Demanding change in a constrained environment: Water usage in schools

by

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Abstract

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Water shortages are currently a global challenge. The scarcity of water sources is particularly evident in developing countries because of over population and high rates of urbanisation. The challenge is further worsened by the constraints on financial resources in these countries. For example, schools in the Western Cape experienced increased financial losses due water shortages brought on by the drought that hit the province between 2016 to 2018.

As such, this research study proposed water demand solutions that use real-time data to understand and manage school water demand. This was done by using historical water data to understand and classify school water use. The effects of socio-economic and political variables on school water demand were then analysed. Thereafter, in an effort to reduce school water demand, two methods were employed to measure the impact of interventions that evaluated school-time and night-time water usage. The first was the MNF method, used to measure water losses. The other, was a RCT, which was used to quantify the reductions in water usage after employing two behavioural interventions, a *Information Only* and a *Social Norm*.

The results of this research study highlighted several important aspects. The first being the importance of maintenance in managing school water demand. Consequently, effective "quick-fixes" resulted in drastic water usage reductions for several of the participating schools. Secondly, the results revealed that the current governmental funding policies are outdated and hence these policies need to be constantly updated in order to ensure that they influence water demand positively. The RCT results demonstrated that behavioural interventions are valuable in encouraging reduced water usage. Further, the

Information Only intervention showed that self-monitoring is important for improving the overall management and maintenance of school water systems. While, the *Social Norm* intervention helped schools adopt water conservation cultures and was more effective in reducing school water usage during school hours.

Overall, this study shed light on a topic that is often neglected, particularly in developing countries.

Uittreksel

Vringende verandering in 'n beperkte omgewing: Watergebruik in skole

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Watertekorte is tans ń globale probleem. Hierdie skaarsheid van waterbronne is veral sigbaar in ontwikkelende lande as gevolg van oorbevolking en ho verstedelikingsgraad. Dit word verder vererger deur die beperkings op finansiële hulpbronne in hierdie lande. Skole in die Wes-Kaap het byvoorbeeld verhoogde finansile verliese gely deur watertekorte wat veroorsaak is deur die droogte wat die provinsie tussen 2016 en 2018 getref het. As sodanig het hierdie navorsingsstudie watervraagoplossings voorgestel wat real-time data gebruik het om skoolwatervraag te verstaan en te bestuur. Dit is gedoen deur historiese waterdata te gebruik om skoolwatergebruik te verstaan en te klassifiseer. Die gevolge van sosio-ekonomiese en politieke veranderlikes op skoolwatervraag is dan ontleed. Daarna, in ń poging om die skool se watervraag te verminder, is twee metodes aangewend wat gerig is op skool- en nagtydgebruik. Een daarvan was die MNF-metode, wat gebruik is om waterverbruikreduksies te kwantifiseer as ń resultaat van ń basiese instandhoudingsprojek wat by die skole gedoen is. Die ander, was ń RCT, wat gebruik is om die vermindering van waterverbruik te kwantifiseer nadat twee gedragsintervensies en Inligting en Maatskaplike Norm-ingryping aangewend is. Die resultate van hierdie navorsingsstudie het verskeie belangrike aspekte uitgelig. Die eerste is die belangrikheid van instandhouding in die bestuur van skoolwatervraag. Gevolglik het effektiewe "quick fixes"gelei tot drastiese verminderings van waterverbruik vir verskeie van die deelnemende skole. Tweedens, het die resultate getoon dat die huidige regering se befondsingsbeleid ń belangrike rol speel in die skool se vraag na water en daarom moet hierdie beleide voortdurend opgedateer word om te verseker dat hulle die vraag na water positief benvloed. Die RCT-resultate

het getoon dat gedragsintervensies waardevol is om verminderde waterverbruik aan te moedig. Verder het die inligting-inmenging slegs getoon dat selfmonitering belangrik is vir die verbetering van die algehele bestuur en instandhouding van skoolwaterstelsels. Terwyl die Maatskaplike Norm-intervensie gehelp het, het skole waterbewaringskulture aangeneem en was dit meer doeltreffend om skoolwatergebruik gedurende skoolure te verminder.

Publications

Research output from this thesis:

1. **C. Ripunda**, M.J. Booysen, “Understanding and affecting water consumer behaviour using technological interventions at a primary school in Stellenbosch”, WISA 2018, 24 June 2018, Cape Town, South Africa

2. **C. Ripunda**, M.J. Booysen, M. Visser, "Impact of a water-saving campaign at schools in the Western Cape, South Africa","Submitted and currently under review", Journal: Sustainable Cities and Society, Ref: SCS_2018_2544, December 2018, Stellenbosch, South Africa.

3. M.J. Booysen, B. Wijesiri, **C. Ripunda**, A. Goonetilleke, "Influence of school affluence on water demand: Towards sustainability in water resources management in post-apartheid South Africa", "Submitted and currently under review", Journal: Elsevier Sustainable Cities and Society, Ref: SCS_2019_443,February 2019, Stellenbosch, South Africa.

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Contents

List of Figures

List of Tables

Acronyms

AR	Auto Regression
BNs	Bayesian Neural Networks
CSIR	Council for Scientific and Industrial Research
DAG	Directed Acyclic Graph
DiD	Difference in Differences
GSM	Global System for Mobile Communications
HE	High Erratic
ITSA	Interrupted Time Series Analysis
MNF	Minimum Night Flow
M1	Maintenance 1
M2	Maintenance 2
M1+7	seven days post the M1 date
M1-7	seven days pre the M1 date
NNSSF	National Norms and Standards for School Funding
RCT	Randomised Controlled Trial
RMSE	Root Mean Squared Erros
ROI	Return on Investments
SASA	South African Schools Act
SESs	Socio-economic Status
SGBs	School Governing Boards
SS	Single Spike
SWM	Smart Water Meter
T1	Treatment 1
T2	Treatment 2
WCED	Western Cape Department of Education

Symbols

Edu	Educators
$Fees$	Whether the school charges school fees or not
med_vol	median volume
Q_{pre}	MNF pre-maintenance
Q_{post}	MNF post-maintenance
R	Rand
St	Students
$S20$	Section 20
$S21$	Section 21

V_{t}	Total volume
V_{st}	Water usage on Saturday
V_{su}	Water usage on Sunday
V_{w}	Total water usage on weekdays
V_{0508}	Water usage volume between 05h00 to 08h00
V_{0814}	Water usage volume between 08h00 to 14h00
V_{1417}	Water usage volume between 14h00 to 17h00
V_{1722}	Water usage volume between 17h00 to 22h00
V_{2205}	Water usage volume between 22h00 to 05h00

Chapter 1

Introduction

This research study introduces the problem of high water usage and the related financial losses experienced by schools. As such, this chapter serves as an introduction to this the research study. A background to the aspects that affect school water usage were presented first. Thereafter, the problem statement was developed. From this, the specific objectives of this research study were presented. Subsequently, the scope underlined the extent of the subject matter. The contribution of this research study to the existing body of knowledge followed next. The section concludes with a roadmap to the rest of the research study.

1.1 Context

There are numerous factors that affect school water demand. This section will discuss four of these aspects, namely: water scarcity; school water supply and usage in the study area; the two main education funding policies in South Africa and finally the effects of these policies on school water usage will be discussed.

1.1.1 Water scarcity

Freshwater supply is under threat globally, largely because of human activity. Although 70% of the planet is covered by water, only 3% of it is fresh water [1, 2, 3]. The threat is especially noticeable in developing countries like South Africa, where the supply of fresh water sometimes cannot keep up with the demand because of increased urbanisation and development [3, 4, 5, 6]. From 2016 to 2018 this problem was compounded in the Western Cape as it experienced one of its worst droughts in recent years [7].

The South African education system is beset by numerous difficulties, including how to manage its resources in the face of financial constraints [8, 9]. Besides compromising the schools' primary function of educating children, these difficulties also prevent proper management and maintenance of the infrastructure that supports the education system. After the country's Independence in 1994, the government designed and implemented several policies in a effort to combat these challenges. The policies were not able to fully eradicate these financial challenges [10, 11]. These problems were particularly evident in the management and maintenance of school water systems during the Western Cape water shortage period in 2016 to 2018. Consequently, schools generally lose a tremendous amount of water and the related finances because of insufficient knowledge of the general water-related activities in schools, poor maintenance of water systems, delayed feedback on water usage from water councils and outdated funding policies. Therefore, this study aimed to address these issues in an effort to help schools limit their financial losses and save water.

1.1.2 Water supply and usage in South African schools

Water supply within South African schools has been noted to be unreliable, especially for schools in poorer communities. The Department of Basic Education in South Africa, reported that of the 23,589 schools in the country, 452 had no water supply and a further 4,773 had an unreliable supply [12]. Moreover, in 2017 the City of Cape warned that should the water crisis continue it could mean closing some schools in the province [8, 13]. It was evident that water provision and the maintenance of water systems are part of the basic needs of every school and if not prioritised, can lead to major disruptions.

Subsequently, sources of accurate data on school water usage are urgently needed for research purposes. Reliable data is required for conducting research in order to solve these financial loss challenges. However, water usage data that is accurate and reliable is often unavailable. For instance, water usage data in Western Cape schools, as obtained from the database of the provincial department of educational, was found to be incomplete and inaccurate. This could be attributed to the inadequate data collection methods employed. The available dataset indicated that four methods are used for recording a school's monthly water usage reading: physical readings by (1) the school and/or by the (2) water councils, (3) automatic estimation as well as (4) re-estimation if over estimation occurred. From these, the two commonly used methods were automatic estimation and collection by water councils. It was also evident that the majority of schools in the Western Cape had several months with no recorded water meter reading, of which the worst case was a school that had no recorded data for 10 months in 2017. In light of this, one of the contributions of this study was collecting accurate water usage data that can be used for research purposes.

Only one study was found that quantified the amount of water schools use within the country. This study was conducted by the CSIR (Council for Scientific and Industrial Research). In 2003, the CSIR estimated that, at the time South African urban schools were using 245 mega-litres of water annually in total. Further, the CSIR estimated that 10 mega-litres were wasted yearly through inefficient management of school facilities, in the form of water leakages. The estimates were based on data collected by the Green Buildings for Africa programme [14]. To date, it remains unknown to what degree maintenance affects schools' water usage, largely due to a lack of reliable data. Therefore, this study aimed to begin filling that gap.

Moreover, schools in the Western Cape face a major challenge in terms of water billing information from water councils (also known as municipalities), which is an inefficient feedback system between water councils and schools. Water bills delivery to schools is generally delayed by up to two months. This is mostly because the councils are unable to record water meter readings regularly at the schools. Additionally, there is often missing readings and the councils are hence forced to estimates based on historic readings. This issue was evident in the database of the WCED on schools' water usage data, a snapshot of which can be found in Chapter 3. The figure shows the number of schools with missing data and further indicates where councils were forced to perform estimations. On top of that, several schools reported that water bills are only issued every two months despite the fact that several of these schools are responsible for directly settling their own water bills, typically the case for affluent schools [9, 15]. The other schools' bills are centrally paid out of governmental allocation for each school, typically the case for poorer schools, which further delays the water feedback loop. Consequently, schools are unable to effectively monitor or track their water usage patterns. This delayed feedback makes it difficult for schools to detect and deal with maintenance issues in a timely manner.

