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Temporal case study of household behavioural response to Cape Town's "Day Zero" using smart meter data

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Abstract

Faced with the threat of "Day Zero", when it was feared that Cape Town's taps could run dry, consumers reduced household water usage from 540 to 280 litres per household per day over the 36 months between January 2015 and January 2018. This paper describes the events that prompted this reduction. We look at how changes in water use were affected by official announcements and by public engagement with this news via the social media activity and internet searches. We analysed the water usage of a subset of middle to high income households where smart hot and cold water meters were installed. For hot water usage patterns we compared meter readings with that in another area unaffected by the drought. We further map our cold water smart meter readings against that of the City of Cape Town's municipal data for domestic freestanding households — a sample of more than 400,000 households. We found that the introduction of Level 5 restrictions had a perverse effect on consumption, possibly due to confusing messages. The most dramatic change in behaviour appears to have been instigated by a media storm and consequent user panic after the release of the City's Critical Water Shortages Disaster Plan in October 2017. However, contradictory communication from national and provincial government eroded some of this gain. The paper concludes with recommendations for demand management in a similar future scenario.

Keywords: Drought response; demand side management; user behaviour; household water usage; time-of-day analysis; smart water meters; Cape Town drought

Word count: 4661 words.

1. Introduction

In 2017, experiencing one of the Western Cape's worst droughts since 1904, Cape Town became notorious in the international media as a major world city about to run out of municipal water. The prospect of dry

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taps was dramatically named "Day Zero" by the City Council. From November 2016 to Feb 2018, the City of Cape Town incrementally imposed six levels of water restrictions, from Level 3 to Level 6B, in an attempt to curb usage.

There are only four previous studies that examine user water saving responses to the Cape Town drought. Visser and Brühl (2018) and Köhlin et al. (2018) note that household usage in Cape Town, especially by affluent users, declined sharply over the three year period from January 2015 to January 2018, from 540 to 280 litres per household per day, as the drought intensified. Brick et al. (2018) show that "behavioural nudges" sent to domestic households in the early stages of the drought, between November 2015 and May 2016, had a modest effect, reducing water usage by 0.6 % to 1.3 %, and Brick and Visser (2018) note that a subsequent campaign of warning letters in March 2017, targeting households using more than 50 kL/month was effective in reducing usage by 3%.

The topic of drought and water usage behaviour is well covered in the international literature. Understanding water users' behaviour at a time of water shortage is vital for managing demand and supply effectively (Teo et al., 2015; Anderson et al., 2018). Analysis of the interaction between drought-related messages from the various spheres of government and the media and the citizens' behavioural responses could provide valuable information for improving management and communication during a crisis of this kind and achieving the desired result, in any water-scarce city like Cape Town (Kazianga and Udry, 2006; Polebitski and Palmer, 2010; Makwiza et al., 2017; Anderson and Nagarajan, 2016; Quesnel and Ajami, 2017). The possibility of climate change increasing the likelihood of prolonged droughts, such as those recently experienced in cities in Queensland, Sãu Paulo and cities in California, makes this particularly pertinent (Grant et al., 2013; Amir et al., 2014; Diffenbaugh et al., 2015; Teo et al., 2015; Soriano et al., 2016).

Measuring user participation in water-conscious usage during droughts, Dascher et al. (2014) found that, to drive demand-side management of water resources, better results would be achieved by water usage restrictions and educational campaigns than by incentives to use water conservation technologies. Using internet search terms and monthly smart meter data to evaluate user responses to media articles in severe weather conditions in California, Quesnel and Ajami (2017) found a strong correlation between media coverage of severe weather (drought) and reduced monthly usage.

Rein et al. (2013) found that analysing water usage patterns through billing information is problematic because the usual monthly reading of meters hides many of the transient effects that may only last a day or a week. They noted that achieving water usage targets through demand side management is challenging, since the user has to access the water meter manually and make frequent readings and interpret them meaningfully.

High frequency sampling is required to discern users' reactions to the barrage of municipal notices and media messages during a water crisis. Smart metering provides a useful means of obtaining data and has been used in a number of studies (Willis et al., 2011; Gurung et al., 2015, 2017; Beal and Flynn, 2015; Cominola et al., 2015; Britton et al., 2013). For example, Gurung et al. (2015) demonstrated how smart water meters can be used to analyse behavioural changes, and how smart meter data analysis can be used to disaggregate usage types.

