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How different Cape Town residential suburbs helped avert Day Zero

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Abstract

Between 2015 and 2018, the Western Cape region of South Africa experienced three consecutive years of below average rainfall. The local authority of Cape Town imposed water restrictions to avert 'Day Zero', an event that was expected to occur if the storage capacity of the main dams supplying the city fell to below 13.5%. This study analyses how different residential areas in Cape Town responded to water restrictions and tariffs that were imposed from January 2016 to October 2018 during the midst of the water crisis. It further explores the potential implications for tariff adjustments that were designed to sustain water conservation measures beyond the drought, while also being sensitive to the ability of poorer households to access sufficient water at an appropriate per capita cost. Different socio-economic groups displayed a different response to the restrictions. A delay or lag-time was observed in lower-income suburbs during the initial phases of water restrictions, while middle- and higher-income suburbs responded immediately. Once the water crisis eased by mid-2018 and restrictions were reduced, more affluent suburbs began relaxing their water conservation efforts. Nevertheless, lower-, middle-, and higher-income suburbs significantly reduced their water demand by 32, 59, and 58%, respectively, over the study period. It can therefore be concluded that water restrictions and accompanying tariffs altered water use of all users regardless of socio-economic status.

Key words: Cape Town drought, water demand management, water restrictions, water tariffs

Highlights

- This paper explains how 'Day Zero' was avoided largely through public response and water demand management.
- This paper presents socio-economic divisions within the city that need more attention in understanding differences in water demand and rate at which the public responds to the call made by the local authority to save water.
- The paper highlights the significance of different responses during restrictions and increased tariffs, and how middle- to higher-income households were more prone to return to higher water usage once restrictions were reduced.
- The findings suggest that water tariff models need to be more flexible and account for the ability of poorer income households to sustain increased tariffs.
- The discussion highlights how the burden of water conservation, especially in a water crisis, is thrust on the urban poor.

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INTRODUCTION

Cape Town is situated in a water-scarce region of South Africa which is, of itself, classified as a water-scarce country. The city is almost entirely dependent on winter rainfall for surface- and groundwater supplies, which are periodically constrained as a result of weather variability and periodic droughts (Currie *et al.* 2017). Approximately 94% of Cape Town's water comes from large surface water storage reservoirs (dams), which are situated in mountainous regions that fall outside the city's municipal boundary and forms part of the Western Cape Water Supply System (WCWSS) (Sinclair-Smith & Winter 2019).

The Western Cape region experienced three consecutive years of below average rainfall between 2015 and 2018 with a return interval that was calculated at 1:311 years, while 2017 received the lowest rainfall on record (Wolski 2018). By early 2018, the total water storage for Cape Town, including the surrounding towns and agriculture sector, had decreased to below 30% (CoCT 2018a). There was a strong possibility that the city would run out of water before the arrival of significant mid-year winter rainfall. The potential for a major city to run out of water was dubbed 'Day Zero', which referred to the day when the average levels of stored water would reach 13.5%, leaving large sections of the city without reticulated water. Over 4 million people would be forced to queue for daily water rations that would be dispensed at 200 distribution sites across the city.

Fortunately, Day Zero was averted as a result of a combination of factors, but mainly due to water demand management (WDM) initiatives (CoCT 2019a), with citizens reducing their water demand by over 55% prior to the first significant rainfall event in April 2018. Different levels of water restrictions and tariffs were rigorously applied at various stages of the City of Cape Town's (CoCT) campaign to avert Day Zero. By February 2018, the most stringent Level 6B restrictions were imposed to ration all citizens to less than 50 l/person/day in a desperate effort to manage the remaining water supply (CoCT 2018a).

This study analyses how different residential suburbs of Cape Town, categorised into three socio-economic groups, contributed to reducing the overall city water demand from a summer peak of 1.2 billion l/day to less than 500 million l/day (CoCT 2018b). The study uses billed monthly household water-use data which were obtained from municipal water records for the period January 2016 to October 2018. A secondary purpose of the study was to examine the response of households to different water restriction levels and accompanying tariff structures in order to consider how water tariff structures could be used for securing greater equity with respect to access and cost across different socio-economic groups within the city. This has implications for how 'Increasing Block Tariffs' (IBTs) are administered to sustain water investments in water service provision and in long-term water conservation efforts while being sensitive to the needs of the urban poor.

Managing water supply and demand in an unequal city

A combination of high levels of inequality, rapid population growth, and limited resources are some of the hallmarks of South Africa's post-constitutional democracy. Alone, each of these issues poses a significant challenge to ensuring reliable and sustainable water supplies and services. In addition, South African cities are urbanising rapidly, with rural–urban migrations placing an additional strain on municipal service delivery in metropolitan cities like Cape Town. As a result, local authorities in metropolitan cities are struggling to fulfil their national mandate of managing urban water systems and ensuring that revenue for water use is collected and used wisely for investing in and maintaining water services and infrastructure (Muller *et al.* 2009). The CoCT, the designated water service provider of Cape Town, is responsible for operating a large, sophisticated water and sanitation system with reticulation that spans a distance of approximately 10,700 and 9,300 km, respectively, has an asset

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value of over R60 billion and a capital budget of R3.5 billion for the 2018/2019 financial year (CoCT 2018b).

In 1998, the CoCT formed a dedicated WDM unit which was recognised as having made an important contribution to its climate change adaptation strategy (Currie *et al.* 2017; Enqvist & Ziervogel 2019). Since then, numerous WDM projects have been implemented and incorporated into national guidelines and policies (Sinclair-Smith & Winter 2019). Technical and non-technical measures were implemented to improve efficiency and to address major challenges in the allocation of limited water resources and the provision of free basic services to the urban poor (Sinclair-Smith & Winter 2019). In the case of the latter, low-income households receive free water services when classified as 'indigent', i.e. if the collective household income is R4,500 or less per month and the market value of the property is less than R300,000. The CoCT relies on cross-subsidisation that is built into its stepped block tariff structure whereby large volume users support the free basic water (FBW) allocation for indigent households (Savenjie & van der Zaag 2002; Jansen & Schulz 2006; Siebrits 2012; CoCT 2018a). WDM is hence a multifaceted approach comprising technological innovation to reduce household water use while also meeting social inequalities and the needs of poor households.

