Understanding and affecting school water behaviour using technological interventions

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Abstract. *This paper reports the results of a study of water usage behaviour at a primary school in Stellenbosch in the period leading up to the 2018 Western Cape drought. The aim of the study was to describe a school's water usage patterns and quantify the usage reduction resulting from technology-driven interventions promoting behavioural change. Three interventions were implemented using smart meter data: posters, playing cards and daily presentations. Only 58% of water usage was during school hours, with the daily peak between 10:00 and 11:00. After-hour usage was more variable than during school hours. The information-sharing interventions reduced the school's water usage by 44% when compared to the usage of a school in the same town where the interventions were not implemented.*

Keywords: School water bill, smart meter, technological intervention, behaviour change

Introduction

Water scarcity has become a global crisis and is getting worse. The main contributors to this problem are rapid population growth, increased urbanisation and climate change. In South Africa the water crisis is particularly severe. Increased urbanisation, coupled with ongoing development, is increasing the demand for water beyond the supply capabilities. Colvin and Muruven (2017) note that 98% of the country's total water supply is already allocated and demand has increased significantly, the major

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sectors responsible for this being agriculture (63%), municipalities (26%) and industry (11%). They note that the recent drought in the country's Western Cape has had adverse effects on the agricultural sector, widening the trade deficit due to losses in agricultural exports.

Cape Town, where the water shortage problems were particularly evident, was subject to severe water restrictions from 1 June 2017 (Brick et al., 2018, Booysen et al., 2019). These restrictions, which applied not only to domestic users but also to public spaces such as sports ground, shopping centres and schools, prohibited residents from using municipal water for irrigation, topping up swimming pools, and so on, and set a low daily usage limit per person. The restrictions were a clear indication of the supply shortage, thus shifting the focus from supply management to demand management. Water-saving solutions that focus on demand management have become a priority, but the residential sector, as one of the biggest water users, has been more in the spotlight than schools. However, schools also use a lot of water, and as they bring together users from many different sectors, they provide an excellent place to spread the message of water conservation to a wide variety of households. Efforts to change water use behaviour at schools could thus help reduce water usage more generally.

Water utilities run campaigns to inform and educate users on the importance of water conservation (Anderson and Nagarajan, 2016). In South Africa several social campaigns have been promoting water efficient technologies and behavioural change to improve water usage habits. The impact of most of these campaigns has thus far not been quantifiable, but technology is favoured as a possible solution (Nel et al. 2014).

The study described in this paper offers an example of the behavioural change that a school campaign can bring about. It also shows that the resulting reduction in water usage can be quantified. The ultimate aim is to help water providers improve their water campaigns and social marketing designs and make their water bills user-friendly.

Purpose of the study

The study's aim was to explore water demand management solutions. Our hypothesis was that our sample school would be more inclined to conserve water if it was given regular and understandable reports of its water usage. We investigated the school's current water behaviour patterns, implemented three behavioural change interventions to reduce its water usage, and quantified the results. We compared our sample school with another similar school in the area using the difference-in-difference method. In the course of the study we also investigated various behaviour theories, to see how they might be applied to water conservation.

Two related studies

We reviewed two studies involving behavioural interventions. The first, Fielding et al. (2012), is of particular relevance to our own study, as it used data from a smart water meter. It was a randomised controlled trial, conducted in South East Queensland, Australia, using three different water usage reduction interventions over five months with 221 participating households. The first was an *informed* intervention that gave the households general information on how to save water in the bathroom, laundry and kitchen and by fixing leaks. The second was a *descriptive norm* intervention that gave the households water-saving tips from 'low water use households'. The third was a *water end-use feedback* intervention, in which a smart water meter was installed at all the households to collect their water usage data and the households were given tailored information in the form of a pie chart showing the water usage of each appliance in their home. Water usage data was also collected from a control group of households, used as a baseline, that were not given the information. Over the study period the reductions, compared with the control group, were significant: 7053 litres less used per household for the informed group, 1794 litres used less per household for the descriptive norm group, and 5720 litres per household for the water end-use feedback group. The descriptive norm group's reduction was smallest because it had more high water users than the other two groups. Towards the end of the study a sizeable number of the smart water meters of all groups were damaged by flooding.