This study adds to the literature on household behavioural responses during droughts by examining the temporal detail of household water saving behaviour in response to official announcements on water restrictions and public engagement with this information via social media activity and internet searches – in the shadow of the realistic threat that taps could run dry if households failed to respond adequately.

Our analysis of household responses to official announcements is guided by Rogers (1975)'s theory of protection motivation. According to Rogers' theory, the household's response is determined by their appraisal of the threat as well as their appraisal of their own ability to respond to the threat. In line with this theory, Witte and Allen (2000)'s meta-analysis found that fear appeals had the greatest impact on behaviour change when they made the public aware of their vulnerability but also made it clear what the public needed to do to help alleviate the problem.

We start by showing trends in hot and cold water use in Cape Town in the eight months leading up to March 2018, when taps were predicted to run dry. The cold water is the total household's water used, and therefore includes water that would eventually be heated. We compared hot water usage in Cape Town to that of two other regions in South Africa, Mpumalanga and Gauteng, that were unaffected by drought but exposed to many of the same drivers of change as Cape Town. These hot water measurements provided a control against which to assess behavioural changes in Cape Town. To cross-check the external validity of our sample of users, we also compare our sample of cold water smart meter data trends with the median monthly metered household water usage for the City of Cape Town (a sample of more than 400,000 domestic free standing households). We tested observed changes in cold water usage behaviour for our smart metered households against an interrupted time series analysis of key events and government announcements. Motivated by Roger's theory model, we used social media analytics to identify points of heightened public engagement with this threat, to understand how the public digested, assessed and navigated the barrage of notices and news that emerged during the crisis. The social analytics simultaneously captured the household assessment of the credibility and severity of their vulnerability (threat appraisal) and household's efforts to find useful ways to respond to the threat and positively affect change (appraisal of their ability to respond to the threat).

2. Data and methods

Before the worst of the drought in the Western Cape, two water management devices had been installed as a pilot project in a small number of households in South Africa: a smart hot water meter called "Geasy" and a smart cold water meter called "Dropula" (Roux and Booysen, 2017; Ripunda and Booysen, 2018). These meters take and report measurements remotely with a per-minute time resolution and 0.5 L volume resolution. The hot water Geasies were installed at volunteering households as part of a funded research project in the Mpumalanga and Gauteng provinces, in the north of South Africa, and in the Western Cape province, in the south, from June 2015 to December 2016. This enabled us to compare the hot water usage of the control group in the north and the drought-affected group in the south. The cold water Dropulas were installed in the Cape Town area from October 2016 to August 2017, either at the households of water-conscious volunteers who tested the technology or users who had the devices installed to manage their water usage. Our sample consisted of 33 households with hot water meters (Geasies) in the Cape Town area, 54 households with hot water meters (Geasies) in the north, and 16 households with cold water meters (Dropulas) in the Western Cape.

As both Geasy and Dropula households are predominantly from the highest income quintile in a South African context, and since there households self-selected to use the devices, the sample is certainly biased - these users can be assumed to be more educated, conscientious and responsive to conservation messaging than the general populace. For this reason we cross-check our findings by mapping our data against that of the City of Cape Town's domestic users' aggregate water consumption, as well as those in the highest income quintile amongst the City's users. It should be noted that this top income quintile, are also the highest water users, and therefore likely to have the biggest effect on overall water usage (Harlan et al., 2009; Brick et al., 2018; Brick and Visser, 2018). We do not claim that our small sample is representative of South Africa as a whole; it was, however, encouraging to find that the trends we observed in our sample were broadly aligned with the City of Cape Town median trends.

To supplement and interpret the quantitative analysis of water usage by various samples, we analysed mainstream media and social media reactions to the government announcements. We used two tools: a social media analysis tool, Talkwalker, and an internet search term analysis tool, Google Trends. Google Trends scales searches on a relative 0.0 to 1.0 scale, where 1.0 is the highest search rate for that term(s) for the entire period, while the Talkwalker results were normalised to report the same metric. We searched terms of two types: firstly those related to the water restriction levels and secondly those that we have called "ariditaphobic", i.e. terms related to fear of the drought and its consequences, especially those used in the disaster plan Critical Water Shortages Disaster Plan of 4 October 2017. The terms in the first list were *Level 5 or Level 5 restrictions or Level 5 water restrictions or water restrictions.* The terms in the second were *collection points, disaster, crisis, South African National Defence Force or SANDF, bottled water, borehole.* We limited the Google Trends search to the Western Cape and the social media search to South Africa, using Twitter, Instagram, Facebook and Google+. We restricted our searches to August 2017 to October 2017, because our data suggested there had been a strong and consistent decrease in water use by our sample of households over those three months.