Water demand management strategies

Water conservation and WDM are widely used as a means of extending current water supplies which is typically achieved by exercising both price- and non-priced-based strategies for managing scarcity and risk.

Price-based WDM strategies

Cost recovery for water and water services is widely used in most countries as an effective tool for regulating water use (Jansen & Schulz 2006) where market-based options are favoured over traditional command-and-control approaches (Olmstead & Stavins 2009). Price-based strategies include seasonal adjustments to the cost of water; charging for excessive usage through implementing punitive pricing strategies; and increasing block rate tariffs according to predetermined limits of water use. These policy tools make use of market signals to encourage behavioural change and the achievement of policy goals. In South Africa, the allocation of a realistic market price is mainly determined by cost recovery but also incorporates social equity considerations (e.g. access to quality water for the poor), and maintenance of, and investments in infrastructure.

Increasing or sliding block tariff structures are widely used across the world in establishing price-based WDM approaches that are dependent on the price elasticity of water demand and accompanying thresholds that coerce water users to reduce their demand because of the increasing cost (Jansen & Schulz 2006). This approach is well known; however, some water demand studies show mixed results in the response to price elasticity. For example, Jansen & Schulz (2006) as well as Duke *et al.* (2002) found that wealthier households were more sensitive to price changes when the cost of water was primarily attributed to outdoor use. These households are price elastic as they tend to alter this component of their water use fairly rapidly while their demand to fulfil basic needs remained relatively constant. Similarly, Hensher *et al.* (2006) investigated customer's willingness to pay to avoid drought-induced water restrictions and concluded that households in Australia, where the study was conducted, were price elastic and thus willing to tolerate high-level restrictions (the highest being no outdoor use) for certain months of the year and to adjust their outdoor water habits instead of paying higher water bills.

Of interest is a study by Dalhuisen *et al.* (2003) in which residential water demand was found to be more elastic in a rising block tariff system. In this case, the amount of water saved and revenue that became available to the water authority increased with an increase 'in absolute elasticity values for a

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specific increase in water tariffs' (Hoffman & du Plessis 2013: 427). These absolute elasticity values are associated with household income levels and highlight the importance of price elasticity per tariff block being carefully negotiated to ensure optimal effectiveness. The general conclusion is that adjustments to higher steps in IBTs are effective in reducing demand for higher-income water users without substantially reducing the revenue available to finance and manage water services (Jansen & Schulz 2006; Olmstead & Stavins 2009).

A stepped tariff system is a cost-effective and practical way of controlling demand compared with non-price demand management strategies (Olmstead & Stavins 2009), but this is not true for low-income households. Once a threshold is reached when a household can no longer afford to pay for any additional water use or reduce their water demand further, despite price increases (van Zyl *et al.* 2007), then the cost of water is no longer an effective management strategy and other measures, such as the implementation of low-flow devices, campaigns, education, and capacity building programmes, were found to be an appropriate means of reducing water demand (Jansen & Schulz 2006).

Non-priced-based WDM strategies

Structural non-price demand-side management strategies include control systems in distribution networks, decreasing non-revenue water through leak detection and repair, pressure management and pipe replacement as well as residential water metering through water management devices (WMDs). It is, however, acknowledged that they are unsuitable in the long term, especially in developing countries, because of limited financial resources. Non-priced-based water conservation strategies include education and training programmes, public information programmes, water-conserving technology, continuous research and the transparent supply of information, water-use ordinances, environmental flow reductions, voluntary and mandatory conservation, as well as water rationing (Renwick & Archibald 1998; Duke *et al.* 2002; Hensher *et al.* 2006; CoCT 2019a).

Studies have confirmed that an integrated approach that makes use of incentives and communication, together with regulatory measures, is more effective in encouraging water conservation practices than tariffs and restrictions alone (Renwick & Archibald 1998; Savenjie & van der Zaag 2002; Siebrits 2012). For example, water restrictions and rationing are effective in reducing demand, but result in a need for cost recovery following a crisis, and consequently increasing the water rates for all water users regardless of their behaviour during the drought (Duke *et al.* 2002). Punitive pricing or scarcity pricing can then be used in combination, to offset this deficit (Duke *et al.* 2002). Education and public information campaigns are aimed at altering the behaviours of water users. By-laws are used to strengthen water regulations that promote water-use efficiency and ensure effective enforcement. Economic incentives such as grants, subsidies, tax differentiation, and allowances are used to prompt the preferential allocation of water to a distinct group of water users for discouraging wasteful behaviour (Savenjie & van der Zaag 2002).

Water demand patterns vary significantly with the level of income of households. It is widely known that socio-economic variables, namely property size, property price, household income, and household size, have a significant effect on household water use (Duke *et al.* 2002; Jansen & Schulz 2006; van Zyl *et al.* 2007; Siebrits 2012). This is particularly pertinent in a socio-economically unequal city, such as Cape Town, where WC/WDM behaviours are constrained because a large portion of households already operate at threshold levels. A combination of socio-institutional capacity and the values and attitudes of water users influences the ability of water institutions (including local authorities) to effectively implement WDM strategies. It is posited that effective demand management should give more consideration to water demand patterns within and between households and their respective socio-economic statuses because patterns are indicators that provide insight into how citizens are likely to behave in response to new policies that are designed to control water demand.

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RESEARCH DESIGN AND METHOD

Monthly household water-use data were obtained from the CoCT that covered the critical period during Cape Town's drought from January 2016 to October 2018. A sample of 11 suburbs was initially selected and categorised into three broad socio-economic groups: lower-, middle-, and higher-income residential areas. The criteria for categorising the groups were based on the combination of property size, property price, household income, dwelling type, and access to services. In addition, an analysis of variance (ANOVA) was conducted to determine whether the different water restriction levels for managing water use were statistically significant within each socio-economic group.

Data organisation

At the outset, a data cleaning process was undertaken to eliminate the records of non-residential properties as well as obvious errors. For example, in the dataset, land that was categorised as 'CLUSTER' appeared to have a number of different uses: apartment blocks, a cluster of informal houses on one plot, retirement homes, elder care villages, self-catering cottages, B&Bs (bed-and-breakfast establishments), and properties that combined small businesses and apartments in the same building. Thus, properties that were classified as 'CLUSTER', 'FLATS', and 'INFORMAL' were discarded to allow for a more accurate calculation of household water use (Table 1). Furthermore, all properties without metered water data for 4 months or more (approximately 11% in total) were rejected as these too would not give an accurate representation of the mean. Lastly, residential properties with unusually high water use were investigated further and rejected if these values did not match those that were recorded for the preceding or subsequent months of the study period.