The quality of the data worsened over time as more water meters failed. The final estimates of water reduction were hence not as reliable as at first and the study had to stop earlier than planned. It was also noted that the reductions were not long term – usage by these groups returned to pre-intervention levels six to ten months after the interventions.

Although these behavioural change interventions successfully reduced water usage, the study had some limitations. The most interesting of these, from the point of view of the present study, was the lag between water use and feedback in the water end-use feedback group. The smart meters used did not have real-time feedback capabilities and many of them were no longer functional towards the end of the study. Users in this group only received feedback monthly. Another limitation was that the participants who agreed to take part in the study may already have been engaged in the issues of water conservation previously, which made it unclear how much of their behavioural change was due to the interventions.

The second case study, (Zoratto et al., 2015), a randomised controlled trial conducted in Belen, Costa Rica, in 2015, investigated the effectiveness of three simple water usage reduction interventions. The study hypothesised that interventions that allowed users to benchmark their usage against their peers would be useful in reducing water usage. Three interventions were designed using insights from a target population focus group: a *neighbourhood comparison* that compared the household's water usage to the average household in their neighbourhood, a *city comparison* that compared the household's usage to the average household in the city of Belen, and a *plan making* intervention that drew the household's attention to their usage and helped them quantify their daily water use reductions, set goals and find ways to achieve these goals. Significant reductions were observed compared with the previous year. The neighbourhood comparison and the plan making interventions had larger reductions than the city comparison intervention. The average monthly water usage reduction over two months was 0.98 to 1.47 kL per household for the neighbourhood comparison intervention and 0.9 to 1.49 kL for the plan making intervention (between 3.7 % and 5.6 % of the control group's consumption for the same period).

The plan making intervention suffered from a limitation caused by the water bills, on which it relied. The bills were often delayed, making it difficult for the households to track their reduction goals in a timely manner, and the information in the bills was not necessarily a true reflection of the household's water usage as it often contained errors caused by manually recording the water usage.

Behaviour theories

Here we summarise three theories of human behaviour: planned behaviour, social practice and diffusion of innovation, as background to our study. The popular and widely applied theory of *planned behaviour* has been used to predict and explain 20 to 30% of variance in behaviour brought about through interventions. It can be used to identify influences that could be targeted to bring about change, but it is not practically useful for designing an intervention that will result in a specific behaviour change (Morris et al. 2012). *Social practice* theory, which sees people's choices and attitudes as often secondary to contextual factors, making them 'carriers' rather than initiators of behaviours, has been used to understand sustainable behaviours in the fields of energy, transport and waste. In focusing on social practice rather than individual behaviour, it helps to explain why certain behaviours are adopted or disregarded and what role technology plays in changing or evolving behaviours. *Diffusion of innovation* theory focuses on innovation as an agent of behaviour change. It states that behaviour will change rapidly if people perceive an innovation as better than the existing options yet still consistent with current values, experiences and needs. The theory takes into account mass media and interpersonal channels for creating awareness and persuading people to change their behaviour. The theory notes that the process requires time. It starts with identification of the problem or need, followed by five steps: knowledge, persuasion, decision, implementation and finally confirmation. For further information on the use of these theories, see Mosler (2012) and Morris et al. (2012) .

For our study, we found all three of these theories useful for ideas on how to use information communication and technology (ICT) to affect and quantify behaviour change.