To test our hypothesis that users' water-use reactions were influenced more strongly by the alarmism in the mainstream media and social media than by the official announcements of restrictions, we used an interrupted time series analysis using daily water use data. This method uses a segmented regression to test whether an event caused a rupture in a level or trend of an outcome, or both. Because we found a high correlation between the outcome variables in sequential time-periods (first-order autocorrelation), we used a generalised least-squares approach. Closely following the notation of Linden (2010) the standard ITSA regression model for a single event and treatment period has the following form: $Y_t = \beta_0 + \beta_1 T_t + \beta_2 X_t + \beta_3 X_t T_t + e_t$, where Y_t is water use per day in litres, T_t is the time since the start of the study, Xt is a dummy (indicator) variable representing the event, $X_t T_t$ is an interaction term and et is the error term. β_0 represents the intercept, 1 is the slope prior to the event, while 2 represents the change in daily water consumption after the event and 3 represents the difference in the slopes for water use before and after the event. For consistency and comparability we excluded weekends. We tested for changes in both the level (volume per day) and the trend at three points in time: 3 September 2017, when Level 5 restrictions were announced, 11 October 2017, when drought panic terms spiked in the mainstream media and social media, and on 31 January 2018 when the restrictions were increased to Level 6B. We also tested 4 October 2017, when the Critical Water Shortages Disaster Plan was announced CoCT (2017b).

3. The municipality's step-by-step management of Cape Town's water crisis

This section provides a chronology of the City's official announcements, which is also shown in Figure 1. The drought-stricken Western Cape was declared a disaster area on 22 May 2017 (WCG, 2017). Since November 2016, Cape Town had been on Level 3 water restrictions, which prohibited the use of garden hoses, sprinkler irrigation and washing of cars. On 1 June 2017 the City implemented Level 4 restrictions, which limited each user to 100 L/person/d and banned all non-essential outdoor water use, including filling of swimming pools (CoCT, 2017d). A month later, on 1 July, Level 4B restrictions were implemented, reducing daily usage to 87 L/person/d and giving households a 10.5 kL/month allocation, based on the per-person usage of a household of four over 30 days (CoCT, 2017a) . Our measurements and the time sequence for our analysis begin after this.

On 17 August, the City's mayor announced the City's Water Resilience Plan, which included plans on water augmentation programmes, punitive measures and fines for heavy users, installation of water restriction devices at non-complying properties at the householder's expense, and a looming additional restriction from

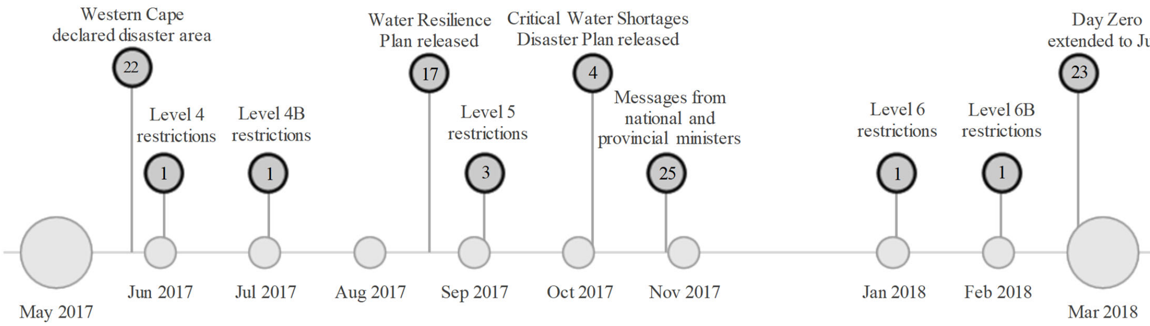

Figure 1: A timeline of the events relating to the management of Cape Town's water crisis.

September (CoCT, 2017a). On 3 September, the City implemented Level 5 restrictions, which included more fines, and announced that water pressure management would begin, to reduce the losses through leaks.

