them stated that they were aware of the current state of water restrictions. When a detailed analysis was conducted across the four LGAs, LGA3 and LGA4 comprised the majority of those unaware of any water restrictions over time (66% and 65% respectively). Householders in LGA2 seemed the most knowledgeable of past and present water restrictions.

Further analyses were conducted to compare knowledge of water restrictions with external end-uses for rainwater (Fig. 3). Results showed that among those participants who reported being unaware of water restrictions in the past or present, there was significantly higher proportion of people who used rainwater for outdoor applications.

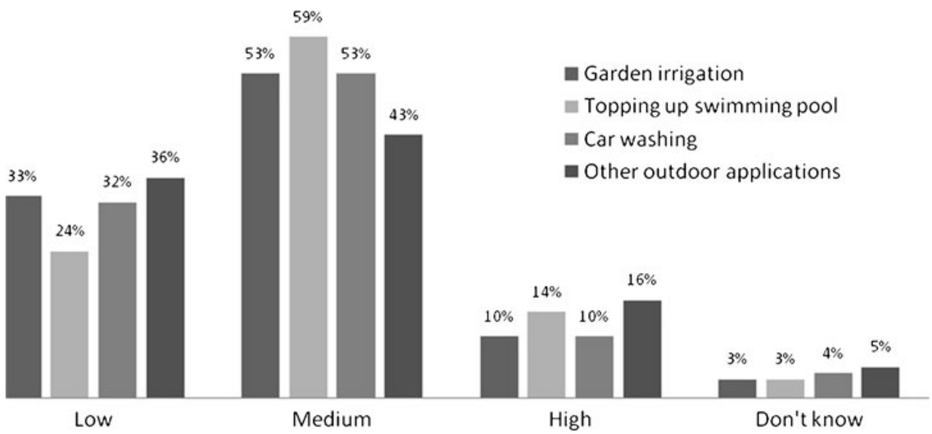

Fig. 2 Inter-relationship analysis of the impact of householders' self-rated water use pattern on their use of rainwater for various end-uses

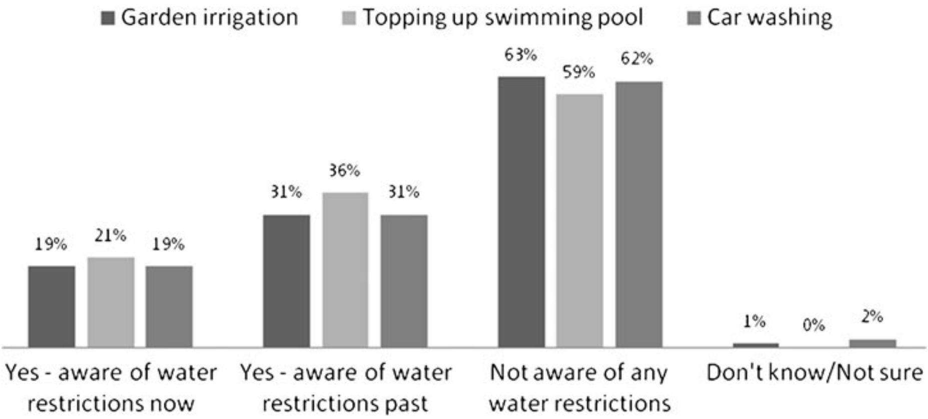

Fig. 3 Inter-relationship analysis between householders' awareness of water restrictions and their use of rainwater for various end-uses

3.3.3 Public Acceptance and Satisfaction for Rainwater

Results also provided a measure of public acceptance for the use of rainwater as a consumable domestic water source. Participants were asked their willingness to use rainwater for potable end-uses such as drinking or cooking, in addition to the non-potable end-uses recommended via the Government mandate (e.g. watering garden, washing car). It was found that most participants had never used their rainwater for drinking or cooking purposes (96%). This finding is not surprising, given that tanks, as part of MP4.2, are only mandated for non-potable applications and not encouraged for consumption. Of the 4% who reported using their rainwater for potable uses, 60% of this sub-sample did not treat the water before consumption. Those who did treat the water prior to consumption typically filtered the rainwater (94%) it or used a UV treatment (6%).

To get an overall perspective on rainwater satisfaction, participants were also asked to indicate how happy they were in terms of the rainwater quality and reliability from their mandated tanks. Results showed that 86% of respondents were either happy or very happy with the quality of their rainwater and 72% were happy or very happy with the reliability of their tank water supply. One-way analyses of variance showed no significant differences in quality or reliability across the four LGAs. Of the 14% of respondents who were unhappy or very unhappy with their rainwater quality, colour of the rainwater (58%) was the most common reason for dissatisfaction.