Difference in differences method

The difference in difference (DiD) method is used to estimate causal effect. It is often used in behavioural economics and the social sciences to estimate the effects of interventions and policy changes. It is most suitable for studies where it is not possible to control for confounding variables, but pre-treatment information is known. It compares four groups of objects, three of which are not affected by treatment: before treatment for the control and treatment groups, and after or during treatment for the control and treatment groups. The study is divided into pre- and post-treatment periods. The research population is divided into a control and a treatment group, with the intervention being applied only to the treatment group (Lechner 2011).

Methods

We installed smart water meters at the school, to monitor the water usage in real time, and used the data to describe the usage patterns and to quantify the usage reductions. The behavioural study involved three interventions, each designed for a particular population of the school: the management, the teachers and the pupils. All the interventions, however, were designed with the same purpose: to affect behaviour by educating the target population about the importance of water and encouraging behaviours that would reduce water wastage.

Smart water meter

The smart water meter used for the study was designed and built by a spin-off company from the Stellenbosch University[3] (Roux 2018). It consists of a standard water meter and a unit, which with the aid of a sensor transmits pulses to a micro-controller. The controller counts the pulses and transmits the cumulative volumes wirelessly to a server for presentation and analysis. The volume of water used is then calculated from the data sent to the server. One pulse is equivalent to 10 litres. The data can be viewed on a website, in a graphic form that can be downloaded.

Setting and study period

The study was conducted in Stellenbosch, in South Africa's Western Cape Province. The town has 27 primary and secondary schools in total, some with hostels and some without. Our sample school had 89 staff members and over 500 pupils. There are four staff houses on the school premises, each with three to four occupants. The school has a large swimming pool and a large field. Borehole water is used for the pool and the field, but the rest of the school's water needs are met with municipal water. The study period was divided into three stages: pre-intervention, to collect baseline data; intervention; and post-intervention, to analyse the data.

The smart meters were installed on 19 May 2017. Data were collected from 20 May 2017 to 17 June 2017 (the intervention period). Monthly municipal bills were used for the previous date ranges back to December of 2016, and the same municipal meter was used for to generate the pulses. The results excluded data from the middle of April to the middle of May 2017 as this was the school holiday. The school's existing water usage data for three weeks prior to the start of the study was used to established baseline data. The typical usage patterns were extracted for the weekdays during the calendar month of June.

[3] Bridgiot: www.bridgiot.co.za

Data

The water usage data is sent to the server every minute with a time stamp. These data made it possible to calculate the water usage patterns: start and end time, volume, flow rate, and duration of each water event. We could then calculate the daily flow, the number of events with a volume above a specific amount, the cumulative daily volume and so on.

School hours are between 07:00 and 14:00 daily. During this time, most occupants of the staff houses are at the school, so usage from these houses was negligible. For most of the school hours, pupils and teachers spend their time inside classrooms. During this time, the main contributors to water use are urinals, toilets and water used in the kitchen. During break times the classrooms are empty, and this hour accounts for the largest water use. Extracurricular activities are between 14:00 and 17:00 every day. This period has minimal water usage as most pupils and teachers will have left or are taking part in extramural activities. This time also includes builders' usage as the builders only left at 16:00. (For the duration of the study, new classrooms were being added to the school.)

The key to calculating losses accurately was being able to isolate the school's actual use from the school's total daily usage. Actual usage means water used by the school alone, excluding the staff houses' usage and losses, for example from leaks or wastage. The school's total usage is made up of four parts: actual use, losses, staff house use and builders' use.

The water use between 00:00 and 05:00, during which time no water should flow, was considered to be losses. These losses would include continuously running or periodically flushing urinals. With water restrictions in place in Stellenbosch at the time of the study, watering gardens with potable water was prohibited, so there were no automatic sprinkler systems using municipal water. We calculated the hourly losses between 00:00 and 05:00 and extrapolated them to the entire day, to estimate the daily losses.

We compared the data from our sample school with data for the same period from a secondary school from across the road in Stellenbosch where no intervention was done.