1.1.3 South African education system funding policies

The South African education system prior to the country's first democratic election in 1994 was both unjust and biased. Further, the political system at the time was one of totalitarianism with regards to school management. Because of this, after the country's independence, the education department established several policies aimed at transforming the education system to be just and fair to all South Africans [10, 16, 17, 18]. As such, the South African education system has two main funding policies, which also dictate how much funds schools have available for the up keep of their infrastructure. These policies also determine whether or not schools are responsible for utility bills.

The SASA (South African Schools Act) of 1996 [16] was a policy whose aim is to involve communities and relevant stakeholders in the day-to-day management of schools. This was achieved by establishing committees that are responsible for the overall governance of schools. These committees are referred to as SGBs (School Governing Boards) and are made up of educators, parents and learners in the case of secondary/high schools. Thus, the introduction of SGBs brought about shared responsibilities in terms of school governance in South Africa, by involving communities in their own upliftment through improved education. In the name of a fair and just system, the SASA defined the responsibilities of SGBs differently, based on the SES (Socio-Economic Status) of each school. Consequently, two types of schools were defined; they were termed Section 20 and 21 schools. For section 20 schools, those with lower SESs, the government was responsible for buying school material and paying utility bills. Section 21 schools on the other hand were allocated funding, from which the SGBs purchased all school materials and pays utility bills. Therefore, SGBs of Section 21 schools had added responsibility and directly controlled school fund expenditure. Moreover, SGBs were mandated to augment state funding by implementing either school fees, in case of Section 21 schools, or alternative fund-raising programmes. These fund-raising programmes included renting out the school grounds to churches and other community stakeholders at a fee. This mandate therefore was an indication of the inadequacy of governmental funding towards general school operations.

The NNSSF (National Norms and Standards for School Funding), which was established in 1998, stipulated how much governmental funding each school received [19]. Governmental funding was allocated to schools based on their Quintile ranking. The Quintile Ranking system was a grouping technique that divided schools into five different groups according to their socio-economic status [10, 16]. All South African schools were hence assigned a quintile grouping number from 1 to 5. Schools in quintiles 1 to 3 were classified as less affluent schools based on their SES (see an example of such a school in Figure 1.1, top left). These schools therefore received higher governmental funding than schools in quintile 4 and 5 and do not charge school fees. For quintile 4 and 5, the more affluent schools (see an example in Figure 1.1, top right), governmental funding was significantly less in comparison, and schools could charge school fees to augment their funding. The aim of the Quintile system was to remedy the great inequality and inequity caused by the pre-independence regime, by increasing governmental funding to schools with a lower SESs [17]. This would therefore provide better opportunities to previously disadvantaged learners through a better education.

1.1.4 Effects of education funding policies on school water demand

Education funding plays a significant role in the management and maintenance of school infrastructure. Education funding policies that are updated can efficiently distribute educational funds to ensure academic excellence throughout the country. However, when these policies that outdated, they can lead a gen-

Figure 1.1: (top left) Impoverished community that has schools in quintiles 1 – 3 (Wallacedene, Cape Town); (top right) Affluent area that has schools in quintiles 1 and 2 (Mostertsdrif, Stellenbosch); (bottom) Aerial view of the two community areas in the Western Cape Province of South Africa. Note 1: Image source for (top left) and (top right) – Google Street View; Note 2: based on typical property prices, the average house prices for the area in Wallacedene, Cape Town will be below US$5,000, and above US$500,000 for the area in Mostertsdrif, Stellenbosch.

erally unequal and low standard of education for the country. In South Africa for instance, the first call for comments on the National Education Policy was only made in 2008. This call was the first to prioritise the general maintenance of school environments in South Africa. At the time, only 12% of government finance for schools was allocated to facilities management as a whole [14, 15]. Interviewed about the 12% allocation, school principals said that it was insufficient to cover even the minimum costs of maintaining their facilities [15]. According to the 2018/19 Western Cape revenue and expenditure report, the province allocated R469.6 (U$34.18) million to its schools for all maintenance and repairs for the year. The report acknowledged, however, that there was a backlog in maintenance of education infrastructure and a shortage of school staff members with the skills to carry out effective maintenance [8]. Insufficient funding and a shortage of skilled staff were recognised as the major contributors to this backlog. The funding the country has provided for maintaining school facilities has not produced the desired results, especially for schools in poorer neighbourhoods. This was particularly evident in the state of maintenance in schools' water systems, discovered through an investigation in the Western Cape schools during the drought period.

1.2 Problem statement

Knowledge of school water usage patterns and their influential factors are key to effective management of school water demand. Water usage patterns would enable schools to identify periods of the day where high water usage occurs. Additionally, they would help define what "normal" water usage was and allow the detection of "abnormal" water usage. Furthermore, school water usage is affected by numerous variables, of these are: the number of learners and educator, governmental allocated funding, maintenance policies, age of the infrastructure, socio-economic status and water billing information.

Further, effective maintenance of school facilities is an essential part of a successful education system. Numerous studies have demonstrated that children do better in well-maintained environments [14, 15, 20]. This means that maintenance of school facilities should be prioritised as an important element in building academic excellence, especially the water system, which is essential for good health. Plumbing is an essential part of the upkeep of the schools' infrastructure: toilets, basins, showers, sinks, drinking fountains, irrigation systems for fields, fire extinguishing systems and require frequent maintenance [21]. Despite this, school facilities maintenance is often not prioritised due to financial constraints. Ironically, this issue often costs schools large sums of money in utility bills because of broken water systems.

Furthermore, governmental policies that are frequently updated according to school's socio-economic statuses are important for ensuring effective funding schemes. These updated policies would ensure efficient distribution of governmental funding, which would improve the general quality of water systems and education nation wide. Yet the two main policies; namely the Quintile Grouping and the NNSSF that affect how much funding schools receive in South Africa and how these funds are spent, are outdated and in need of restructuring.

Accurate and reliable water usage data is useful, not only for demand management but allows for efficient feedback to schools on their water usage by water councils. Water councils in South Africa, for example, require accurate and timely water usage data to provide schools with accurate and frequent billing information. However, these water councils face difficulties in efficiently recording water usage data on schools, thus often relying on estimates of water usage for their billing process. The result is that schools often receive billing information two months or more after usage, resulting in undetected leaks and an inability to verify billing information timely. Since numerous schools are responsible for their own water bills, any money that is unnecessarily spent on water bills reduces the already constrained resources available for educational expenses.

In response to the above mentioned issues, this study proposes school water demand management solutions that includes collecting real-time water usage data using smart water meters. This data was used, in different ways, in an effort to address the above issues, by helping schools free up water-related expenses. First, the data was used to understand school water usage profiles, on a generic level. Secondly, basic maintenance was conducted at the schools after which the minimum night flow metric was applied to the data in order to quantify improvements. Following this, the data was combined with a dataset from the WCED in order to determined how a school's affluence level affects how much water that school will use. This will shed some light on the efficacy of the country's current school maintenance funding policies. Finally, a randomised controlled trial was described, which determine if providing schools with accurate, frequent information on their water usage would encourage reduced water use. Therefore, the aim of this study was to use accurate water usage data from Western Cape schools, in order to help them reduce water usage and the related expenses. The resulting freed up finances that can then be used for the primary objective of schools, academic excellence.

1.3 Research questions

The four main questions that this thesis answered are:

1. What is the temporal (hourly for week days) water usage pattern of schools?

2. What is the cost and benefit (including an ROI) of contracting plumbers to do "easy gain" plumbing maintenance at schools within the Western

Cape, using the minimum night flow as a metric?

3. How does the influence of the surrounding community affect a school's water usage. And how do policy-related determinants affect school water demand?

4. What is the quantitative effect on school water usage behaviour, of sharing weekly aggregate water usage information with school principals, with the intention of them disseminating it to the rest of the school? The usage information being water volume and the corresponding monetary value, using heat maps and visual aids. The dissemination being via poster and electronically. Sharing in this case means: weekly text message, email reports and notification of unexpectedly high usage (also via text).

5. Following from question 4 above, does providing additional comparative/competitive weekly aggregate usage information (with relative ranking) lead to an additional behavioural change (on top of what seen in question 1)?

1.4 Objectives

The aim of the project was to study school's water demand. This was done through achieving four different objectives. These are listed below.

- Model and classify the temporal pattern of school water usage.
  - Establish a general water usage profile for school water behaviour.
- Analyse water leakages at schools using the minimum night flow method after conducting a maintenance project.
  - Conduct a basic plumbing maintenance project at each participating school.
  - Quantify the reduction in minimum night flow water usage as a results of plumbing maintenance done at the schools.
  - Quantify the ROI of the plumbing maintenance cost.
- Determine the impact of a school's SES on its total water usage and funding variables.
  - Determine general school water usage trends using the Bayesian model.
  - Characterise the influence of the community's socio-economic status on the school's water usage pattern/profile.

- Conduct a randomised controlled trial that tests the efficacy of information-based behavioural interventions. Particularly, water usage reports that are accurate, understandable and delivered to the schools on a regular basis.
  - Create behaviour interventions using historical water usage data.
  - Quantify the water usage reduction after applying the treatments.

1.5 Scope

This study focused on understanding school water demand and investigated water management techniques. As such, the range of this study was confined to the non-residential portion of urban water demand, specifically on school water usage. The participating schools were limited to those in the Western Cape province who had smart water meters (the Dropula device) installed in 2018. Accordingly, this included both private and public primary, secondary and high schools. Preparatory schools were only included if they were part of the above types of schools.

The MNF (Mininum Night Flow) metric was used to quantify water reductions during the hours of 01h00 and 04h00 AM, after basic plumbing maintenance was done on the school water systems. Thereafter, the related monetary savings and the return on investments were quantified. Therfore, all calculations were confined to water usage data during this time period. Secondly, only schools with reliable maintenance cost were included in the MNF analysis.

The second phase of this study explored the influence of affluence on school water usage using the Bayesian network model. The parameters used for the developed model included the number of students and educators, Quintile grouping- which determined whether learners pay school fees or not, Section 20/21 classification and water usage - divided into different days and periods of the day. These were all extracted from the WCED database, see Chapter 3 for a sample of this databse.

Thereafter, a RCT was conducted to quantify water reductions as a result of two behavioural interventions; these are discussed in Chapter 7. The trial only included schools with reliable water usage data during the defined baseline period. Schools with missing or erroneous data during the baseline period were therefore excluded.

1.6 Contributions

This study intends to contribute to the relevant literature in two main ways. First by describing and classifying school water usage profiles. Here, the influence of different determinants of school water demand are outlined. Secondly, two different water management techniques will be described. One such method was the minimum night flow method, which was used to quantify night time leakage reduction. A randomised controlled trial was used to encourage conservational water usage by employing behavioural interventions.