It was noticeable that Level 5, when finally implemented, contained two apparently conflicting restrictions: use per person was still limited to 87 L/d (implying 10.5 kL/month for a four-person household), as in Level 4B, but residential properties were capped at capped at 20 kL/month. The City may have intended this more lenient cap on household usage to accommodate low-income properties with larger household sizes or several dwellings per property, but it did not communicate this formally to the public, and the press release associated with this 20 kL/month cap (CoCT, 2017c; News24, 2017b; Cape Talk, 2017b), did not say the limit applied to residences of "eight occupants or more", as was mentioned in one subsequent radio interview (Cape Talk, 2017a). The 20 kL/month limit thus conveyed a mixed and somewhat perverse message to most average-sized households already using below 10.5 kL/month

On 4 October 2017, the City's mayor released its Critical Water Shortages Disaster Plan. Table 1 shows the most striking points of the plan.

On 25 October 2017, after the negative press and the panic that followed the issuing of the disaster plan, the Premier of the Western Cape and the national Minister of Water and Sanitation, in an apparent attempt to calm the situation, issued separate statements to reassure residents that Cape Town would probably not run out of water (Cape Talk, 2017c; Eyewitness News (EWN), 2017).

On 1 January 2018, the City implemented Level 6 water restrictions, which maintained the limit of 87 L/person/d, but crucially, clearly re-stated the monthly household limit of 10.5 kL/month. The City also started to actually impose fines on households exceeding this cap.

On the 1 February 2018, the City implemented Level 6B water restrictions, now with a limit of 50 L/person/d, and a household cap of 6 kL/month. The City also suggested limits per usage type, such as 18 L for washing clothes and 15 L for showering. It also announced that 200 water collection points had been identified for when the City ran out of water, for a city with a population of 4.2 million (WCG, Treasury, 2017).

Table 1: Excerpt from the Critical Water Shortages Disaster Plan, released 4 October 2017 (De Lille, 2017)

Relevance	Description
General	Winter, the rainy season, was over and users were in for a long, hot, dry summer period. 27 % usable water was left in the dams Cape Town was expected to run out of water by March 2018. The national Minister of Water and Sanitation [importantly, from the African National Congress (ANC), the opposition to the governing Democratic Alliance (DA) in the in the Western Cape] had been engaged to discuss water security and new emergency schemes.
Phase 1	This phase was immediately active Water rationing through extreme pressure reduction would be introduced, which would lead to intermittent, localised temporary water supply disruptions. Users were advised to store up to five litres of municipal drinking water only for essential usage.
Phase 2	The whole system would be disrupted with a limited number of supply points. Water collection points would be put up. The defence force (SANDF) and the police service (SAPS) would be deployed to ensure that general safety was maintained throughout the city. Critical services, and areas with an increased risk of disease and fires, would continue to receive drinking water.
Phase 3	The existing system would collapse