Behavioural interventions

After the smart meters had been installed, the staff attended a presentation in which we explained the study's purpose and raised awareness of the need for water conservation. We showed them the school's water usage figures for the previous three days, pointed out the heavy losses, explained ways to save water, and informed them about the three behavioural interventions that would follow. These took three forms: *posters*, *playing cards* and *daily reports*. The posters were aimed at the pupils – the hypothesis being that if they were given information about the school's water usage, they would be more inclined to save water. The poster was kept as simple as possible, showing only the volume for each day, compared with the previous week (Figure 1). It was put up in all the boys' and girls' washrooms every morning at nine o'clock, an hour before the ten o'clock break. The *playing cards* were the Top Trumps kind (Figure 2). Each student was given 15 cards, each card showing a daily usage, water losses due to leaks and the total volume for the day. The values on the cards were actual water usage readings obtained during the intervention period. The card game worked as follows: two players each presented a card and the player whose total volume was lower won both cards. The aim was to collect as many cards as possible. This game engaged the pupils and got them used to the range of values of the daily usage, which would help them make sense of the information on the posters. The playing cards intervention thus goes hand-in-hand with the poster intervention. The *daily report* was in the form of a simple bar graph showing the school's daily water usage, divided into actual use and losses. The graph also showed the cost of each day's usage in rands, thus adding a financial incentive to change water use behaviour. The report was shown in the staffroom during break time using a data projector.

Results and Discussion

Figure 3 shows the distribution of the school's average hourly water usage between 07:00 and 17:00 for weekdays (Mondays to Fridays) for the calendar month of June 2017. The distribution of the medians is a positively skewed, with the mass of the distribution being concentrated on the left, with a peak at 1.4 kL/hr between 09:00 and 10:00. This peak is after the start of classes and before the morning tea break, when children and teachers are occupied in classes. This seems to suggest that the peak is a result of water use in the kitchen, which would include washing the cups and plates after the pre-class staff meeting and filling the urns in preparation for the tea break; general cleaning, such as mopping the passages and cleaning the toilets; gardening; and water used for construction. It transpired that despite the restrictions, minimal gardening activities were still using municipal water. Due to the construction of at the school, the usage pattern may not be representative for all schools. However, in a subsequent study that included 355 schools, we observed that some level of construction is a normal occurrence at schools.

Although the median peak was fairly early, more variance was evident between 10:00 and 11:00 and 15:00 and 16:00. The high variance of these two timeslots was probably because of the building work. Builders use water at irregular times, for example for mixing cement, and do not work when it is raining, which leads to discontinuous usage patterns.

Figure 4 shows the distribution of the average daily water usage by the various contributors to the schools total usage for the month of June 2017. The total use during school hours (7.5 kL/day) makes up only 58% of the total usage (12.9 kL/day). The losses period has a high variance, demonstrating the large effect of small behaviour changes, such as closing a tap rather than leaving it running overnight. The after-hours and houses' contributions are very similar, with similar variances. Most of the large water usage happens around 10:00, the period before, during and after the tea break. During break, all the teachers and pupils are not in the classrooms and most of the water activities involve eating and drinking and using the facilities. Our focus was on reducing losses to reduce water use. On a few occasions, the staff closed all the taps throughout the school at the end of the day to locate and resolve leaks, for example a tap left open or stuck toilet flusher would manifest as losses, potentially masking real pipe leaks. These periods thus had the lowest values and contributed to the high variance seen in the losses periods. The other time periods had much lower variance, which is what one would expect with consistent water use behaviour.

Figure 5 shows weekly water usage data for the three weeks before the study, intervention, the three weeks of the intervention, and the week after the intervention, week four. The weeks with the lowest usage were weeks three and four, when the intervention had settled. Weeks three and four used 9 and 8.6 kL less than the baseline week respectively. The daily total decreased from 20 to 14.8 kL for second week of the intervention. This value decreased further to 11.4 kL in the last week of the intervention.