Socio-economic clustering

Studies confirm that the main variables that determine residential water use are household income, property/stand size, property price, number of occupants in a dwelling or household, as well as the cost of water (Duke *et al.* 2002; van Zyl *et al.* 2007; Siebrits 2012). The informal settlement of

Table 1 | Determining the dataset for each suburb relative to the original (%)

Suburb	Original dataset	Total properties after excluding those with 4 or more missing months		Category 1: residential properties only		Category 2: single unit residential properties only	
Bonteheuewel	7,254	6,933	96%	6,829	94%	6,755	93%
Dunoon	2,885	1,537	53%	1,502	52%	1,493	52%
Edgemead	3,362	3,210	95%	3,175	94%	3,166	94%
Fish Hoek	3,449	3,210	93%	3,112	90%	2,971	86%
Gordons Bay	1,019	879	86%	863	85%	833	82%
Langa	3,737	3,208	86%	3,094	83%	3,041	81%
Lavender Hill	1,452	1,329	92%	1,300	90%	1,265	87%
Meadowridge	823	798	97%	783	95%	777	94%
Melkbosstrand	3,029	2,858	93%	2,765	90%	2,745	89%
Newlands	2,013	1,825	91%	1,724	86%	1,681	84%
Ocean View	2,712	2,547	94%	2,495	92%	2,433	90%
Total	31,785	28,334	89%	27,642	87%	27,160	85%

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Dunoon was initially selected as one of the 11 suburbs, however, on further investigation it was determined that there was no discrete bulk water meter data to accurately represent the informal service delivery in this settlement, with the only available data being for formal houses, businesses and industries. Consequently, the informal settlement was discarded. Ten suburbs were finally selected and categorised into three different socio-economic categories, namely lower-, middle-, and higher-income residential suburbs. The location of the selected suburbs is shown in the map (Figure 1).

Household income, dwelling type, as well as the household service profile (e.g. access to piped water and toilet facilities) for each suburb were obtained from the Population Census of 2011 (CoCT 2019b). Median property valuations (property price and property size) for freehold residential properties for each suburb (for 2015) were obtained from the CoCT (CoCT 2019b). The socio-economic groups that were selected for this study concurred with the socio-economic indices as outlined in the CoCT's Regional Development Profile as well as those in a more recent study by Currie *et al.* (2017).

Suburban water-use data were clustered according to each socio-economic cluster. It is important to note that the representative sample in each socio-economic group did not constitute the same number of suburbs or data points. Similarly, each restriction level did not constitute the same number of months and data points. In addition, the data were found to be non-normally distributed and despite a rigorous data cleaning process, outliers still exist. The medians were therefore calculated for each restriction level for all the residential properties within each socio-economic group.

Spatial and temporal analyses

The median water usage of Category 1 data (Table 1) was compiled for the purpose of comparing and analysing changes in water use arising from various levels of water restrictions that were imposed

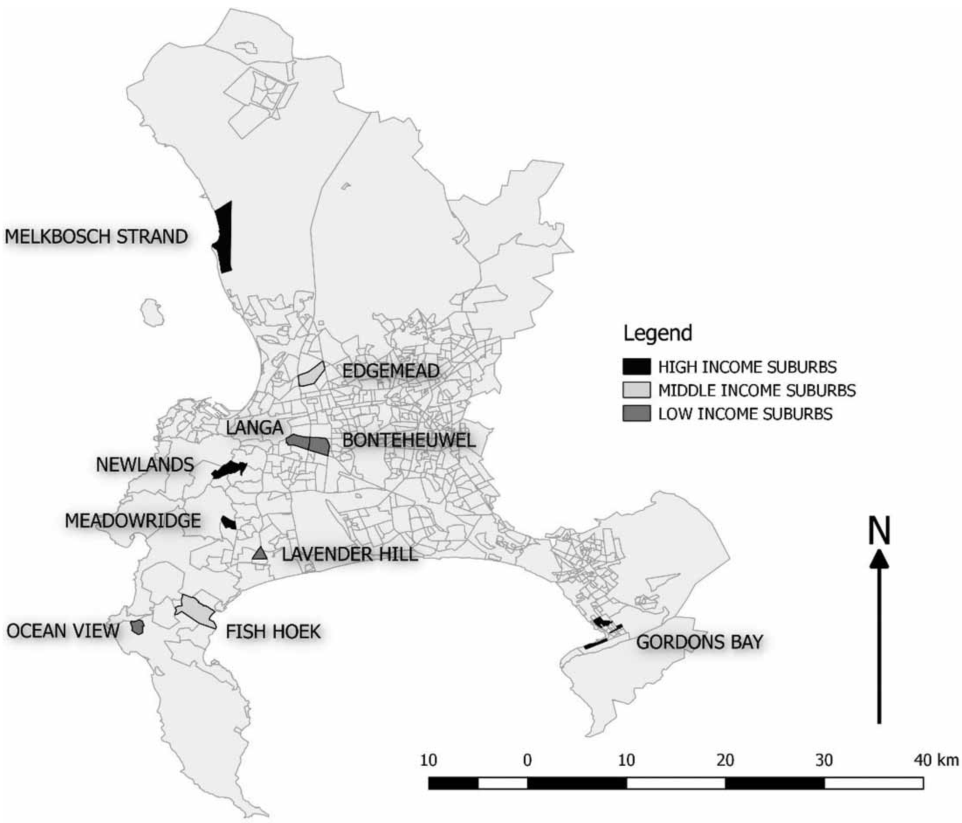

Figure 1 | Map of the CoCT showing the socio-economic clusters in the study.

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during the drought. In addition, a percentage change in water use was calculated to compare the water use in each suburb and the delay in time before households responded to changes required by the water restriction level. Spatial clusters were then used to analyse this data both temporally and within different socio-economic residential clusters.

Statistical analyses

Cluster analysis was used to identify trends within the data and to prepare the data for further analysis. Median monthly water data (Category 1 data) were used to generate nine scatter plots, from which trendlines were drawn for each restriction level. The three gradients within each plot were used to compare the behaviour and extent of the responses at each restriction level for each socio-economic group.