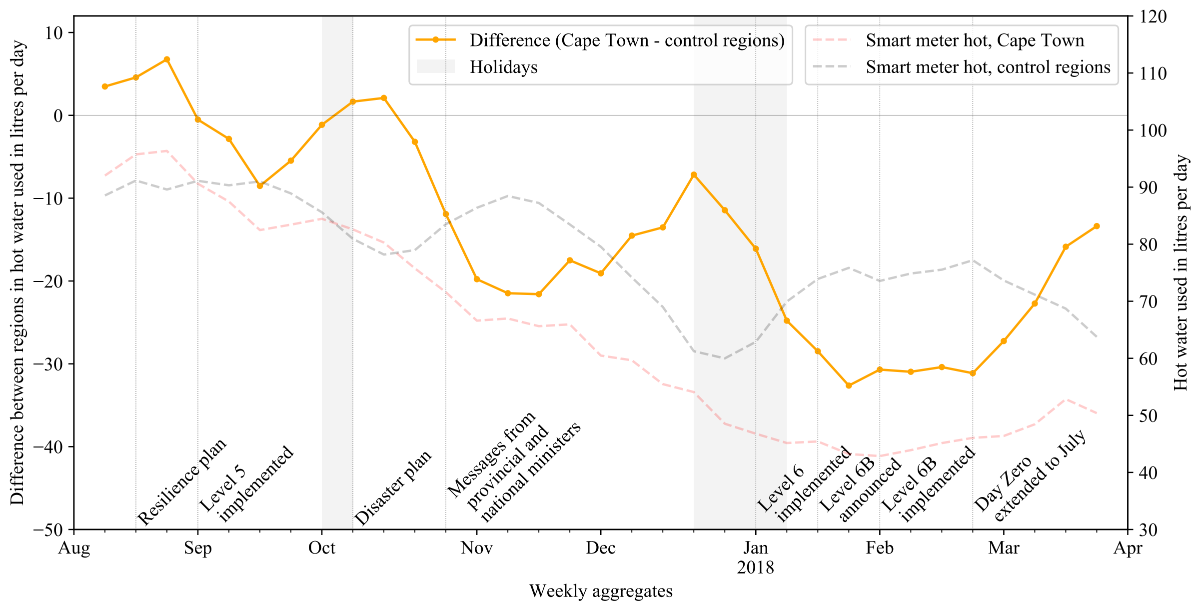

Figure 2: Household hot water use in Cape Town based on weekly medians expressed as average use per day, from Geasy smart controllers, compared with control areas (in Mpumalanga and Gauteng) unaffected by the drought. Usage for the control areas is normalised to the first month of Cape Town's. The orange line is the difference between the two regions, while the grey and light red lines contain the absolute usage values.

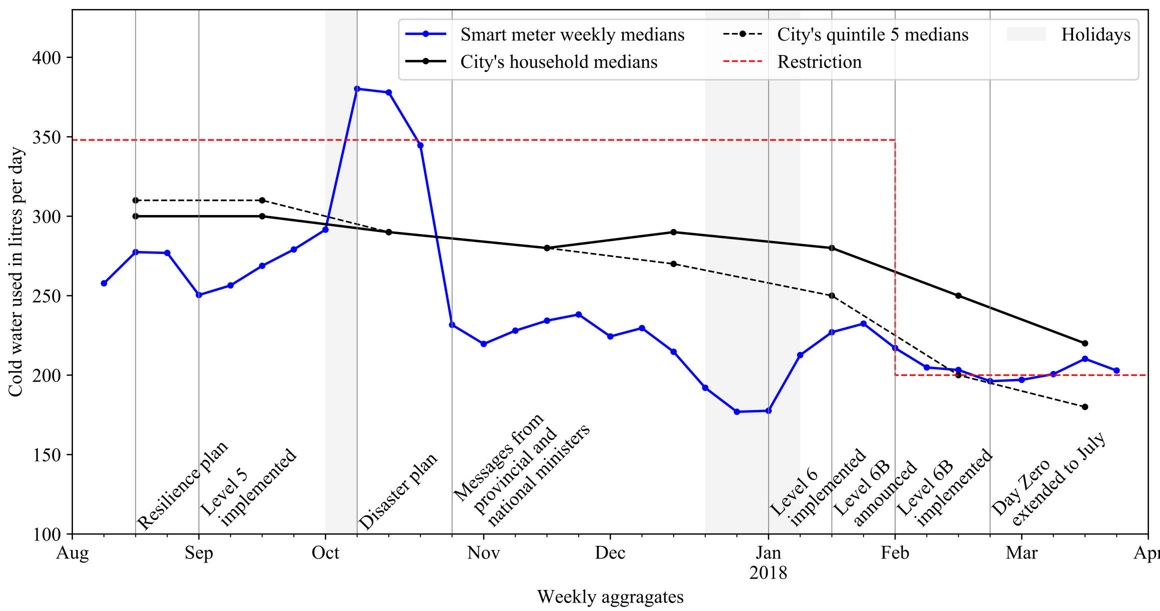

Figure 3: Household cold water used in Cape Town (including water that would eventually be heated) based on weekly medians expressed as average use per day, from Dropula smart water meters, and monthly Cape Town household medians.

4. Descriptive analysis

4.1. Observed trends in water use, August 2017 to March 2018

4.1.1. Hot water

Figure 2 shows **hot water** usage by the drought-affected Western Cape sample and by the sample from regions of the country that were not affected by the drought. The sampling points represent the weekly aggregated data, expressed as the daily average usage, for each preceding week captured by the Geasy smart controllers. The profiles show how the difference between the Western Cape and the control region usage (the orange line) dropped from the middle of August 2017, after the release of the Water Resilience Plan. The difference is stark and continues to increase to a peak difference of $-9\,\mathrm{L/d}$ after the second week of September. A week after the Level 5 restrictions were introduced, the Cape Town usage perversely increases, and the difference between the two samples quickly reduces to $2\,\mathrm{L/d}$ in the following four weeks, apparently indicating diminished savings subsequent to Level 5 implementation.