1.7 Roadmap

The thesis is organised in the following way:

Chapter 2 provides a synthesis of the current related research. Initially two studies on facilities maintenance in South African school are examined. Thereafter, the topics of focus are: using the minimum night flow metric for leakage detection; water demand variables and determinants; and finally behaviour intervention studies for water demand management.

Chapter 3 follows with a detail of the methodology used for this study. Details of the study area and data collection sources are provided.

Chapter 4 focuses on understanding and describing the general profile of school water use. As a start, this was done for one school as a pilot study, from which the rest of this paper's objectives were derived. The results of this study further resulted in a larger scale study that included more school within the Western Cape.

Chapter 5 describes details of a basic maintenance project conducted on the participating school's water systems. Thereafter, the effects of the maintenance on night time flow are quantified using the minimum night flow metric.

Chapter 6 analysed the effect of a school's SES on water demand. The bayesian method was used to classify a school's affluence using water usage along with funding related variables.

Chapter 7 describes a RCT that was conducted in order to reduce daily school water usage by employing information and social comparison behavioural interventions. Historical water usage data was used to design these behaviour interventions.

Chapter 8 concludes the research study and provides recommendations for further studies.

Chapter 2

Literature review

A substantial amount of research has been dedicated to understanding urban water demand. Water demand management is especially important in developing countries. It is essential to their development, as efficient water supply has been known to improve the health and productivity in urban areas [22]. Further, in 2012, it was reported that 62% of the South African population lived in urban areas [5]. As such, the rate of urbanisation was noted to increase the pressure on urban water supply [3]. This pressure is particularly seen in the general lack of supply, poor maintenance of the infrastructure and droughts that have struck large cities across the world. Therefore, there is a need for research studies that continue to address these issues.

Studies dedicated to urban water have been classified into the three sectors of urban water demand; residential, non-residential and non-revenue water. The majority of these have been dedicated to the residential sector and their topics include; demand forecasting [23, 24, 25, 26, 27] and modelling [28], general demand [29], and water usage management interventions [1, 3, 30]. On the other hand, there is limited research that is readily available for the non-residential or non-revenue sector of urban water demand. Therefore, this research intends to focus on the non-residential sector, primarily on school water demand.

Two studies on maintenance within South African schools were reviewed as a starting point to understanding existing literature on school water in South Africa. Secondly, studies on water demand variables and determinants follow, focusing on those that lead to high water usage. The third stage of this review will examine studies on water usage reduction, particularly those that used the MNF and those that employed behavioural interventions to achieve water conservation. The review mainly utilised studies in the residential as those in the non-residential sector where lacking or limited. Therefore, the main objective here was to explore methods that were previously used to reduce water usage and variables that contributed the most to high usage in general.

2.1 Recent studies on facilities maintenance in South Africa

A few studies have evaluated water-saving interventions and water awareness campaigns at schools in South Africa [31, 32]. One such study evaluated the status and use of water efficiency devices in the commercial and domestic environments in South Africa, including schools [32]. Two schools were evaluated. In the first, flushing urinals were replaced with flush-less equivalents. However, due to problems with odour, the urinals were reverted to flushing versions. The second school replaced automatic flushing urinals with flush-on-demand versions and reduced the volume of water flushed in the toilets, and reduced their water usage by 75%. Although the report expanded further on awareness campaigns, maintenance was not addressed.

This research study reviewed the only two available South African studies of school facilities maintenance. These two qualitative studies covered four aspects: the current state of school maintenance, common practices, ideas for an effective school maintenance plan, and financial requirements. Although their focus was not only on water system maintenance specifically, their general observations are relevant to this research.

The first study, carried out by Nhlapo, investigated maintenance plans and needs at a sample of 16 schools in the Gauteng province and suggested ways to incorporate maintenance into the schools' general management [15]. The investigation showed that the current maintenance plans were reactive rather than proactive, consisting mainly of corrective and emergency plans, which suggested that maintenance was not considered a fundamental part of the educational system. The author suggested that schools need intensive and strategic plans for maintaining their facilities. For example, most schools' maintenance was done by gardeners and groundsmen, as needed and through trial-and-error. Plumbing mainly focused on repairs, and major maintenance needs were assigned to external contractors. The author noted a low priority assigned to maintenance by the schools and their general lack of knowledge about how to do it. The study suggested that the author viewed maintenance as part of a bigger system geared towards using the available infrastructure for educational purposes. Schools had little knowledge on what school infrastructure was and what it entailed. Therefore, schools were in need of policies that defined maintenance in a school context.

The second study was a follow-up by Xaba to the study by Nhlapo [9]. Principals and vice principals from 20 schools in Gauteng were interviewed regarding their practices for maintaining school facilities. Xaba argues that an effective school maintenance procedure should consist of three main aspects: a maintenance plan that defines duties and responsibilities and establishes a committee solely responsible for maintenance; inspections that use check-lists (which can also be used for the planning phase); and a strategy for getting the maximum use out of the school facilities. Xaba summed up the whole school maintenance strategy as involving the following: organisational structure in the form of a committee, inspections, policies, a maintenance plan and funding.

Most of the schools in the study by Xaba were found to have some form of maintenance committee. These were made up mainly of cleaning staff and were responsible for the school's cleanliness and minor repairs. The lack of school staff who were qualified to carry out maintenance was similar to what was found by Nhlapo. Most of the schools in Xaba's study said that inspection was usually done only after breakdown or damage had occurred. It was apparent from the study that schools had no standard maintenance procedures in place. Notably, most of the schools mentioned their need for staff members with maintenance skills.

Referring to the above general allocation of funds for school facilities maintenance in South Africa. It was found that South African schools were prohibited by government from using funds allocated to other purposes for maintenance. All the schools interviewed by Nhlapo said the allocation was insufficient to sustain an efficient maintenance plan. Both these studies found that the biggest obstacle in maintaining school facilities in South Africa was financial constraints.

Schools were often left with the responsibility of augmenting this allocation. This was particularly difficult for public schools. Poorer schools were defined as schools in quintiles 1 to 3 and suburban schools as those in quintiles 4 and 5 [8]. These categories were defined according to whether or not learners were expected to pay school fees [8]. A principal interviewed by Nhlapo said that their annual maintenance budget was in the range of R50,000 and that for 2009 this amount came partly from winning a competition. This shows how difficult it was for these schools to find extra sources of income for maintenance. Principals from two private schools said their maintenance fees come to R400,000 and R500,000 annually, indicating that suburban schools were more equipped to supplement their allocation than public schools. This meant that the private schools had better maintenance facilities than the public schools [15].

The small samples in these two studies showed that the upkeep of school facilities was commonly disregarded until the condition became bad enough to disrupt daily activities. Maintenance was not given the necessary priority. There was a disturbing lack of knowledge about the importance of maintenance plans. Effective maintenance strategies were not explored. The cost of maintenance was usually a mere estimate, based on little to no knowledge of how to create an effective maintenance plan. Plumbing, was considered only a small part of maintenance and thus was often overlooked. The schools in the samples for both studies tended not to know either the cost or the benefit of maintenance, be it basic or extensive. Their main problems were insufficient funding, a lack of staff qualified to perform maintenance, and lack of strategic maintenance policies.

2.2 Minimum night flow

The MNF metric is an analysis commonly used for leakage detection. Studies that use this metric, use water flow profiles and separates genuine consumer water usage from leakages. As such, the period used for this was normally early morning hours when user water usage was expected to be zero. Additionally, the leakage components was expected to be highest contributor to water flow [33]. MNF was analysed within a metered area to ensure accurate estimations. Water flow into and out of this metered area was marked off by valves [4]. Further, detection or classification of water flow as MNF was defined by a set threshold water flow level pre-determined by the analyst. This was to account for water activities that cause 24 hour water flow, like certain types of urinals, that were not part of leakages. Therefore, the MNF metric reveals the condition of the water system. The resulting leakages identified from these methods were often linked to the non-revenue sector of urban water demand [34]. Therefore, understanding and reducing the MNF is paramount to the overall effective management of urban water demand.

In an effort to understand and reduce leakages, several studies have used the MNF metric to detect leakages. These used the MNF to achieve different objectives related to leakages in water systems. The studies aimed to; improve leakage management in an urban area [35]; detect leakages using high-resolution data loggers [36]; estimate water loss in an city [34] and to determine the effect of leakage feedback information to consumers to improve leakage reduction. The results of these studies showed that the MNF method can be successfully used to reduce night time loss. An average MNF of 759 litres/minute was reported in a rural agricultural area of Corentyne district in Berbice Guyana, which included both residential and non-residential users [37]. Another study reported real losses of 1500 m^3/month, an amount that was said to be able to supply 7500 people for a day in the area. This study involved a mixture of users, residential, commercial and public users [4].

2.3 Water demand variables and determinants

Water demand determinants are those variables that influence or affect how much water is used. These are also known as the main drivers or predictors of water usage behaviour. The ability to identify and understand the influence of water determinants is a crucial part of demand management. Understanding the effect of these would enable policy makers to affect these determinants in a way that will positively influence urban water demand [38].

The interaction between these variables is multi-scale from individual, household, regional to a national level [39]. Secondly, it is cross-scale in nature and their effect vary over time [38]. Hence, this results in a large number of determinants, which adds to the complexity of the relationship between these variables [23]. Therefore, understanding their interaction is crucial to being able to control these variables.

Numerous studies have identified several different variables that were most important influencers of water usage. For example, a number of studies identified demographic, psychosocial, behavioural and infrastructural variables to be the main drivers of water usage in the residential sector. The number of occupants was found to have the highest positive effect [38, 40, 41]. Further, household dynamics or water cultures also influenced water usage substantially. Education level was an insignificant influencer according to one study [40], although another study identified household demographics and socio-demographics to have a high influence for high-end water users. The study recommended the implementation of governmental policies that aim to permanently change water cultures within the residential sector to achieve lower water usage behaviour [40]. Research has identified other variables that drive water demand. These were: water usage tariff, climate and geography features, rainfall and altitude, income per capita, appliance and fixture and end-use characteristics [38, 41, 42]. Although current research shows that there is a vast number of variables that significantly contribute to water demand, few of these studies explored political or policy related water demand determinants. Therefore, research studies focusing on the role that politics and policy play in urban water demand is worthwhile.

2.4 Behaviour interventions studies

Numerous studies have explored the efficacy of behaviour interventions in encouraging water reduction in the residential sector. A number of these studies will be discussed below, these can be found in Table 2.1.