A total of 34 months' data was clustered into seven water restriction levels for the purpose of identifying general trends at each restriction level within each socio-economic group. The null hypothesis (H_0) for the ANOVA test posited that the water restrictions that were imposed by the CoCT did not amount to significant changes in water use. An alpha value of 0.05 was used to ensure a 95% confidence level. Where the variables were found to be different within each socio-economic group, a *post hoc* test comparing the different restrictions levels was conducted to determine the origin of these differences.

The Bonferroni correction was used to offset the problem of multiple comparisons as a result of several statistical tests being performed simultaneously. Consequently, the Bonferroni-corrected *p*-value was determined at 0.00625 by dividing the *0.05 alpha value by the number of comparisons* ($n = 8$). The *p*-values generated by the *post hoc t*-tests were compared with the Bonferroni correction. Where the *p*-value was found to be smaller than the Bonferroni correction, the 'between group' variance was observed and subsequently identified the restriction levels that were significantly different from each other.

The ANOVA test results need to be treated with caution as the data were not normally distributed. A Kruskal–Wallis test, a rank-based non-parametric equivalent to the ANOVA test, was therefore used to substantiate the results rendered by the ANOVA test. Chi-squared values, *F*-statistics, as well as *p*-values were subsequently generated, and *post hoc* pairwise Wilcox tests, with the Bonferroni correction, were used to determine the origin of the differences.

LIMITATIONS

In general, access to current data is a major challenge in South Africa. For example, household and population data for Cape Town were limited largely to the Population Census of 2011 (CoCT 2019b). Given an annual city-wide growth rate of approximately 3% in 2014 (Currie *et al.* 2017), census data were unlikely to be particularly representative in the case of informal settlements which constitute 21% of households in Cape Town. Likewise, the 2015 and 2016 CoCT ward-scale population data were unsuitable for downscaling at a suburban scale, and this problem was also experienced in a country-wide study by van Zyl *et al.* (2007). Thus, the study was limited in accurately assessing household-level water use without the confirmation of household population data. The household response to water restrictions might be underestimated in this study.

Given the results from the 2011 Census, the numbers of units in this dataset are likely to underenumerate the number of households in the majority of the suburbs (Table 2). This could have a significant impact on the results. Furthermore, the informal settlement of Dunoon had to be omitted from the analysis, and thus the study was unable to account for the response of residents living in an informal settlement.

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Table 2 | The number of households in each suburb compared with the number of households in the dataset

Suburb	Number of households (Census 2011)	Number of units/households in CoCT original dataset
Bonteheuwel	11,037	7,254
Dunoon	11,496	2,887
Edgemead	3,699	3,362
Fish Hoek	3,837	3,449
Gordon's Bay	5,715	1,019
Langa	17,400	3,737
Lavender Hill	6,504	1,452
Meadowridge	1,122	823
Melkbosstrand	3,918	3,079
Newlands	2,034	2,013
Ocean View	3,084	2,712

RESULTS

In order to compare household water use in different socio-economic suburbs, and ultimately the reduction in water use throughout the study period, the median monthly per unit (household) water use for each socio-economic group was calculated from the Category 1 data and used to create scatter plots (Figure 2). Each correlation graph compares the water demand of two different socio-economic groups over the entire study period, by plotting a different socio-economic group on each axis. Figure 2(c) shows the highest correlation between middle- and high-income socio-economic groups (R^2 value of 0.99). Water use in both socio-economic groups was almost identical throughout the study period. Lower- and higher-income suburbs also show a strong correlation (0.89). Household size of lower-income households is a significant contributor even though per person water use in lower-income suburbs is within the allocated ration during the most stringent restrictions, total monthly household water use is greater than that of higher-income households as there are more people residing on each property. The R^2 value between the lower- and middle-income groups was slightly lower (0.88), but still significant. Lower- and middle-income households have a similar household size, resulting in similar water usage during the most stringent restrictions. This greater difference between the two groups can therefore be attributed to the lag in response time during the initial restriction levels, which will be discussed later. Overall, the three socio-economic groups followed a similar pattern in responding to the city's WDM programme which was strongly influenced by water restrictions and increasing water tariffs (IBTs). Undoubtedly non-price factors also played a significant role, but the study was not designed to determine the significance of these influences on water demand.

A second set of scatter plots was created to compare the average water use of all months during each restriction level within each socio-economic group. The gradients of these trend lines are summarised in Table 3. A negative gradient signals a reduction in water use from the previous restriction level until the end of the current restriction level. During Level 6B, the most stringent water restriction, a positive gradient was observed; however, water use here remained one of the lowest recorded throughout the study period.

An ANOVA was conducted to investigate whether the different water restriction levels rendered a statistically significant change in water use within each socio-economic group. The ANOVA test for each socio-economic group resulted in *F*-values that were greater than the *F*-critical values (Table 4). Furthermore, all *p*-values were smaller than alpha at a 95% confidence level and hence show that a statistically significant difference in water use was found between some of the restriction