A week after the announcement of the disaster plan on 4 October 2017, the difference between the regions starts to increase, reaching $-21\,\mathrm{L/d}$ in the first week of November, indicating a substantial reduction in the Cape Town sample's usage. In mid-November, after the intervention by the premier and the national minister, the difference between the groups plateaus and then decreases to $-6\,\mathrm{L/d}$ at the start of the holiday period (18 December 2017 to 7 January 2018).

After the holiday period, which overlaps with the implementation of Level 6 restrictions, the difference between the groups increases steadily, reaching −33 L/d in the last week of January 2018, as the Cape Town sample reduce their usage in response to the looming crisis and the introduction of Level 6B restrictions. After the peak in the difference between the groups, it plateaus until such time that Day Zero was postponed to July, from where the difference between the groups sharply reduces again as the Cape Town sample's usage steadily increases.

4.1.2. Cold water

Figure 2 shows the **cold water** usage by the Dropula smart water meter sample and by City of Cape Town households. A weekly aggregate was taken of the medians of the smart water meter data, which are captured every minute. The City of Cape Town data are the monthly medians of all households in the city.

The Dropula sample's cold water usage profile bears a general resemblance to the City of Cape Town's, but, as expected, the former use significantly less than the latter, probably because of the self-selection effect of water-conscious users who opted to install the smart meter. Also, the sample's profile suggests that they reacted earlier than the City of Cape Town users, as a study by Anderson et al. (2018) leads us to expect. The more frequent sampling rate (aggregated to weekly) of the smart water meter data makes it possible to see the short transient effects that may be hidden in the monthly City of Cape Town readings. For example, we can see a plunge in the Dropula profile from the first week of October 2017, after the announcement of the disaster plan, and a rise in the last week of October, after the messages from the premier and the national minister.

The cold water profile shows an initial increasing trend in the second week of August 2017, as temperatures rose and users started irrigating their gardens and filling their swimming pools, reflecting the trend observed from 2014 to 2016 in the City of Cape Town household data, and reported by Visser and Brühl (2018) and Köhlin et al. (2018).

Three noteworthy events occurred in the first two weeks of August that might explain the apparent levelling of and subsequent reduction in the last half of August: the national government derided the city for not reacting adequately to the drought crisis, the City threatened to install water restriction devices for heavy users, and the mainstay annual West Coast Flower Show was cancelled because of the drought (IOL, 2017c,a,b). Crucially, however, on 17 August the City publicly announced the Water Resilience Plan.

Although behaviour was affected at this point, an increase in usage can be seen after the first week of September 2017, which is when the Level 5 restrictions were implemented. At this point the smart meter users were at 250 L/d, which equates to 7.5 kL/month (The Cape Town median was at 300 L/d per over the month). The perverse effect of the contradiction in the Level 5 restrictions (described above) may explain the increase in usage to over 350 L/d (or 10.5 kL/month) at the end of the September school break (30 September to 8 October, shaded in the graph). We might expect higher usage during this break, as more people would be at home, but the higher usage is maintained into the first week of October, following the profile of previous years.

A reduction can be seen in the second and third week of October, after the city announced the disaster plan on 4 October 2017. Following the release of the plan, an outpouring of alarmist and distrustful articles appeared in the media, voicing threats of dams less than a third full at the end of the rainy season, disease and death, and accusing the City of mismanagement and bad planning and non-viable augmentation schemes (Head, 2017; The South African; Davis; Cape Business News; Deklerk and Collins, 2017; Koopman and de Buys, 2017; News24, 2017c). A team of experts from the Climate System Analysis Group, the South African Environmental Observation Network and the Departments of Environmental and Geographical Science and the Built Environment at the University of Cape Town in unison stated publicly on 11 October that the City's aquifer extraction plan was impossible (News24, 2017a) [1].

The graph shows the sudden effect on the user profile, with usage plummeting for the three weeks following the media surge, as Quesnel and Ajami (2017) predicted. But after the calming statements by the premier and the national minister on 25 October 2017, usage plateaus with a slight increasing trend and does not decrease again until the second week of December, overlapping with a small increase in social media activity seen in Figure 4.

It is difficult to draw conclusions from the holiday period's usage (18 December 2017 to 7 January 2018, and possibly the immediately preceding and following weeks too), since many people, particularly the mostly affluent smart water meter users, may not have been at home. However, after the second week in January usage increases steadily to levels higher than before the holiday period, matching an increase in the City of Cape Town household data. This increase peaks shortly after the City's announcement of Level 6B restrictions. A further reduction follows the implementation of Level 6B on 1 February, after which usage plateaus and slightly increases with the announcement on 22 February that Day Zero had been postponed to July.