Price conducted a field study using norm-based messages to reduce residential water usage [43]. The study area was Cobb county in Atlanta Georgia and included a sample of 100 000 households. Three treatment groups and one control group were used. The first treatment group was defined as an *"Information Only"* group and simply received a document with water saving tips. The second was called the *"Weak Social-Norm"* group; they received water saving tips and a second text that explained the scarcity of water sources in the city. This group was further encouraged to reduce water usage. The *"Strong Social-Norm"* group was the final treatment group. Users herein,

Table 2.1: Intervention characteristics of behavioural interventions reviewed

Authors and year	Data type	Types of interventions	Delivery mode	Sample size	Nr. of treatment groups
M. Price and P. Ferraro 2011	Water bill	Social comparison, Pro-social message and Technical information	Mail	100,000 households	4
K. Fielding, A. Spinks and S. Russel et al. 2012	Smart meter data	Information only, Description only and Water end-use feedback	Mail	948 households	4
V. Seyranian, G. Sinara and M. Plikoff 2015	Water water meter reading	Social norm, Social identity, Personal identity and Knowledge deficient approach	Mail	374 households	4
A. Lui, D. Guirco and P. Mukheibir 2016	Smart water meter data	End-use analysis approach	Mail	141 homes	2
S. Datta M. Darling J. Miranda et al. 2015	Water bills	Neighbourhood comparison, City comparison and Plan making intervention	Mail	5626 households	3

received water saving tips and a comparison of their water usage with the median usage of the county. All three interventions were successful in reducing water usage; reductions were 7.83% for the control and 8.41%, 10.08% and 12.01% for group 1 to 3 respectively. Although the results were confirmed to be statistically significant, the reductions were temporary and decreased over time.

Thereafter, in a different study, Fielding [1] tested the efficacy of voluntary demand management methods by analysing their ability to encourage long-term reductions in residential water usage. The study had a sample size of 221 households and was conducted after Queensland, Australia had experienced a severe drought. Similar to [43], the study consisted of three treatments and one control group. The *"Information Only"* treatment was similar to that of [43], in that it only provided users with ways to save water. The *"Descriptive Norm"* group received water saving tips and information on households similar to theirs that had lower water usage. The final *"Water End-use Feedback"* group received water saving tips and a breakdown of their overall usage. The treatment period of this study was 120 days and post-treatment period was defined as the 330 days after the treatment. For the *"Information Only"* group, water usage per person decreased by 2.4 litres/day over the short term and to 32.5 litres/day over the long term. *"Descriptive Norm"* group had daily reductions of 15 and 9.2 litres per person over the short and long term respectively. Lastly, the *"Water End-use Feedback"* group reduced usage by 11.9 litres over the short term and over the long term, daily water usage increased by 3.9 litres per person.

Another study focused on 374 up-scale households in the Los Angeles County [44]. This study employed social identity interventions. A *"Social Identity"* treatment outlined the water shortages in the county and stressed the importance of water reduction by using language with inclusive pronouns such as *"we"* and *"us"*. This was the only difference when compared to the *"Personal Identity"* treatment which used personal pronouns such as *"your"* and *"you"*. The *"Social Norm"* group received information on their water usage and whether their usage was below or above the mean usage of an average household in the county. The control group, named the *"Information Only"* treatment for this study, only received water saving tips. The study ran over eight weeks and data was collected four times during this period. Data collection was done by physically reading each house's water meter. The highest reduction was seen in the control group. This daily reduction was 1.02 litres/day per person over the short term but increased to 3.3 litres/day over the long term. This was similar to what was seen by [43]. Other groups did not show any significant reductions. The worst performing group was the *"Social Norm"* group that saw an increase of 45.02 and 17.9 litres/day over the short and long term respectively.

Further studies that attempted to answer similar questions were [45] and [3]. Datta obtained reductions of 3.4-56% using social and plan making interventions [3]. The *"Plan Making"* treatment; where users set personal goals on the reduction they hoped to achieve, was more effective for low water users. In comparison, the social norm intervention was better suited for high water users. This was in agreement with what was found by Seyranian where the social norm treatment achieved the highest water usage reduction [44]. This was expected, as their study focused on affluent households; who are known to be high water users.

Data used for interventions

The reviewed studies used numerous data sources. Fielding [1], for instance, used smart water meters which were equipped with data loggers to record 1.4 mL pulses at an interval of 5 seconds. Liu [45] also used data recorded by a smart water meter. The meter, however, had limited storage and was only able to record several weeks data at a time. This limited the amount of data available for the study. On the other hand, Datta [3] and Price [43] used municipal bills as the data sources for their studies. Which resulted in a lack of control over the quality or quantity of the data. Another limitation was the frequency of treatments, as the study relied on the local municipality to send treatments with user's monthly bills. The resulting interventions hence presented water usage information that was a month old. The results of the studies were hence affected negatively. Another study employed people to physically go to houses and take water meter readings [44]. The quantity and quality of the data were confined to the readings taken four times during the eight week whole study period.

Types of behaviour interventions

The common behavioural treatments used in the reviewed studies were Social-Norm [43, 44, 46, 47, 48], Descriptive [3, 43, 46, 48, 49] and Information [1, 3, 43, 44, 50, 51] based interventions.

Delmas [51] reviewed 156 studies that used information strategies to influence energy conservation behaviour and found that personal monitoring and consultation were more effective than providing users with historic or peer comparison feedback. This observation was in agreement with what Datta [3] found. Social comparison was found to best work for heavy users whose decision was not driven by price [43, 44].

Discussion

All the above mentioned studies indicate that water reductions as a result of the treatment implemented are not sustainable long term. Several hypothesised that for long term sustainability, treatment would have to continue. This hypothesis was tested by [1], and it was found that *"Information Only"* treatment had the highest sustained reductions over the long term. *"Descriptive Norm"* and *"Water End-Use"* interventions reductions were minimal over the long term.

There was no specific sample size seen across the reviewed studies. Another aspect that varied significantly was the study period and data collection period. These differences made comparison of results across the studies complex. All the studies reviewed did include a control group for comparison. For the majority of the studies, control groups did not receive any treatment. One study did however include a control group that received water savings tips as an intervention. All other groups in this study also received this form of "baseline" intervention. This was found to be a way to conduct RCTs which encourage some form of water conservation across all groups, as the study took place during a drought condition [3].

2.5 Summary

It can be concluded from the two studies in [15] and [9] that schools within South Africa that face three main challenges around the issue of facilities maintenance. These were noted to be: insufficient funding; a lack of staff qualified to perform efficient maintenance and strategic maintenance policies in place to execute appropriate maintenance. It was also evident that the impact of maintenance, be it basic or extensive, were not known. The impact of maintenance on water usage or on the return on investment remained unknown. These could be why facilities maintenance in schools was not prioritised. It should however be noted that the two studies focused on underprivileged areas and hence did not include schools that do have effective maintenance policies and strategies and whose grounds are well maintained.

Using the MNF metric has proven to be effective in leakage detection, particularly in the residential sector and urban water systems. However, this method was not yet commonly used for detecting leakages in school water demand.

Research has found a considerable number of factors that are at the heart of water demand. Still, research has not fully explored what role political and policy-related variables play in school water demand.

Furthermore, although a significant amount of research has been dedicated to behaviour interventions studies that aim to reduce water usage, the majority of these have predominantly only focused on the residential sector of urban water demand. A review of these found several shortcomings in their methods. It was noted that there was lack of consistency in the type of data used to design behaviour interventions. The data sources used by the studies reviewed were municipal bills, smart water meters and physical reading of water meters. Moreover, social norm and information based behaviour interventions were observed to have the highest impact on water usage reduction across all the reviewed studies. Their results however were not consistent over the short and long term. Therefore research studies that explore these facets of school water demand are crucial to water demand management.

Chapter 3

Data collection

In order to achieve the objectives of this research study, three different methods were used. The results of these methods will be presented in Chapter 5, 6, 7. This chapter explains the general data collection process.

Initially, details of the Study Area were provided, followed by specifics of the #SmartWaterMeterChallenge initiative. The #SmartWaterMeterChallenge was an initiative whose objective was to raise awareness on water conservation and help schools within the Western Cape reduce their overall water usage. Thereafter, the Smart Water Meter device used to collect water usage data was described. This was followed by details of the different datasets used to achieve the objectives of this research study. The chapter concludes with the limitations of the research study.

3.1 Study area

This research study took place in the Western Cape province of South Africa. At the time, the province was experiencing a severe water shortage. The Western Cape province is one of 9 provinces in South Africa and has the third highest population as 11.3% of the total population resides in this province, which is approximately 6.6 million. The province is the fourth largest with an estimated area size of 130 square kilometres. The province has a Mediterranean climate with warm, dry summers and moist winters. The temperature ranges between 23 to 29 degrees Celsius in the summers and 5 to 22 degrees Celsius in the winters [52]. The majority of the province's water supply comes mainly from six dams: Theewaterkloof, Wemmershoek, Steenbras, Voelvlei (upper and lower) and Berg River dams. The largest city in the province is Cape Town and approximately two thirds of the provincial population resides in this city. Cape Town has the largest water utility company.

3.2 The Smart Water Meter Challenge campaign

After a research group at the University of Stellenobosch conducted a pilot study at Stellenbosch Primary School, the Shoprite Group approached the university about rolling out the project on a larger scale. Consequently, in November 2017 the Shoprite Group, in association with other companies and institutions, launched a project called the #SmartWaterMeterChallenge to address water problems, particularly in view of the drought crisis, at 100 Western Cape schools. The project was later expanded to another 244 schools in the province, as more companies joined the campaign.

The entities that came together to create the Smart Water Meter Challenge were BridgIoT, Stellenbosch University, the University of Cape Town, Shoprite, Pragma, the Office of the Premier of the Western Cape, Cape Talk, the Western Cape Department of Education and 98 other corporate entities. One of these, BridgIoT, was a spin-off company from the University of Stellenbosch that specialises in smart metering and smart controllers. Given their expertise, BridgIoT was responsible for managing the entire project and continuously assessing and reporting its results. Additionally, BridgIoT provided the water usage datasets and facilitated securing of all other datasets used for this research study. The water metering was done using a *Dropula* device (see `www.schoolswater.co.za/` for further details on the project).