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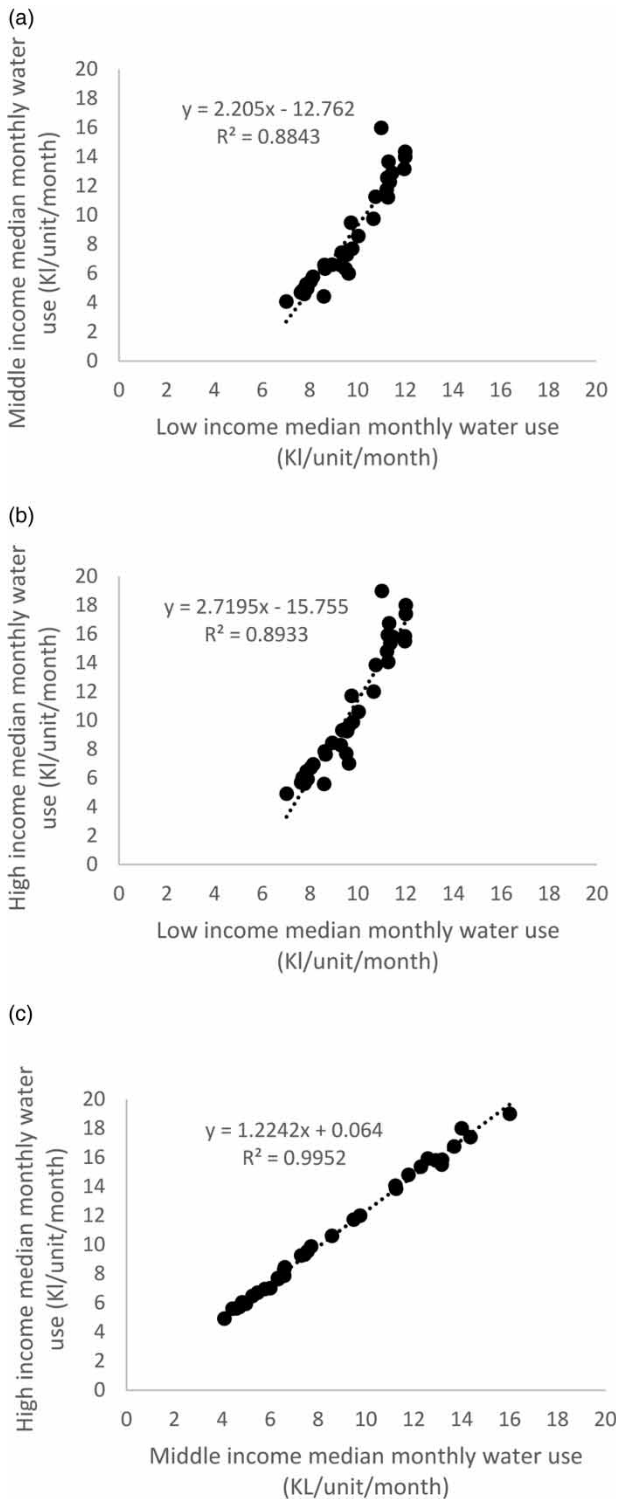

Figure 2 | (a)–(c) Comparisons of the median monthly water use per unit (household) over the entire study period between: (a) lower- and middle-income, (b) lower- and higher-income, and (c) middle- and higher-income socio-economic groups.

levels within each socio-economic group. A non-parametric alternative (one-way ANOVA on ranks) was used to scrutinise these results. The Kruskal–Wallis test for each group also rendered *p*-values smaller than alpha ($<2.2 \times 10^{-16}$) and large chi-squared values ($>$7,000). The null hypothesis was therefore rejected. The statistical analysis confirmed that a close correlation exists between the

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Table 3 | Table of gradients

	Restriction level								
Socio-economic group	**2**	**3**	**3B**	**4**	**4B**	**5**	**6**	**6B**	**5**
Low income	0.002	−0.019	−0.014	−0.012	−0.011	−0.003	−0.072	0.005	−0.001
Middle income	− 0.003	−0.043	−0.033	−0.026	−0.016	−0.018	−0.056	0.008	0.045
High income	− 0.005	−0.049	−0.037	−0.029	−0.018	−0.072	−0.072	0.010	0.049

Table 4 | Summary of the one-way ANOVA test results

	ANOVA test				*Post hoc* test		
Socio-economic group	***F*-critical**	***F*-value**	**Alpha**	***P*-value**	**Bonferroni correction**	**$P <$ Bonferroni correction**	**$P(T \leq t)$ two-tail**
Low income	1.9385	6.1432	0.05	5.99×10^{-8}	0.00625	True at restriction Level 5	0.0013
Middle income	1.9386	85.1133	0.05	7.87×10^{-141}	0.00625	True at restriction Level 3	0.0025
High income	1.9386	43.4289	0.05	5.47×10^{-70}	0.00625	True at restriction Level 3B	2.358×10^{-10}

imposition of water restrictions and household water conservation. It can therefore be concluded that water restrictions altered water use for all users regardless of the socio-economic group.

Post hoc tests were conducted to determine differences between the restriction levels. Both the *t*-test and the pairwise Wilcoxon test results were consistent with those in Table 3. A lag-time was observed in the case of lower-income suburbs in their response to the restriction levels, as the *p*-value was only smaller than the Bonferroni correction at restriction Level 5, whereas the middle- and higher-income groups responded almost immediately (Table 4). However, slight differences do exist in the two tests since the data were not normally distributed.

Monthly trends were plotted for water use over the entire study period (January 2016 to October 2018) for each socio-economic group (Figure 3). Dashed horizontal lines on the map demonstrate the level of water use above which a household was fined and/or prioritised for the installation of

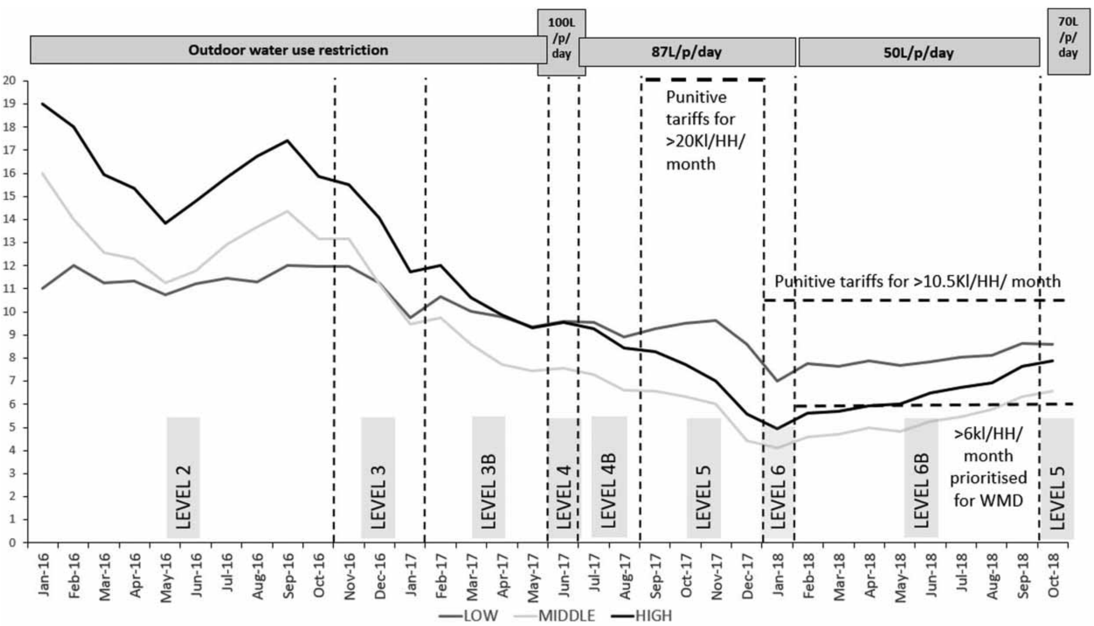

Figure 3 | Comparison of the median monthly household water use (kl/month/unit) for each socio-economic group throughout the study period.