Table 1 shows the difference-in-difference results. In comparison to the baseline period and baseline school, the interventions successfully reduced water use. The effect of the interventions, compared to a control school was a 44% reduction in water use.

These results show that behavioural change by intervention is effective over short to medium periods but that long-term effectiveness may require continued intervention or different strategies. Deteriorating results post-intervention were also experienced by other studies that used randomised controlled trials, such as Fielding et al. (2012) and Ferraro & Price (2013).

Conclusion

With freshwater sources becoming scarcer because of over population, urbanisation and pollution, managing water demand has become crucial. Schools are a major contributor to municipal water use, hence managing this demand could significantly reduce total usage. However, schools are rarely the focus of conservation campaigns. This study investigated the normal water behaviour of a school and showed that behavioural interventions are effective in inspiring water conservation behaviour. Behavioural economics were applied to quantify the effect of interventions on behavioural change. By applying these interventions, the study was able to reduce a primary school's daily water use by 44%, when using a control school as baseline. The largest part of the reduction resulted from a change in managing losses. The study is the first to provide insight into the water behaviour patterns of a primary school, highlighting the times of use and categorising usage and evaluating the impact of technological interventions.

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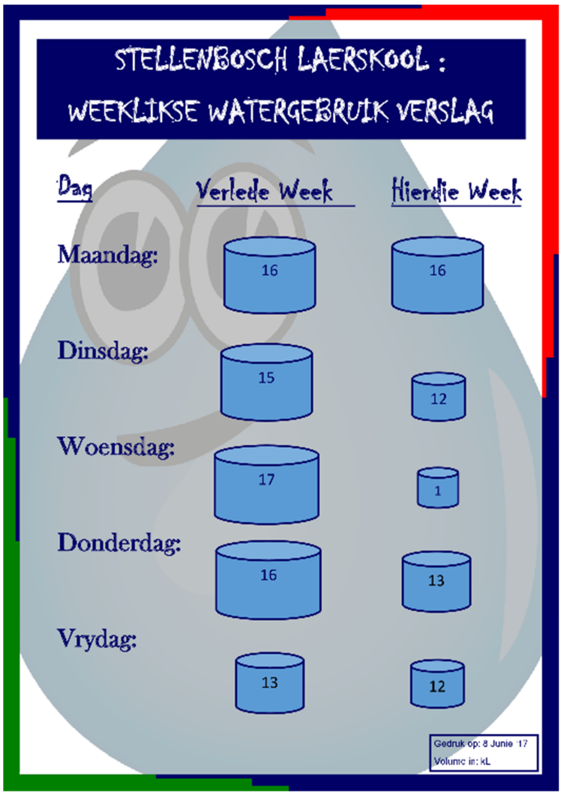

Figure 1: Poster. In English, the titles are from left to right: 'Day', 'Previous Week', 'This Week'. Each line is a day of the week.

Figure 2: Top Trumps playing cards Intervention

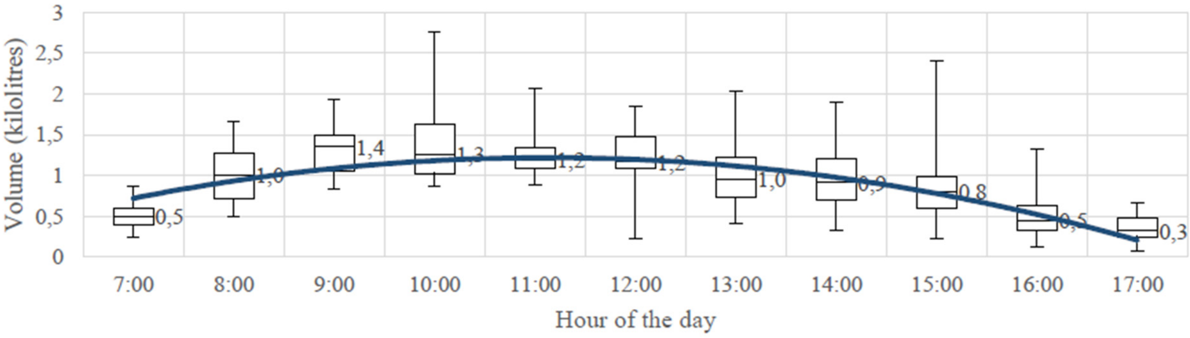

Figure 3: Usage distribution for weekdays for June 2017 (the month after the intervention)