4.2. Internet searches and social media activity

In this section we examine the public engagement with government announcements by analysing spikes in internet searches and social media activity. Based on Rogers' theory of protection motivation (1975), we consider threat appraisal and the appraisal of the household's ability to respond to be crucial mediating factors for behavioural change. Our hypothesis was that internet searches and social media activity are

[1] The Mayor of Cape Town, Patricia de Lille, was placed on leave on the eve of the release of the disaster plan, facing accusations of misappropriation of funds. This probably further damaged people's trust in the City of Cape Town at that point.

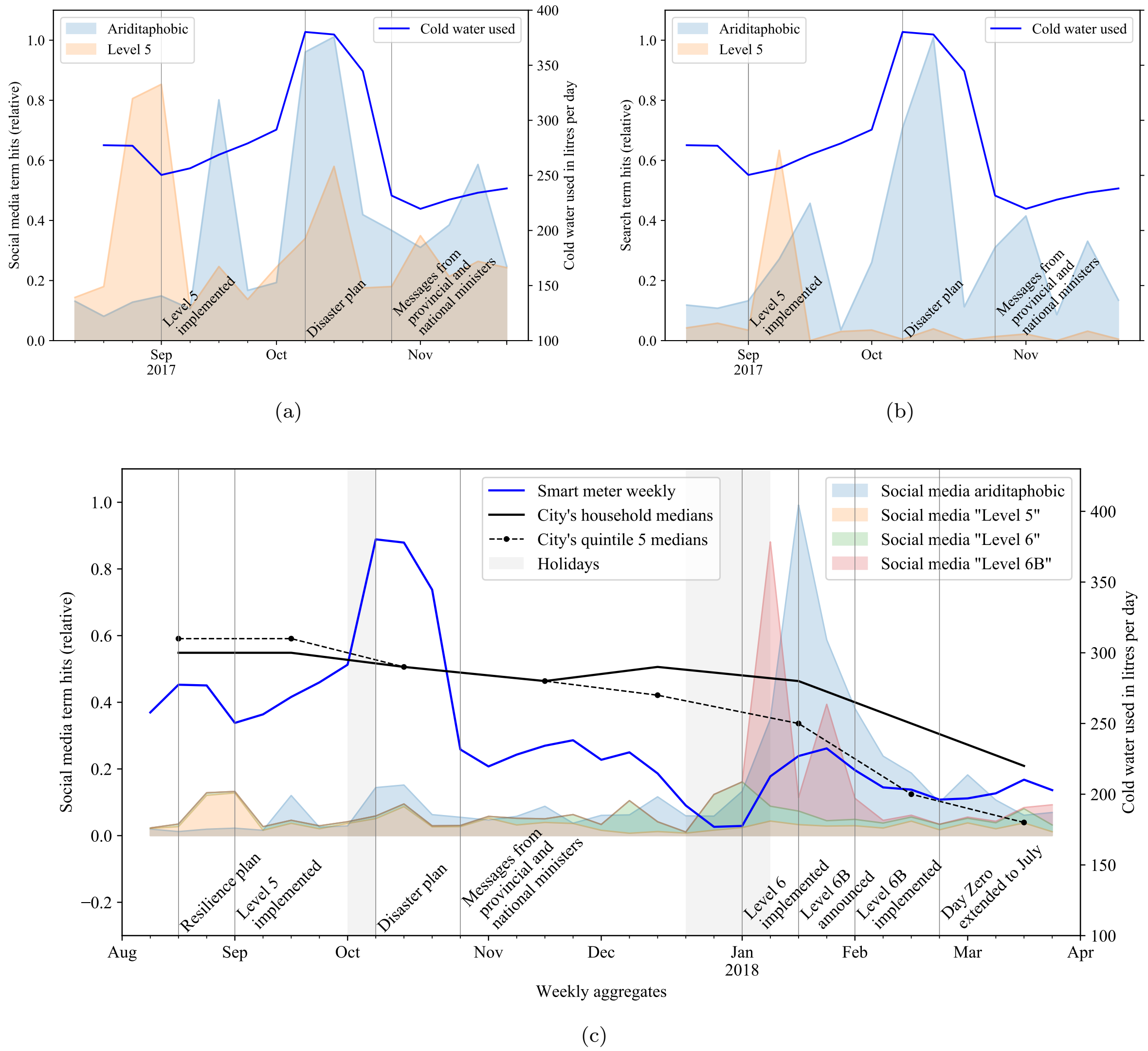

Figure 4: Results from social media search and Google Trends search showing the prevalence of water restrictions terms and ariditaphobic (fear of drought) terms. (a) Search terms and (b) social terms for period around October 2017. (c) Social terms for the period August 2017 to March 2018.