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a WMD on the premises, which limits households to its daily water quota by switching off the taps when this is reached.

The low-income group had the lowest initial water use of between 70 and 88 l/person/day since water use is largely confined to indoor purposes with the assumption that household size was five and four people, respectively (van Zyl *et al.* 2007). Middle- and higher-income suburbs displayed a greater initial household water demand with a monthly average of 129 and 204 l/person/day, respectively, in this case with a household size of four and three people, respectively (van Zyl *et al.* 2007). During Level 3 restrictions, the middle-income suburbs reduced their median household water demand to below that of the lower-income suburbs. By the end of April 2018, lower- and higher-income suburbs had a median monthly household demand of approximately 8.8 kilolitres (kl). Low-income households typically have a larger household size and, as a result, the per capita water use remained greater in higher-income suburbs at 107 l/person/day compared with 56 l/person/day for the lower-income group.

The percentage change in water use, as per the restriction level, presents an overview of different responses within each socio-economic group. Tables 5 and 6 were calculated using average water use at each restriction level (Category 1 data). These results display an obvious lag in the rate of response; lower-income suburbs displayed the greatest change between restriction Levels 5 and 6, while the middle- and higher-income suburbs showed the greatest effort in reducing water demand during the initial restrictions targeting outdoor water use (between restriction Levels 2 and 3 as well as 3 and 3B) and then again between restriction Levels 5 and 6, the most stringent restrictions (Table 5).

All groups showed an increase in conservation effort which coincides with increasingly stringent restrictions (Table 6). However, once restrictions were reduced following the highest level, Level 6B, the middle- and high-income suburbs eased up on their water conservation effort to 59 and 58% savings, respectively, while low-income suburbs continued to decrease their demand (Table 6).

The initial water savings observed for middle- and high-income suburbs were directed at reducing and eventually curtailing outdoor water use. Here, the savings from outdoor water at the end of Level 3B were approximately 45 and 43%, respectively.

The effectiveness of water restrictions in volumetric savings for this study period provides a useful measure of water conservation practices and can be used to compare its success to that of other

Table 5 | Percentage change in water use after each consecutive restriction level

	Percentage change in water use after each restriction level							
Socio-economic group	**2 to 3 (%)**	**3 to 3B (%)**	**3B to 4 (%)**	**4 to 4B (%)**	**4B to 5 (%)**	**5 to 6 (%)**	**6 to 6B (%)**	**6B to 5 (%)**
Low income	−2	−9	−5	−6	−1	−20	13.4	−4.9
Middle income	−14	−23	−8	−8	−15	−31	24.4	21.5
High income	−13	−21	−5	−8	−16	−30	20.4	17.6

Table 6 | Percentage change in water use from January 2016 to each restriction level

	Percentage change in water use from January 2016 to each restriction level								
Socio-economic group	**Jan 2016 to 2 (%)**	**Jan 2016 to 3 (%)**	**Jan 2016 to 3B (%)**	**Jan 2016 to 4 (%)**	**Jan 2016 to 4B (%)**	**Jan 2016 to 5 (%)**	**Jan 2016 to 6 (%)**	**Jan 2016 to 6B (%)**	**Jan 2016 to 5 (%)**
Low income	3	1	−8	−13	−18	−21	−37	−28	−32
Middle income	−17	−29	−45	−50	−54	−61	−73	−66	−59
High income	−16	−27	−43	−46	−50	−58	−71	−65	−58

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demand-side management strategies as well as various other drought responses like supply augmentation (Table 7). All socio-economic groups reduced their water demand over the period January 2016 to October 2018. In the case of low-income suburbs, these savings took place in the context of already moderately low volumes per household.

DISCUSSION

During the drought, the CoCT relied largely on WDM to manage the water crisis rather than attempting to build its way out of the drought by investing large amounts of capital in emergency projects such as desalination and groundwater abstraction. WDM focused largely on domestic water use as this accounts for 70% of water demand by the city, while commercial and industrial use accounts for 13.5 and 4.2%, respectively (CoCT 2018b). Thus, water restrictions and the adjustments to the water tariffs, the principle means of influencing water conservation behaviour during the crisis, were largely directed towards reducing domestic household use.

Outdoor water use constitutes approximately 73% of residential water demand, especially in developed countries (Siebrits 2012), while in Cape Town one study determined that it was closer to 40% (van Zyl *et al.* 2007). The earlier levels of water restrictions were directed at specific water uses by restricting outdoor water use to certain hours and days (Levels 1 and 2), while Level 3 prohibited outdoor use entirely, e.g. no topping up of swimming pools, no private car washing, and only hand carried buckets could be used for watering gardens. Once curtailed, these restrictions resulted in a significant reduction in demand by affluent households when compared with lower-income households, where demand is largely restricted to indoor use (van Zyl *et al.* 2007). In addition, the water use of lower-income households already bordered on threshold levels (approximately 70 l/person/day) and hence had limited means of attempting additional reductions in demand (Figure 3). This could explain why the total savings of the low-income suburbs (32%) was lower than that of the middle- and higher-income groups (59 and 58%, respectively) (Table 7). These findings concur with previous studies which found that higher-income households have a greater potential to conserve, while households with below average water use have very little room for adopting further conservation measures (Duke *et al.* 2002). This has an added implication on the effectiveness of tariffs – van Zyl *et al.* (2007) state that price elasticity for outdoor water use is significantly higher for middle- and higher-income households in South Africa than for lower-income users. Duke *et al.* (2002) and Renwick & Archibald (1998) claim that higher-income households are income elastic to price changes as they have a higher potential to conserve outdoor water use and are therefore able to keep their water bill unchanged despite increased water rates during droughts.

A delay or lag-time is observed in the lower-income suburbs in response to the changes in water restrictions. This is attributed to the fact that the initial restrictions were directed at outdoor water use and hence did little to alter their already moderate water demand. The first significant reduction in water demand was observed in the lower-income suburbs with the introduction of Levels 5 and 6 and later 6B water restrictions, restricting water use to 87 and 50 l/person/day, respectively (Figure 3).