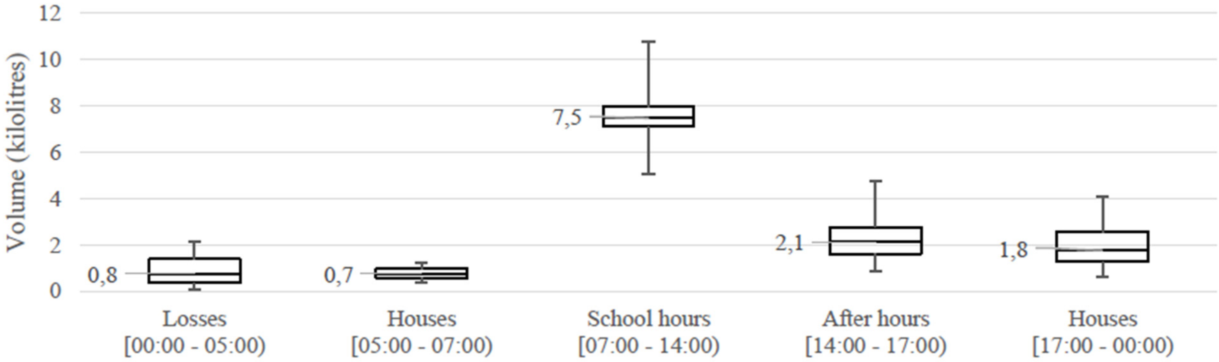

Figure 4: Usage distribution for only weekdays for June 2017 (the month after intervention)

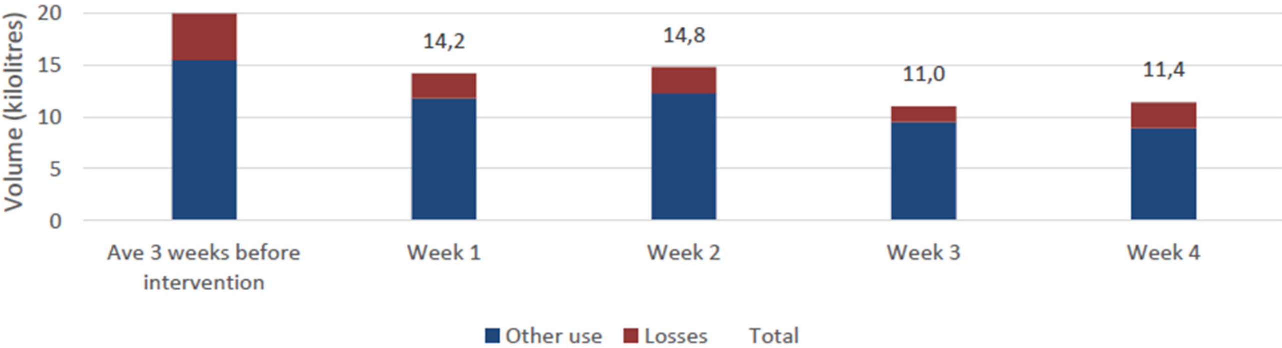

Figure 5: Usage distribution for weekdays for before and during the intervention weeks.

Table 1: Difference-in-differences (DiD) comparison: Average usage per day in kL compared to the control school

DiD average water use per day	Treatment (kL/day)	Control (kL/day)	Differences (%)
Mid Dec 2016 – mid April	21.6	26.3	-4.6
Mid May – mid June	12.3	26.5	-14.2
Differences	9.4	-0.2	-44%