important and easily observable conduits for the household's efforts to appraise both their own vulnerability and also their ability to positively contribute to reducing this risk.

We expected that in some cases the media's interpretation and discussion of an announcement might represent an event in itself, giving the announcement added force by imagining its implications, rightly or wrongly.

Figure 4 (a) and (b) shows that during the week preceding the drop in usage there was an increase in ariditaphobic terms and a decrease in terms relating to the Level 5 restrictions. Spikes in the frequency of terms related to drought panic, however, do not overlap with the announcement of Level 5 on 3 September but occur much later, towards early October. These spikes in search terms and social media activity give

Table 2: Interrupted time series analysis (Prais-Winsten first order autocorrelation regression) of the events in question, with evaluation using the Durbin-Watson statistic.

Nr of obs		174	F(7,166)			8.01
Prob $> F$		0.00	Root MSE			44.78
R^2		0.25	Adjusted R^2			0.22
Water	Coef.	Std.errors	t	$P > \|t\|$	95%	CI
Trend	0.4	2.0	0.2	0.8	-3.5	4.4
3 Sept	-49.2	37.0	-1.3	0.2	-122.3	23.9
3 Sept trend	3.7	2.8	1.3	0.2	-1.9	9.2
11 Oct 17	**-99.6**	**31.9**	**-3.1**	**0.0**	**-162.6**	**-36.6**
11 Oct trend	-5.0	1.8	-2.8	0.0	-8.6	-1.4
31 Jan	15.3	27.3	0.6	0.6	-38.5	69.3
31 Jan trend	0.9	1.00	0.9	0.4	-1.0	2.9
Usage	222.9	30.6	7.3	0.0	162.5	283.2
rho			0.444			
Durbin-Watson statistic (original)			1.12			
Durbin-Watson statistic (transformed)			2.04			

the impression that the announcement of tighter water restrictions may have had less effect on the social mindset than the media frenzy and scaremongering that ensued after the release of the Critical Water Shortage Disaster Plan, which referred to the risk of running out of water, the possibility of having to queue for a ration of drinking water at collection points, and the increased threat of fire and disease in crowded settlements.

We tested this hypothesis with the interrupted time series analysis using daily water usage data, as explained in the methods section above. Table 2 shows evidence of a large and significant rupture in the level and trend of water use at 11 October 2017, but not on 3 September 2017 (Level 5 restrictions implemented) or 31 January 2018 (Level 6B restrictions implemented). The 11 October water use levels declined by 100 L/d and the trend in water use decreased by 5 L/d after that date. We found no significant change on 4 October (test not shown in Table 2, but for 4 October 2017 $P > |T| = 0.495$) when the disaster plan was introduced. However, the strong correlation found on 11 October was persistent until 17 October, matching exactly the pattern observed in the social media and internet search analysis before weekly aggregation.

Figure 4 (c) illustrates the scale of the panic that coincided with the announcement of Level 6B and imminent threat of Day Zero, which is followed by the apparent further reduction in usage.

5. Conclusion

This paper describes the sequence of events leading up to Cape Town's purported "Day Zero" in 2017 and 2018, and connects key events to the changes in behaviour of a small sample of users with smart meters that measure cold and hot water respectively. Social media and search term analyses in combination with a time series analysis show that the biggest response was observed, not when the restrictions or tariff increases were imposed, but in response to a three-phased disaster plan that warned of disastrous outcomes. The results suggest that users responded more strongly to the threat of waterless taps than to the implemented levels of water restrictions.

Our smart meter data in combination with billing data from the City points to a remarkable success on the side of citizens to drastically revise their consumption patterns over a relatively short period of time. Moreover our research seems to indicate that while inciting some level of fear-mongering may have been a risky strategy for the municipality to undertake, it may have been the single most successful intervention in effecting profound behavioural change amongst citizens.

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