3.3 Methodology

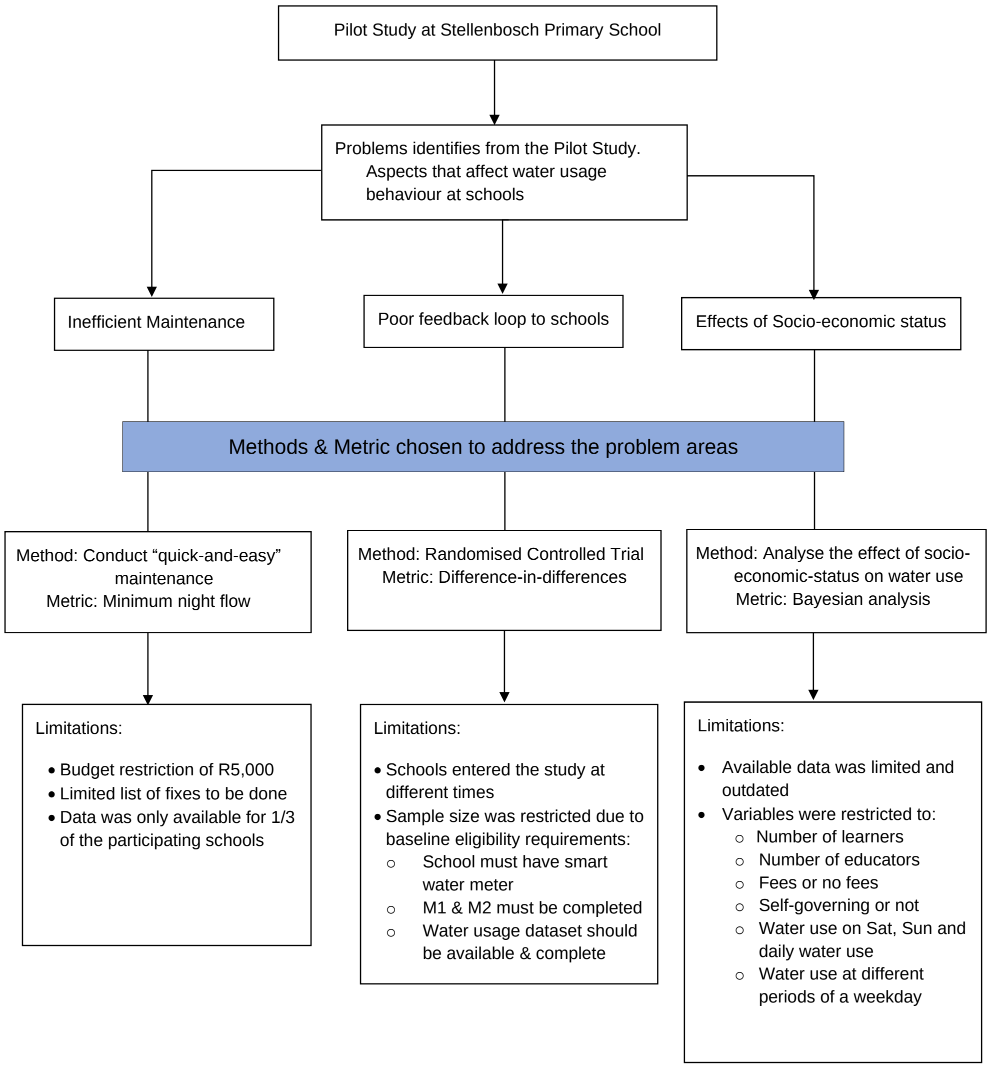

Figure 3.1: Diagram showing the methods of the study and thier related limitations

As part of the initiative, each school had a *Dropula* device installed on their main municipal water meter to measure water usage in real time. The data from the *Dropula* device was used to assess the pre-existing water levels of the

#SmartWaterMeterChallenge initiative. The collected data was time-stamped water usage for each school. Therefore, the water usage data was used for the different objectives of this study in a effort to assist schools in reducing water usage and the related costs.

One of the practical objectives of the campaign was to stop water wastage by contracting local plumbing companies to carry out essential maintenance at the participating schools. The maintenance was carried out in two steps: basic maintenance (M1), where each plumber was given a list of "quick-and-easy" fixes" and a budget restriction of R5,000, and an in-depth follow-up maintenance (M2), to assess the M1 work and consider the need for further work. The list of what were deemed as "quick-and-easy" fixes can be found in Appendix A, Figure A.1. The project was designed to free up school finance commonly lost due to high water bills.

Secondly, the campaign classified school water usage patterns and characterised the influence of a school's SES on school water demand, using the Bayesian method. The variables used for the Bayesian method were: Quintile grouping, section 20/21 classification and water usage on different days and at different times of the day.

Finally, the project aimed to change water usage behaviour by creating awareness of the need to conserve water, by using a RCT to quantify the effects of two behavioural interventions on school water demand. The two interventions used were an *Information Only* and a *Social Norm* interventions and were designed using historical data.

3.4 Smart water meter

The data used for this research study were collected using a smart water metering device called the *Dropula*. The *Dropula* device was connected onto the main municipal meter of each school, as shown in Figure 3.2. The device's circuit was made up of a pulse counter and a modem. The pulse counter recorded the number of pulses in a specific time period, each pulse representing 10 litres. For communication, the device initially used GSM (Global System for Mobile Communications), which was later upgraded to Sigfox Connect. This device measured water usage data in real-time. The modem sends the data to an online platform for storage and processing. The processed data were then made available for downloading and viewing. The data was collected in one minute intervals and each recorded data was time stamped.

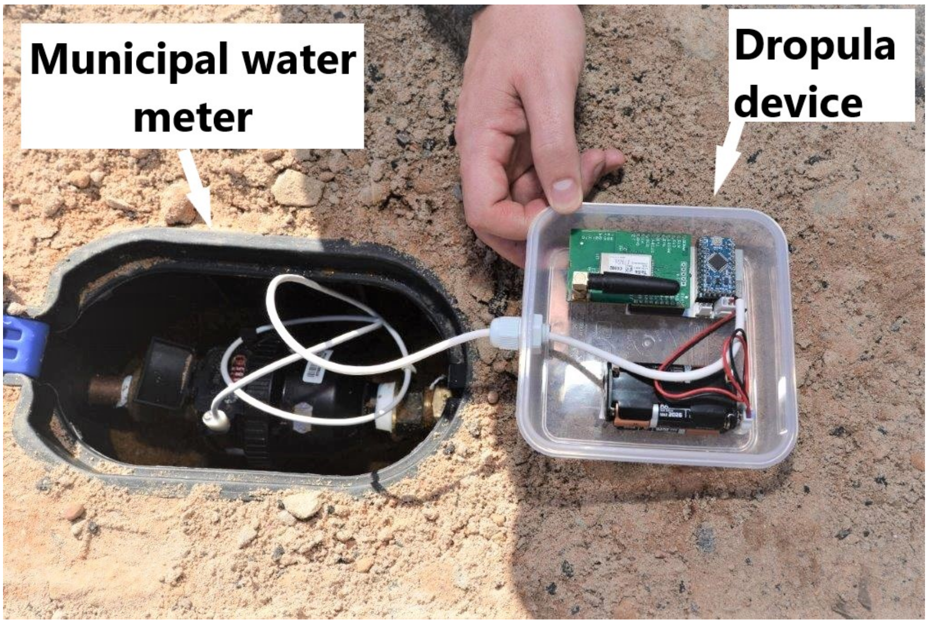

Figure 3.2: The *Dropula* device

3.5 Data collection

3.5.1 Datasets

Cm	_id	first	imei	timestamp
0	zEWSXbCXayWSwvaG2	TRUE	214F93000000000	1510075143
0	MqpAsf89EBgQb89QC	TRUE	214F93000000000	1510074543
0	3hNKKSPqAQYsW4eiq	TRUE	214F93000000000	1510074032
70	YdZctdSXozPdmonyB	TRUE	214F93000000000	1510073346
80	peQZEkXzMJ2zPH8fN	TRUE	214F93000000000	1510072748
90	7vN4nMfPWtEd9zmYT	TRUE	214F93000000000	1510072149
90	FdipgZZaWGdTDYfgR	TRUE	214F93000000000	1510071550
100	24FNoMeQ5FRFJXydS	TRUE	214F93000000000	1510070952
90	BfJEyR5YGSeFpgYKG	TRUE	214F93000000000	1510070353
90	z7o76GLczAFH2XxJo	TRUE	214F93000000000	1510069755
90	EmKWaMmSrtPKdSB3d	TRUE	214F93000000000	1510069158
90	MTxSQKor8TkoR4huY	TRUE	214F93000000000	1510068562
110	Sv78TPECiYadMdJLr	TRUE	214F93000000000	1510068216

Figure 3.3: Water usage dataset sample. Cm represents the water flow which is measured in litres, _id is an identifier for each reading, imei is the identifier for each smart water meter and each water flow was recorded with a timestamp value.

This study employed data sets from four different sources. One of these was a water usage dataset shown in Figure 3.3. The study consisted of approximately 350 schools located in the Western Cape Province and each school had a dataset similar to that shown in Figure 3.3. This datasets were obtained from the database of a company called Bridgiot as part of the #SmartWater-

MeterChallenge campaign. The water usage data for each school was recorded as a water flow reading that was accompanied by a time-stamp. This allowed for real time capturing of water usage data. This feature was instrumental to achieving the objectives of this research study as it provided an opportunity to monitor and notify schools when unusually high water usage was observed. It further made it possible to track and analyse school water usage behaviour, leaks and wastages throughout the day. The water usage data had to go through a pre-processing stage to ensure consistency and reliability in the dataset. The dataset had two fields of interest for each reading, a time stamp and a volume value. The preprocessing stage removed outliers, noise and fields with missing data. Thereafter, the fields with missing data were padded to create a holistic dataset.

NatEmis	Section21	Quintile	Fees?	NoFeeSchool	Learners_2016	Educators_2016
100000037	NO	2	TRUE	NO	388	14
100000038	NO		TRUE	NO	84	12
100000054	NO		TRUE	NO	54	12
100000055	YES	5	TRUE	NO	478	26
100000056	NO	4	FALSE	YES	663	16
100000065	NO	5	TRUE	NO	594	51
100000070	NO	3	TRUE	NO	142	21
100000078	NO	3	FALSE	YES	537	33
100000091	NO	4	TRUE	NO	725	21
100000103	NO	5	TRUE	NO	268	37
100000108	NO	5	TRUE	NO	298	18
100000109	NO	4	TRUE	NO	752	25
100000110	NO	5	TRUE	NO	646	34
100000122	NO	1	FALSE	YES	870	28
100000123	YES	3	FALSE	YES	1009	28
100000124	NO	4	FALSE	YES	956	27
100000126	NO	4	FALSE	YES	1418	30
100000127	YES	4	TRUE	NO	735	26
100000128	NO		TRUE	NO	146	7

Figure 3.4: A Sample of Western Cape Education Department (WCED) schools data set. The data set is for each school's Section 21 classification, Quintile Grouping and whether the learners pay school fees or not, number of learners and educators.

The second dataset was from the WCED, which had details of different variables of all the schools within the province. Among these variables were each school's Quintile grouping, Section 20/21 classification, number of learners and educators, and whether or not the learners paid school fees. The sample was chosen because it gave a good representation of the full data set. A sample of this can be found in Figure 3.4. This dataset, which was the only available data on these variables was unfortunately outdated. Therefore, there is a clear need for improved data collection and storage methods.

The third dataset can be found in Appendix B, Figure B.1 and was obtained from the City of Cape Town and here each school was represented by a unique serial number and the sample shows the type of methods used for recording water meter readings as well as water consumption values for May to October of 2018. The fourth data set was again from the WCED. Appendix B, FigureB.2 shows school names, meter reading type, consumption values for May to September as well as water meter readings.

The final dataset was from the three local plumbing companies hired for the #SmartWaterMeterChallenge project, only one company had reliable maintenance cost data. Consequently, the maintenance cost dataset was made up only of schools whose maintenance was performed by this one company. Therefore, from the total 344 schools that had maintenance done, 148 were excluded from the study because of lack data, reducing the sample of schools with reliable data to 196. This was the third dataset.