Table 7 | Volumetric and percentage change for the entire study period

	Actual savings entire study period			
Socio-economic group	**Jan 2016 (kl)**	**Oct 2018 (kl)**	**Reduction (kl)**	**% Reduction**
Low income	258,884	176,350	82,534	−32
Middle income	135,182	56,012	79,170	−59
High income	178,327	74,225	104,102	−58

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It is, however, unclear if the substantial decline in water use can be attributed to water restrictions alone, or whether the CoCT's pressure management initiatives in early 2018 contributed to the savings (CoCT 2018b). Nonetheless, the scatter plots (Figure 2), as well as the percentage savings presented in Table 7, signal that all residential suburbs responded to the restrictions remarkably well.

Effect of tariffs and restrictions on investment in water services and infrastructure

Price elasticity changes with time and it is therefore possible to distinguish between short-term and long-term elasticity. Price increases will have an immediate effect on water demand patterns (i.e. short-term elasticity) and in the longer term, increased water tariffs result in water-saving plumbing fixtures and thus higher elasticity values (van Zyl *et al.* 2007). The role of water restrictions and water rationing within WDM is well documented in the research literature, but there are limited accounts of the socio-economic impact of WDM tools in a developmental state like South Africa. In the first instance, restrictions necessitate an increase in tariffs for all water users regardless of their conservation behaviour during a crisis (Duke *et al.* 2002). A decline in revenue from decreased water sales places a strain on the local authority's ability to maintain services, to invest in water infrastructure, and to recover the costs of administering water awareness campaigns and new investments for supporting emergency interventions, e.g. in expanding pressure management operations; and public works that are dedicated to detecting and fixing leaks. Between February 2016 and February 2018, the domestic sale of water declined by 66% (CoCT 2018b). The CoCT therefore altered the stepped tariff structure on a number of occasions (Table 8); removed two of the six steps in tariffs; and removed the FBW allocation of 6 kl/household/month, in order to arrest the decline in revenue with the only legal requirement being a guarantee that FBW would be granted to indigent populations (Table 8).

By 1 July 2017, all households, with the exception of indigent households, were required to pay for their monthly water use which included the cost of the basic allocation of 6 kl/month. During Level 6, step 2 tariffs came into effect on 1 February 2018 which consisted of punitive charges to households using more than 6 kl a month. According to Enqvist & Ziervogel (2019), this impacted on lower-income households as it left them with higher water bills despite a decreasing per capita use – household water demand exceeded 6 kl due to the household size. The conservation burden was therefore shifted to those with already low water demands.

Subsequently, along with the actual water-use restriction of 87 l/person/day, this abrupt increase in tariffs could explain why the low-income suburbs' response was significantly enhanced with the introduction of Level 6 restrictions. It further explains why lower-income suburbs continued to reduce their demand, despite the easing of restrictions in September 2018, while that of middle- and

Table 8 | Residential water tariffs (domestic full and cluster)

Water steps (kl)	Step in 2015/ 2016	Level 4 (1 July 2017–31 January 2018)	Level 6 (from 1 February 2018)	Level 1 (from 1 July 2019)
Step 1 ($>0 \leq 6$ kl)	R0.00	R4.65 (free for indigent households)	R29.93 (free for indigent households)	R17.15 (free for indigent households)
Step 2 ($>6 \leq 10.5$ kl)	R12.30	R17.75	R52.44	R24.39 (free for indigent households)
Step 3 ($>10.5 \leq 20$ kl)	R21.45	R25.97	R114	R34.63 ($>10.5 \leq 35$ kl)
Step 4 ($>20 \leq 35$ kl)	R37.32	R43.69	R342	R76.04 (>35 kl)
Step 5 ($>35 \leq 50$ kl)	R60.51	R113.99	R912	No step
Step 6 (>50 kl)	R182,38	R302.24	R912	No step

Domestic full, standalone houses; domestic cluster, apartments, cluster developments (CoCT 2018b).

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higher-income suburbs displayed a decreasing trend in conservation. This contradicts the study by Gunatilake *et al.* (2001) who found low-income groups to be inelastic in Sri Lanka, but is consistent with that of Renwick & Archibald (1998) who found households to be more price-sensitive where water bills make up a larger proportion of their income.

Effectiveness of restrictions

The response of lower-income groups to the restrictions contradicts the findings of Jansen & Schulz (2006) who found that once a threshold of water use was reached, other forms of demand-side management policies and strategies (e.g. information campaigns and the adoption of water-saving technologies) are necessary, as water restrictions will have little effect on reducing water use further. The CoCT was responsible for implementing significant and widespread campaigns to build strong awareness that centred on Day Zero messaging, e.g. signage on electronic notice boards along major highways; flying banners from aircrafts over the city; and the use of social media. Researchers claim that these non-price-based interventions had a significant effect on water conservation behaviours and attitudes (Enqvist & Ziervogel 2019); however, the water-use data that were used to inform this study were unable to identify and distinguish the role of these campaigns. Nevertheless, the statistical analysis confirmed the significance of a well-orchestrated and comprehensive price- and non-price-based campaign, particularly the water restrictions and tariffs, in reducing the water demand of all citizens.

Potential to sustain these savings

In general, the main priorities for achieving sustainable urban water management for any town or city are to provide safe drinking water and clean sanitation; to minimise and limit public and environmental harm from waste and contaminated water; and to reduce the risk and frequency of droughts and flooding. Worldwide these priorities are pursued with different approaches, tools, and policies. In South Africa, there is a fourth priority which is to address social inequalities that affect access to clean water and sanitation, and it is therefore of particular interest in this study to understand how different socio-economic groups responded to tariff adjustments and restrictions during the drought.

South Africa faces a range of socio-political challenges that are embedded in its history of colonial and Apartheid rule. These legacies continue to trouble the pathway of a post-1994 democracy and are compounded by issues of rapid population growth, a declining economy, increasing national debt, corruption and unemployment, that make it difficult to establish a just and sustainable transition in a developmental state (Swilling *et al.* 2016). These issues, among others, also shape the form and context of water service provision in South Africa and the tension between a neoliberal market-based financing system for the provision of water resources and the human right to water that is enshrined in the country's constitution and institutionalised in the National Water Act of 1998 and the Water Services Act of 1997. Water justice remains an overarching challenge in the CoCT. This is compounded by the prediction that drought events will become increasingly common in areas with a Mediterranean climate such as Cape Town and the surrounding region (March *et al.* 2013). Therefore, if water governance systems are to be sustainable, programmes initiated during the drought will have to continue to ensure future water security and accordingly allow for the much-needed growth that water insecurity itself constrains.