3.3.4 Perceptions of Water Shortage Threat

Participants were asked to indicate whether they perceived any threat associated with the occurrence of permanent water shortages affecting SEQ now or in the future. Results showed that while only 22% of respondents felt that SEQ was currently experiencing the effects of water shortages, a majority of respondents felt that water shortages would affect SEQ in the future (65%). Among this minority of who felt that SEQ was already facing water shortage issues, the most common reasons cited for this were population growth and water use habits among people living in SEQ. These reasons were also cited among those who felt that SEQ was at risk of future water shortages, along with the belief that SEQ water collection infrastructure (e.g. dams) was limited and that SEQ would experience inconsistent rainfall in the future.

The results also show that while most respondents believed that there was a risk of future water shortages in SEQ, 7% of participants felt that there was no threat of water shortages at all for SEQ. Among these respondents, increased rainfall, consistently sub-tropical climate and "full" dams, were cited as reasons for why SEQ was not experiencing water shortages at present and why SEQ would not be affected by water shortages in the future.

Across the four LGAs, Chi-square analyses indicated a significant association between perceptions of water shortage threat and LGA, with moderate effect sizes. Results showed that respondents from LGA1 and LGA2 perceived significantly higher risk of current water shortages, χ^2=(3, 1134)=12.98, p=.005, Cramer's V=.12). In contrast, respondents from LGA3 and LGA4 did not believe that was any risk of water shortages affecting SEQ now or in the future, χ^2=(3, 1134)=12.84, p=.005, Cramer's V=.12. This finding corresponds with results from Section 3.3.2 which found that a majority of respondents in LGA3 and LGA4 also reported being unaware of water restrictions affecting SEQ in the past or at present.

4 Discussion

Traditionally, urban Australians have enjoyed centralised mains water supply services delivered directly to their homes and this water is considered a reliable and cost effective mode of supply. Homeowners are not involved in any way in the operation and maintenance of these systems and, for all intents and purposes, this supply is relatively "invisible" to the urban householders (Mankad et al. 2010). Due to factors like climate change, population growth, increased urbanisation and industrialisation, the long-term reliability and availability of water from traditional sources is being questioned. During the 2002–2007 drought, SEQ residents were forced to realise that their centralised water supply sources were fallible and that changes would need to be made to SEQ's future water strategy, to cope with the altered water conditions.

The primary aim of this study was to identify and examine the key biophysical descriptors that are likely to be influential in affecting rainwater consumption and future analyses on mains water savings yield from the implementation of mandated rainwater tanks. Results highlighted that most new dwellings post-2007 met the required minimum volume for their mandated rainwater tank (≥5 kL), as per the QDC Part MP4.2 requirements. Only 7% of the total sample reported having rainwater tanks of less volume. Validation of the other basic compliancy requirements also revealed that most detached dwellings within the four target LGAs had their tanks connected to the appropriate roof catchment areas, had an appropriate number of downpipes connecting to the tank, were internally plumbed (for toilet flushing, laundry taps and washing machine), and had at least one external rainwater tap. Thus, the majority of homes in this sample were compliant with QDC MP 4.2.

The results also established that the detached dwellings included in this study did not have any other alternative water systems that could potentially impact on the water savings from mandated rainwater tanks. However, it was interesting to note that a high proportion of householders had domestic water-efficient appliances installed at their premises. This will indirectly present significant challenges for future research looking to understand the extent to which the mandated rainwater tanks alone can provide mains water savings. With the findings from this study, however, it may allow researchers to devise various "controlled" groups in order to single out the net impact of dwellings with water-efficient appliances installed, in terms of total water consumption and savings.

In terms of "social-hydrology", most householders showed a high implicit behavioural acceptance of the integration of rainwater as part of their daily water use behaviours. In this instance, the majority of households reported using the rainwater harvested for toilet flushing, clothes washing and external garden irrigation purposes (see Section 3.1.3). Such a high rainwater utilisation rate indicates that the public are happy and satisfied with the water quality sourced from their rainwater tanks for non-potable uses. However, it was found that almost all householders were less receptive to the notion of using rainwater for higher (potable) end-uses, such as cooking or drinking. This might be owing to the fact that many urban residents have lower acceptance and strong public perceptions toward the public health risks associated with rainwater (e.g. see Mankad and Tapsuwan 2011). Further, drinking rainwater is discouraged in many current water policy documents (e.g. Queensland Water Commission 2007).