3.6 Limitations

There were limitations observed throughout the course of the study, the majority of which affected the available data and its quality and quantity. For example, for the maintenance dataset, there was a limitation on the number of schools that had reliable data. This reduced the sample size significantly as only one out of the three plumbing companies had reliable maintenance cost data. Therefore this could have had adverse effects on the generalisability of the results as the dataset may possibly only include specific kinds of schools.

Another constraint was on the available data on schools water usage in the Western Cape from the WCED database, which was unreliable and incomplete. The available dataset used in 2018 for this study, had not been updated from 2017. This is likely to skew the results and interpretation thereof.

The RCT aimed to make water usage data available to the participating school through real-time online platforms. Due to a lack of internet access in several of the schools, the intervention treatments had to send out via email, text message and posters.

Finally, the sample size of the RCT decreased throughout the study as delays in water meter installations meant several schools had to be excluded form the study. Another area of issue was baseline setting. There were several issues with establishing accurate and trustworthy data for several schools during the baseline period because faulty meters, vandalism and theft corrupted these dataset. For a reliable baseline, a dataset that represented the schools' water usage accurately had to be created, faulty data was hence omitted from the dataset. If a day's data were missing, or several hours were not recorded, that day was omitted from the analysis. As a result the number of schools with viable baselines and therefore the number of schools entered into the study was significantly reduced.

Chapter 4

Understanding and classifying school water use

This phase of the research study explored solutions that focused on water demand management. The primary objective was to investigate and describe the general water usage patterns of a primary school. Therefore, the first aim was to gain a general understanding of school water usage with the purpose of profiling it. Secondly, the obtained knowledge was used to help schools reduce water related expenses by reducing water usage. Several behavioural change interventions were implemented in hopes of reducing the water usage of the school. Therefore, the primary objectives were divided into two parts; (i) studying the school's current water behaviour patterns and (ii) conducting a water usage reduction quantitative study involving several behavioural interventions.

This chapter initially discussed the details of the pilot study. Thereafter, the behavioural interventions employed were presented, followed by the results and the analysis thereof. The chapter concludes with a summary.

4.1 Pilot study

A pilot study was conducted at a primary school in Stellenbosch, to determine the feasibility of the above approaches with the goal of implementing them on a larger scale. Accordingly, a smart water meter was installed at the school to monitor the water usage in real-time. The chosen school had 89 staff members and over 800 learners. There were four houses on the school premises that housed some of the school's staff. These had three to five people residing in each. The school further had a large swimming pool and large sports field, these however, used borehole water. The rest of the school's water needs were met with council-supplied water. The data from the meter were used to understand and describe the school's usage pattern. The school's water usage profile had to be described on an hourly basis to establish times of high and low usage. The data were further used to design the behaviour interventions to encourage reduced water use. The behavioural study involved three different interventions for the three members of the school, namely: the management team, teachers and learners. Each intervention's design was based on who the target audience was. However, all the interventions were designed with the same purpose to affect behaviour change by educating on the importance of water and encouraging behaviours that reduce water usage. Therefore, the pilot study was essential for determining the benefits and feasibility of the thesis objectives in order to roll them out on a larger scale.

The smart meters were installed on the 19th of May 2017. Data was collected from the 20th of May 2017 to the 17th of June 2017, while water bills were used for other date ranges.

4.1.1 Insight on the collected water usage data

For this study, school hours were identified as the period between 07h00 and 14h00 daily. During this time of day, most occupants of the houses were at the school and hence the houses were expected to have negligible water usage. For the majority of the school hours, both learner and teachers spend their time inside classrooms. Therefore, during this period, the main contributors to water usage were assumed to be urinals, toilets and water used in the kitchen. Further, break time was between 10h00 and 10h45, which was when classes were empty. This time period accounted for the largest water use. Extra curricular activities were to be defined between 14h00 and 17h00 daily. This period had minimal water usage activities as most learners and teachers would have left the school premises. During the course of the study period, the school was undergoing renovations. This was a significant contributor to water use, particularly during the hours of 08h00 and 16h00, which was when construction-related water activities took place. Consequently, the water usage between 00h00 and 05h00 was considered to be losses. During this time, no water flow was expected and whatever flow occurred in this period was classified as leakages. With the active water restrictions in Stellenbosch, sprinklers and watering plants with potable water was prohibited. Urinals water usage was included in the losses as they occur throughout the whole day. The hourly losses between 00h00 and 05h00 were calculated and extrapolated for the entire day, to determine estimated daily water losses. Therefore, the key to calculating losses accurately was being able to eliminate or isolate the school's actual usage from the school's total daily usage. It was important to note here that actual usage and total usage were different. Actual water usage referred to water used by the school alone, excluding losses and houses' usage. The school's total usage is made up of all four different parts; actual use, losses, house and builders' use. Finally, the results were compared for the same period with another school from in the same town where no intervention was done.

4.1.2 Behaviour intervention

The behavioural intervention implemented in the study had three aspects to it: posters, playing cards and reports. The intervention was preceded by an intervention presentation to the staff members of the school after the installation of the Dropula device. This presentation was an introduction to the study and raised awareness with regards to water conservation. The presentation further focused on the school's water usage over the previous three days. It was noted that the school had severe losses, these were shown and explained to the staff members. Secondly, the presentation informed the staff members of ways to reduce the school's water usage and to explain the details of the behavioural study which was to be implemented at the school. Details of the different aspects of the intervention, which were the poster, cards and reports were provided, along with their aims, these will be shown and discussed below in more detail.

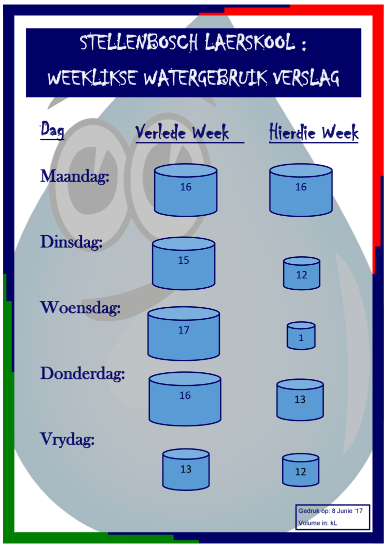

Figure 4.1: School poster intervention

Figure 4.2: Top trump-type playing cards intervention

Poster

The first aspect of the intervention was aimed at the learners - the hypothesis was that given information on the school's water usage, they would be more inclined to save water. The poster design, as seen in Figure 4.1 was kept as simple as possible, as the focus of this aspect of the intervention was presenting water usage volume for each day. A poster was put up in all the boy's and girl's bathrooms on a daily basis for a month. For maximum exposure, the poster was put up at nine o'clock every morning, an hour before break time, which is at ten o'clock.

Playing cards

The second aspect of the intervention aimed at changing the learner's behaviour was *Top Trump-type* playing cards, shown in Figure 4.2. Each student was given 15 cards, with each card having the following information: daily usage, water losses due to leaks and the total volume for the day. The values on the cards were actual water usage readings of the school obtained during the intervention period. The card game played by the students was as follows; two players present a card each and the player whose total volume was lower won and got to keep both cards. The aim, for each player, was to collect as many cards as possible. This aspect of the intervention was aimed at engaging the learners and exposing them to the range of values of the school's daily volumes. It was hypothesised that exposure to the water volume values would help learners understand the information in the posters and encourage water saving practices. The playing cards hence went hand in hand with the poster intervention.

Daily report

The final aspect of the intervention was a simple pdf report, showing bar graphs of the school's daily water use. This usage was divided into actual usage and losses. The graph also indicated the cost of each day's water usage in Rands, which targeted behavioural change tied to financial benefits.

4.2 Results and analysis

This section presents a detailed analysis of the results from the pilot study. The water usage pattern for an average week day was discussed first. The water usage distribution followed thereafter and the section ends with a discussion of the difference-in-differences analysis.

Figure 4.3 shows the water usage distribution for the average hourly water usage of the school between 07h00 and 17h00 for weekdays in June 2017. The distribution of the medians was seen as a positively skewed distribution with the mass being concentrated on the left. The median water usage distribution between 09h00 and 10h00 was 1.4 kilo-liters. The time periods 08h00 to 10h00 and 13h00 to 15h00 had significantly high variances.

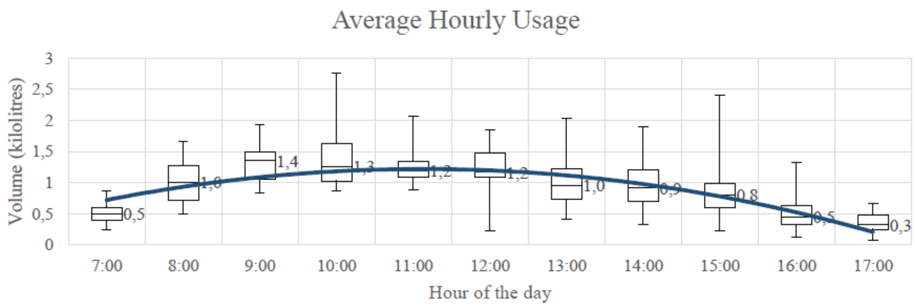

Figure 4.3: Water usage distribution for weekdays only for June 2017 (the month after intervention)

Figure 4.4 shows the distribution of the different contributors to the school's total water usage. This was an average daily distribution for the month of June 2017. When losses and total water usage were excluded, i.e throughout the day, the school's water usage had a Gaussian distribution. The highest mean occurred during school hours, which was expected. The losses time period has the highest variance and its distribution was skewed to the right. The other three time periods have significantly lower variances. Further, the total water usage also had high variances. The majority of the large water activities took place around 10h00, this behaviour was expected as this time period was during the school break time. During break, all teachers and learners were outside class and most of the water activities were centred around eating and drinking and using the facilities. Losses were the area of focus in terms of reducing water usage. There were periods when taps throughout the school were manually closed at the end of the day to locate leaks. These periods hence had the lowest values and contributed to the high variance seen in the losses periods. The other time periods had much lower variances, which was what one would expect with consistent water usage behaviour. To classify these, the losses were seen as usage that is unpredictable and irregular to normal usage and the rest of the periods represented normal school usage that is more predictable.

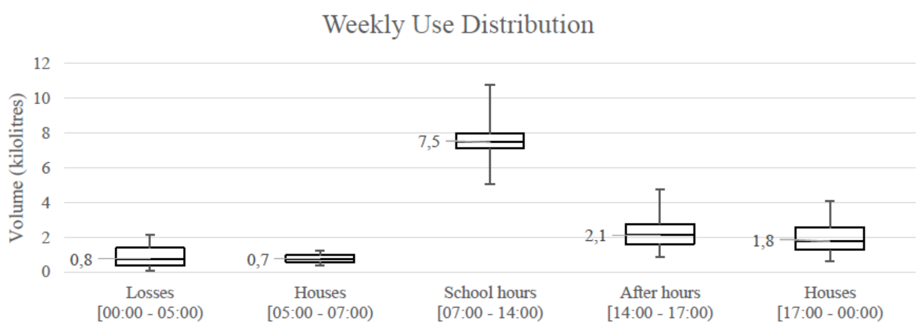

Figure 4.4: General water usage profile for Stellenbosch Primary for the duration of the pilot study period.