The savings presented in Table 7 suggest the potential for the 'ramping up' of WC/WDM programmes that are not confined to an emergency drought response. This is consistent with a previous drought experience in Spain, as outlined by March *et al.* (2013). Here, the drought triggered a heightened environmental consciousness by its residents and awareness of water scarcity in the

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region. Subsequently, water-saving efforts were maintained to the time of the study, 3 years after the drought had ended, despite full dams. Gilbertson *et al.* (2011) also noted that people who have experienced droughts in the past are more prepared to alter their daily water-use behaviours. Additionally, continued water conservation behaviours that were adopted by domestic water users during Metropolitan São Paulo's most severe drought (2014–2015) helped buffer the city against yet another low rainfall year which was experienced in 2018, providing evidence that water conservation habits can be sustained during non-drought years (Braga & Kelman 2020).

Higher-income suburbs were able to reduce their water demand by 58% in part, because they had the financial means to invest in alternative supply sources, e.g. by installing boreholes in their backyards (Enqvist & Ziervogel 2019) and acquiring tanks for rainwater harvesting. These measures partly explain how significant reductions in water demand were achieved in those households that could afford investing in technologies and thereby reducing the demand from central dam supplies. The relatively high costs of investing in technology could also explain why lower-income suburbs were limited to a saving of 32%.

A key lesson learned from the recent drought in the CoCT is that water tariff model needs to be restructured. Not only did the water restrictions and accompanying tariffs shift the conservation burden during the drought to those with already low water demands, the fixed charge implemented by the CoCT to recover the cost of the water network post-drought, may make water services unaffordable to low- and middle-income households (CoCT 2020). When ramping up conservation efforts during non-drought years, the water utility's revenue will be significantly reduced. Careful consideration is needed to ensure that the water tariff model is sensitive to the urban poor and social needs, even in times of severe water scarcity. Other key initiatives, already being implemented in São Paulo, could help ensure equity include subsidies to help lower-income households install water-efficient appliances and low-interest loans to help apartment owners install individual water meters (Braga & Kelman 2020).

CONCLUSION

This study found that all suburbs, regardless of their socio-economic category, significantly decreased water use and collectively contributed to averting Day Zero. Lower-income suburbs displayed 32% savings, middle-income 59%, and higher-income suburbs reduced their water demand by 58%. However, different socio-economic groups did display a different response to the restrictions. Middle- and higher-income suburbs showed an immediate response to the water restrictions, while a delay or lag-time was observed in lower-income suburbs. This can be attributed to the fact that the initial restrictions were directed towards outdoor water use, with the transition from Level 5 to Level 6B restrictions signalling the first stage at which lower-income residents showed a significant decrease in their water use. As the water crisis eased by mid-2018 and the restriction levels were reduced, middle- and higher-income households relaxed their water conservation efforts. The statistical analysis of each socio-economic group rendered the null hypothesis false: that is no difference in water use between the restriction levels. It can therefore be concluded that a close correlation exists between the imposition of water restrictions and reductions in household water use within all suburbs.

Water restrictions were accompanied by progressively stringent tariffs. These accompanying tariffs contributed to an enhanced reduction in lower- and middle-income suburbs. The manipulation of tariffs, for example, could have resulted in a slightly better conservation effort for middle-income (59%) compared with high-income households (58%), despite having a significantly lower initial water demand. Although the analysis was not designed to distinguish other influences such as non-priced-based interventions on water savings, e.g. pressure management systems and information

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campaigns, it can be concluded from this study that water restrictions and tariffs did indeed play a significant role in informing the observed reductions.

Drought events are predicted to become increasingly common in areas with a Mediterranean climate (March *et al.* 2013) such as Cape Town and the surrounding region. Already the experience of the drought is being viewed as the 'new normal' (Enqvist & Ziervogel 2019). In addition, water justice remains an overarching challenge in the CoCT and needs to be addressed if water governance systems are to be sustainable (Enqvist & Ziervogel 2019). The drought allowed for a 'belt-tightening' that could never have been easily accepted under normal circumstances. It afforded the City an opportunity to adopt and finance numerous demand-side and supply-side programmes. Those programmes that were initiated during the drought are set to continue in order to increase the city's resilience even after the drought has eased. They will assist in addressing future water scarcity and accordingly allow for the much-needed growth that water insecurity itself constrains.

Water savings that were highlighted through this study raise the potential to significantly increase current WC/WDM strategies that are not confined to drought conditions. Studies have also found that people who have previously experienced drought have a heightened consciousness of the value of water and are more aware of their water futures. This increases the likelihood of continuing conservation behaviour post-drought (Gilbertson *et al.* 2011; March *et al.* 2013; Braga & Kelman 2020). Further research should seek to extend this study and explore the potential to prolong the drought savings that were observed in Cape Town into permanent water conservation behaviours. However, reducing residential water demand significantly reduces the water utility's revenue and inextricably undermines its ability to maintain and upgrade the water supply system. Cape Town's Water Strategy (CoCT 2020) states that the City's policy to remain revenue-neutral during drought restrictions places a financial burden on water users. This study provides insights into how accompanying tariffs helped alter water-use behaviours of different socio-economic groups and particularly how it shifted the conservation burden onto the lower-income group. This calls for a reform in the current water tariff model to one that is sensitive to the urban poor and social needs, even in times of severe water scarcity.

Lastly, Cape Town's Water Strategy states that beyond the social policy of ensuring that the basic amount of water is accessible to everyone (a basic human right), the city will continue to use pricing to promote wise water use through the 'long-term marginal cost' of water (CoCT 2020). The city further aims to improve its by-laws, regulatory mechanisms, and other water conservation incentives (e.g. debt write-off and leak repairs for indigent households), as well as to promote the reuse of groundwater, wastewater, and stormwater. Further enquiry is therefore needed into how mixed measures are useful in enhancing water security in water challenged cities like Cape Town and their implications for lower-income households. Further studies should seek to determine how the proposed fixed charges can best be implemented, so that water services do not become unaffordable to lower-income households.

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