Despite installing water efficient appliances in the home, a majority of respondents reported that they were unaware of any past or current water restrictions affecting their region. This is unusual, since not only do water restrictions apply to plumbed rainwater tanks, but water restrictions have been a pervasive part of the SEQ water culture for many years. This finding is consistent with a study conducted by Beal and colleagues (2011b), which showed that irrigation in SEQ homes occurred outside the recommended timings during permanent water conservation restrictions, regardless of whether households were using rainwater or not. Interestingly, Mankad and colleagues (2010) have highlighted that SEQ residents believe themselves to be very knowledgeable of water issues affecting the region. However, the present findings suggest that either survey participants were genuinely unaware of water restrictions, or their responses were potentially biased as an artefact of the survey design (i.e. asking about tank water use). This latter explanation is further supported by the current finding that a majority of participants believed that there would be a risk of water shortages in SEQ now or in the future. Having such high threat perceptions of water shortage among the majority of participants does not seem to fit with the parallel finding of poor knowledge of water restrictions among participants. A potential explanation for this could be that participants may feel that if they report themselves as being aware of water restriction, yet are seen to be using excessive water, they incriminate themselves in some way. Future empirical research is required to assess the level of knowledge specific to water restrictions among SEQ residents. There is also enough evidence in the present research to suggest that water restrictions may have a direct impact on the householders' attitude and behaviour to irrigate their garden, therefore, this should also be explored in future research.

Interestingly, given that many respondents reported being unaware of water restrictions, the majority of householders regarded themselves as either medium or low water users, when providing self-ratings of perceived water use patterns. This is consistent with past research on demand management, where SEQ residents typically identified themselves as "water conservers" (Beal et al. 2011c; Fielding et al. 2010). Further, the phenomena of actual water use differing from self-reported water use among SEQ householders has recently been discussed by Beal and colleagues (2011), where it was found that respondents who self-nominated as high water users had significantly greater self-identity as water conservers. However, in the present study it was found that such self-descriptions did not necessarily mean that they were water conservationists *or* prolific water users. This type of positively biased responding may be explained by the social desirability effect of responding via the CATI process, where participants are interacting with another person on the telephone, rather than the anonymous activity of responding to a paper survey. Further, participants may also be fearful that their individual information will be used to reprimand high water users, despite being assured of confidentiality. Interestingly, the detailed analysis showed that most householders who chose *not* to irrigate their garden, or top up a swimming pool, or use rainwater for car washing all lay within the high water users group.

Finally, in terms of household composition, this sample was found to be different from the general census district population (ABS 2010), in that they were over-representative of two-adult homes. Therefore, researchers focusing on mandated tank households when estimating mains water savings from rainwater tanks must acknowledge that demographic generalisations cannot be made for this sub-population, as they are not representative of the general SEQ population. Accurate demographic and household composition information is vital to the precision of water consumption calculations and is likely to influence rainwater use in homes and overall mains water savings (Sydney Water 2008). The importance of obtaining demographic information from communities utilising rainwater cannot be under-estimated and accurate measurement of demographic variables is strongly recommended for future research. An important point to further consider is that for some biophysical and social variables measured in this study, results varied significantly across the LGAs. This suggests that when designing future research, differences in system set-up, rainwater end-uses and rainwater acceptability between various communities must be considered. These important factors are likely to have significant implications on actual household water use and will influence the amount of water savings that could potentially yield from the installation of a decentralised system at the domestic level.

5 Conclusions

In closing, it is important to note that householders in the present study were happy with the reliability of supply from their rainwater tanks and did not view the system as a threat or inconvenience to their daily activities. It is likely that there are a number of other possible social and cultural issues that must be examined to provide a holistic understanding of mandated rainwater tank use and the households that use them. Lifestyle changes associated with a reduced water supply, as well as changing water infrastructure, are also likely to have important and ongoing enduring consequences for the social environment. Therefore, multidisciplinary research examining biophysical and socio-demographic factors is important to understand decentralised water systems implementation in the planning of total urban water cycle from a holistic perspective. With this, it is anticipated the current study will provides an important linking step that informs urban water planners and modellers towards achieving the best practices of utilising alternative rainwater sources from domestic rainwater tanks to offset the mains grid water demands.

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