Table 4.1: Difference-in-Differences (DiD) comparison: Average consumption per day in kiloliters compared to another school in the same town

DiD avg water usage per day	Treatment	Control	Differences
mid Dec - mid April	21.6	26.3	-4.6
mid May - mid June	12.3	26.5	-14.2
Differences	9.4	-0.2	-44%

The school's existing water usage data for three weeks prior to the start of the study was used to established the baseline data. The graph in Figure 4.5 shows weekly water usage data for the entire study period. The weeks with the lowest usage were week 3 and 4; these were the intervention weeks, specifically those interventions aimed at learners. Compared to baseline data, week 3 and 4 used 9.0 and 8.6 kilo-liters less than the baseline week respectively. This was an indication of the positive impact of the interventions.

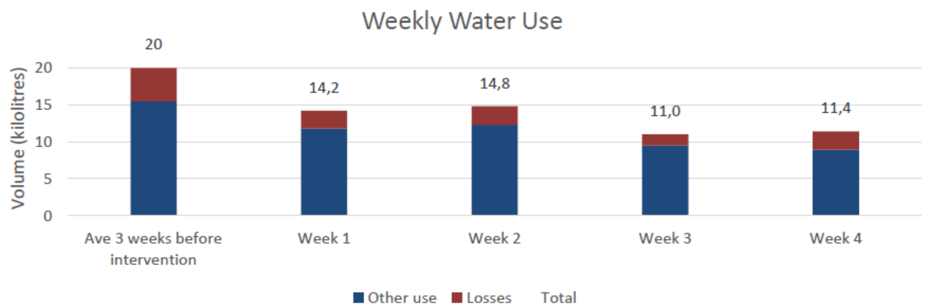

Figure 4.5: Water usage distribution for only weekdays in June 2017 (the month of intervention)

The difference-in-difference method results were as seen in Table 4.1. In comparison to the baseline period, the intervention successfully aided in reducing the school's water usage. The daily total decreased from 20 to 14.8 kilo-liter for the first part of the intervention. This value decreased further to 11.4 kilo-liter in the last week of the intervention. Week 3 had the lowest water usage as this was when all the different aspect of the intervention were running. These results show that behavioural change by intervention was effective over short-medium periods but that long term effectiveness may require continued intervention or different strategies. Deteriorating results post study were also experienced by other studies that employed randomised controlled trials, such as [1] and [43]. Furthermore, the effects of the intervention, when compared to a similar school that had no intervention, was a 44% reduction in water use. The results excluded data for the school holiday period, which was from the middle of April to the middle of May 2017.

4.3 Summary

This chapter described the normal water usage behaviour of a school and demonstrated that a behavioural intervention can be effective in invoking water conservation behaviour. The difference-in-difference method was then used to quantify the effect of intervention on behavioural change. As such, the pilot study was able to successfully reduce a primary school's daily water usage by 44% compared with a control school. Although this reduction was done by applying a behavioural intervention, the biggest reduction came from a change in managing leakages, identifiable during early morning hours.

Furthermore, several valuable lessons were learned, that could be used to guide future researchers. The first was the effect of poor maintenance on the overall water bills of the school. Inefficient management and maintenance of the water system was recognised as big contributor to night water usage, this usage was identified as water leakages. In order to reduce water leakages and the related expenses, strategic maintenance plans would have to be implemented. Secondly, the school did not have a good water culture as the general water usage behaviour was non-conservational. It was clear that the school lacked the knowledge that would entice behaviour change around water activities.

Chapter 5

School facilities maintenance

As a result of the lessons learned from the pilot study, the second phase of this research study focused on water facilities maintenance within schools in the Western Cape. Hence, basic plumbing maintenance was conducted in an effort to reduce water wastage. As such, a list of fixes were defined, based on the pilot study, whose aim was to reduce water wastages by reducing night time usage. These fixes had to be easy and inexpensive so that even schools with low SESs (social economic statuses) could execute and benefit from them in the future. Notably, because of the water crisis in the province at the time, water usage reduction remained a constant priority throughout this study. As such, plumbers were contracted to do basic plumbing at a subsample of 196 of these schools with a budget limitation to R5,000 (US$350) per school. Data from the Dropula device along with the minimum night flow (MNF) metric were used to identify any abnormal water flow that might indicate leakages. Additionally, maintenance cost data were used to conduct a cost-benefit analysis of the results, to assess the return on investment (ROI).

This chapter begins by describing the data and metric used to determine the impact of the maintenance project on the MNF. The analysis of the results follows next and finally a summary is given.

5.1 Data and metric used

5.1.1 Data

To create a dataset that was representative of a schools' water usage, some faulty data were omitted from the dataset. This was on the basis that if a day's data were missing, or several hours were not recorded, that day was omitted from the analysis. Additionally, from the three local plumbing companies hired for the project, only one had reliable maintenance cost data. Consequently, the maintenance cost dataset was made up only of schools whose maintenance was performed by this company. Therefore, the total number of schools was

Table 5.1: Maintenance cost breakdown

Description	Amount [R]
Materials cost	520,693
Transport cost	144,131
Labour cost	558,034
Total	1,222,859

reduced from 344 to 196. Table 5.1 shows that the bulk of the costs was for materials and labour.

5.1.2 Metrics

Research has shown the minimum night flow (MNF) technique to be effective in detecting water leakages. Numerous studies have used it for this purpose [4, 14, 34, 35, 37, 53, 54], only a few examples are cited here. Although the period for MNF was defined differently in each of these seven cited studies, all were in the range of 00:00 to 05:00 daily. For this research study, the MNF period was defined as 01:00 to 04:00, with the MNF calculated as the average hourly water usage for this period. The MNF was calculated using the aggregate of each day for a six-day period before and after the reported M1 date. The MNF metric was used to reveal the presence of water leakages at the schools. Consequently, the main aspects calculated for this analysis were the following; aggregate MNF, percentage reduction in MNF, total water and monetary savings, and return on investments. Since the maintenance of the schools was done as part of a staggered campaign over several months, the datasets were re-aligned to centre on each school's reported maintenance day (M1). Notably, the percentage change in MNF was calculated using Equation 5.1,

$$\mathit{\Delta} Q = \frac{Q_{pre} - Q_{post}}{Q_{pre}} * 100\% \tag{5.1}$$

where Q_{pre} is the MNF pre-maintenance and Q_{post} is the MNF post-maintenance.

All water and monetary savings calculated and presented here were derived from water usage between 01:00 and 04:00 daily. For the monetary calculations, the tariff was taken as R97.17/kilo-liter, from the [13] tariffs of 2018/19. These were then extrapolated to 24 hours for each day. The ROI (return on investment) period of the maintenance project was calculated based on the extrapolated MNF water savings.

5.2 Results and analysis

This sections provides details of the MNF analysis following the maintenance project that was done at the schools. First, the MNF for each day relative to the maintenance date was presented. Secondly, a histogram was given, that showed the decrease in MNF as a result of the maintenance done at the schools. Thereafter, the general change in the MNF distribution before and after maintenance was presented. Following that was the percentage change in MNF. The section concluded the results portion with the distribution of expenses and savings.

Figure 5.1 depicts the mean and median of all the schools' usage for the days preceding, including, and following the reported day of maintenance. Also shown were the means of the two sets before and after the reported day of maintenance. The results showed that for some schools the maintenance date was likely to have occurred up to three days before the plumber eventually captured it on the reporting system, as evidenced by the steady decrease from M1-3 to M1 in the mean usage, seen in Figure 5.1. Despite this inaccuracy, the weekly average of the daily mean usage changes by 28%, or 55/liter from the preceding to the following week. Moreover, the weekly mean of the median usage was 34%, or 16/liter lower in the following week.

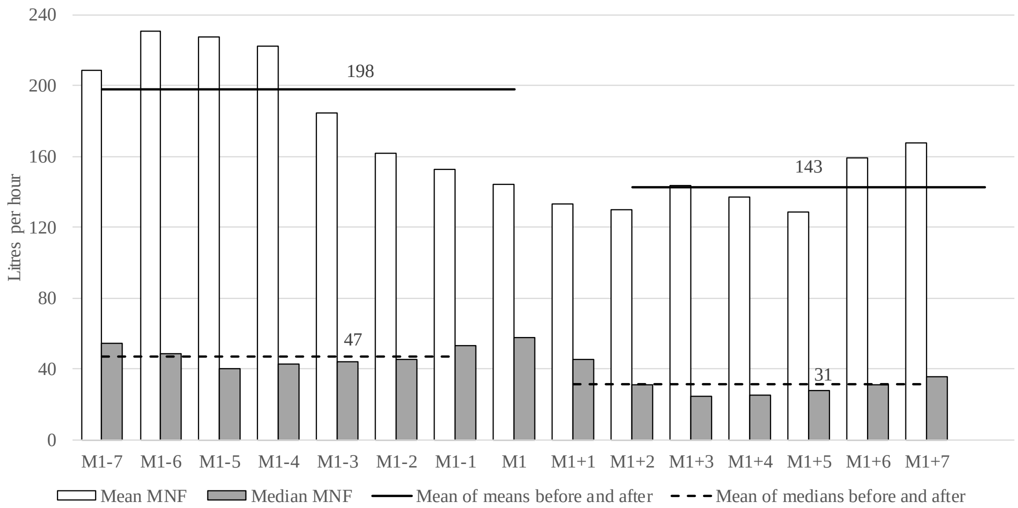

Figure 5.1: Median and mean of schools' MNF for each day relative to the reported day of maintenance, M1.

Given the high means relative to the medians, it can be concluded that the highest losses are contributed by a small number of errant schools. In fact, at day M1-7, the 75th percentile of schools had an MNF of 241 liter/hour, and on M1+7 the 75th percentile was at 136 liter/hour, close to the means for these times. To further illustrate this point, the distribution of MNF flow rates of one day a week before (M1-7) and one day a week (M1+7) after the reported maintenance day were given in Figure 5.2. This figure showed that the distribution of schools in terms of MNF improved most for schools with MNFs in the bracket of (200,500] liter/hour, followed by (500,1000] liter/hour, rather than for the lower volumes. Most of the schools appear to have shifted into the 0 and (50,100] liter/hour brackets, as their MNFs reduced after maintenance.

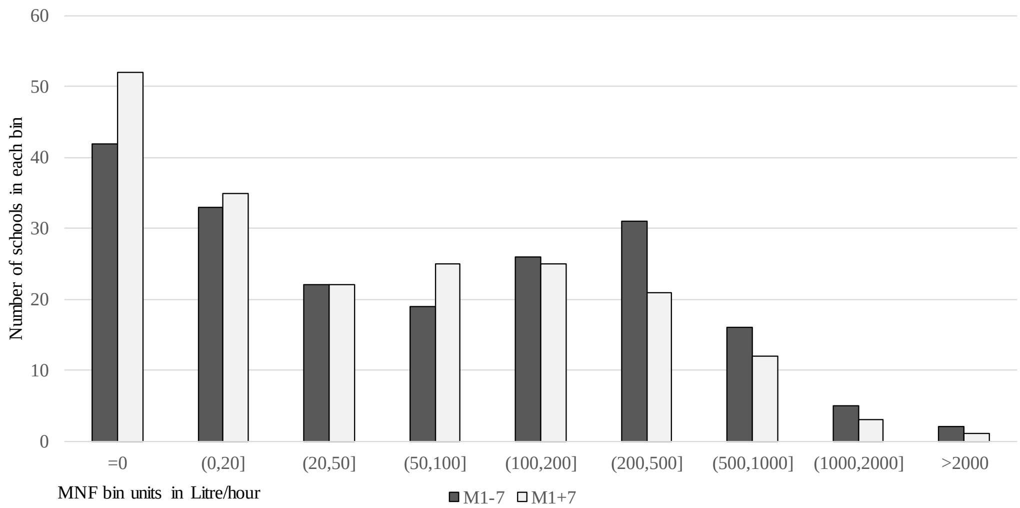

Figure 5.2: Histogram of the MNFs for all the schools for a week before (M1-7) and after (M1+7) the reported maintenance day, illustrating a shift from high MNFs to lower MNFs.

Next, the changes over the period are evaluated by comparing the usage distributions per day across schools against a baseline made up of M1-8 to M1-6. The comparison expresses each day's usage as a percentage of the baseline and the results were shown in Figure 5.3. Only 160 schools were included that did not start from a baseline of zero for the volumetric plot, Figure 5.3 (a). The figure showed that the median of the volume differential did not change much, while the 25th percentile of the ratios reduced substantially from M1, along with a substantial reduction in the average ratio for each day after M1-3. This further demonstrated that the bulk of the savings were achieved in a relatively small number of the participating schools. The average reduction per school at M1+5 was 97 liter/hour, while the median change at the same time was 25 liter/hour. For the ratio plot, Figure 5.3 (b), only 103 schools that had a baseline of more than 42 liter/hour were included. This was done to ensure that schools with a small MNF and relatively small changes, did not skew the percentage change result. The medians made a drastic shift on the day before the reported maintenance, and after M1 a substantial and consistent reduction was visible in the 25th percentile. At M1+5, the MNF of the median school was only 45% of what it was before maintenance was performed. The large reduction in the medians of the ratio plot (b) relative to the small reductions in the volume plots (a), demonstrated a substantial reduction, as a percentage, even in schools with smaller MNFs, although their reductions may have had a smaller impact on the total savings.

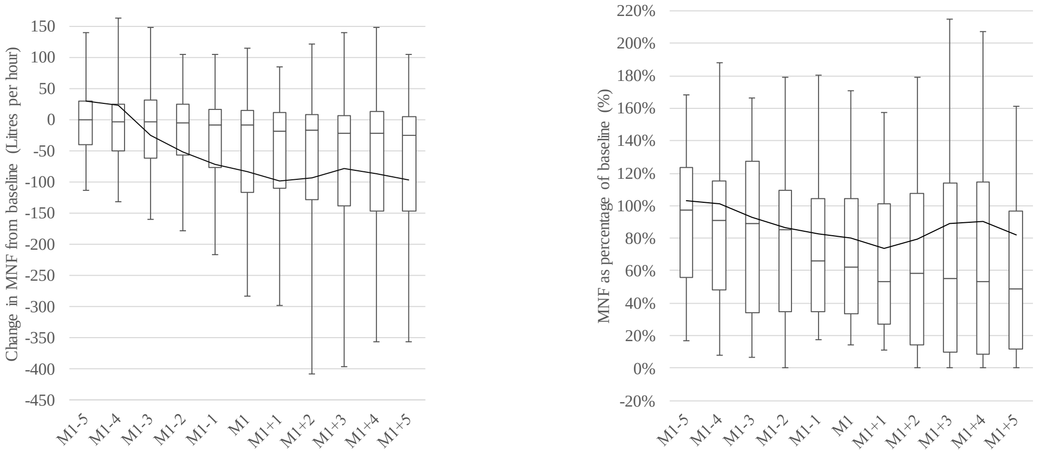

Figure 5.3: MNF change distributions of schools in the days preceding and following the reported maintenance date, M1. The solid black line represents the means. The volume of MNF change relative to the baseline of M1-8 to M1+7 is given in (a) for the 160 schools with a baseline of more than zero. The MNF as a percentage of the baseline is given in (b) for the 103 schools with an MNF of 42 liter/hour, equivalent to 1 liter/day.

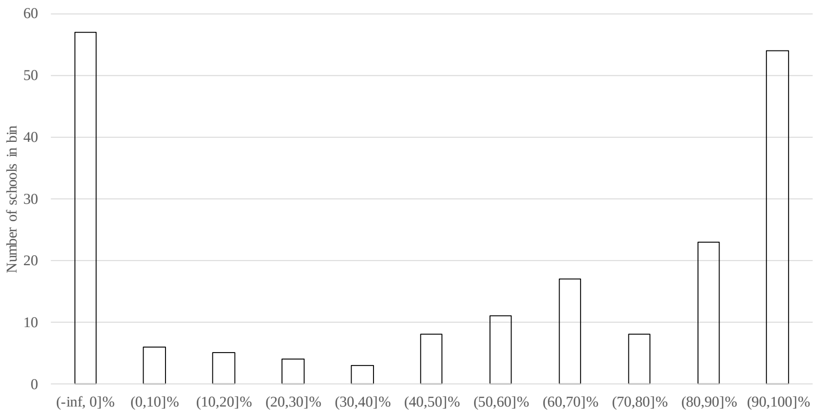

Figure 5.4: Percentage change in minimum night flow for 196 schools – before and after intervention.

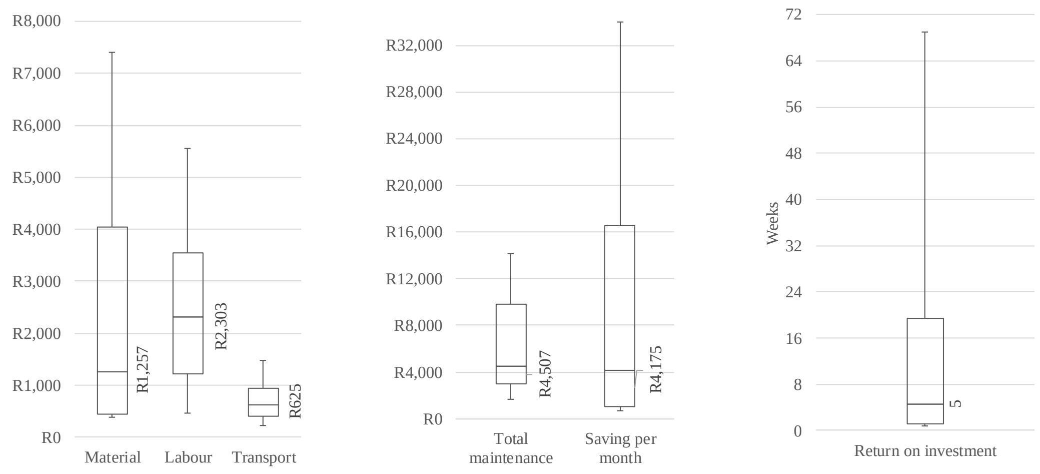

Figure 5.5: Distributions of expenses and savings. The cost of breakdown of maintenance done at all schools is shown in the left figure. The total cost of maintenance and savings distributions for 139 schools where actual savings were achieved are shown per month in the central figure. The return of investment distribution of the schools in the central figure is shown in the figure on the right.

Figure 5.4 gives another view on the MNF changes. For this comparison, the baseline was compared against the MNF for the week subsequent to the maintenance in a histogram to determine the changes for the whole school set. There was a 95% to 100% reduction in MNF for 54 schools and 67 schools lowered their MNF usage by 50 to 95%. For 37 schools, the MNF reduction was more than 0 and below 50%. For 38 of the schools, the MNF did not change (0% change) after the maintenance work. In hind-sight, it was realised that these schools should not have received maintenance, since the majority of them started off with zero MNF. Unfortunately, because of the panic caused by the drought and the threat of "Day Zero", when the pipes would run dry, there was no time to assess all the schools adequately before M1 was done. "Day Zero" was the date given by the City of Cape Town, when water cuts were predicted to take place.

What was unexpected was the 19 schools whose MNF reduction was negative – i.e. whose MNF actually increased. However, this perhaps should have been expected, as the 'quick fixes', i.e. the plumbing repairs that required the least amount of effort and expense, could not address all the plumbing problems that were already apparent and worsening at these schools. It is possible that in some cases the plumbing work revealed new damage. This was not necessarily the plumbers' fault because often when one problem is fixed, another deeper issue might surface. It was also expected that pipes and plumbing fixtures would deteriorate with time, and it was natural for pressurised water to surface when given the opportunity, hence the need for pro-active maintenance. It can therefore be considered normal that in certain cases the plumbing infrastructure would have failed in any event, which was another indication of the dire need for adequate maintenance at these schools. Finally, the financial cost and benefit of the maintenance part of the project was evaluated, which was depicted in Figure 5.5. Figure 5.5 (a) showed a statistical summary of the different expense types listed in Table 5.1. The plot in the figure showed that considering medians, labour cost was the main contributor to the expenses, but the variability and unpredictability of material costs resulted in more outliers. Transport cost was small and relatively constant, which was expected for schools in close proximity. For the cost and savings plot in Figure 5.5 (b), only the schools that managed to reduce their consumption were included, which comprised total expenses of R912,658 and savings per month of R1,898,349 for the 139 schools. The median spent per school was R4,507, while the median saving per month was R4,175, but with a lot more variation compared to the maintenance cost. It was discovered towards the end of the M1 phase that the work at 74 schools was allowed to exceed the budget on an ad-hoc basis, and the average spent per school, for all the schools, was R6,284. The return on investment for each of the 139 schools was calculated separately and the distribution was shown in Figure 5.5 (c): a median return on investment of five weeks, and a seven week return on investment for the 75th percentile. It should be noted, however, that some of the plumbers were threatened, robbed, and even shot at, since many of these schools were in impoverished and dangerous areas – a cost that was fortunately not quantifiable.

5.3 Summary

The aim of this phase was to investigate the financial implications on water related expenses, of doing basic maintenance on school water systems. From the above results, the significance of efficient maintenance, particularly on the water systems, was evident. Even the most basic maintenance fixes yielded significant return on investments for the participating schools. Furthermore, the results revealed the lack skilled staff members at the schools with the capacity to carry out effective maintenance plans. Maintenance plans, were evidently either incomplete or completely lacking in the participating schools. Therefore, this study shed light on several issues that contribute to inefficient maintenance in these schools. Addressing this issues would help schools save finances lost due to wasted water.

From the MNF results for instance, before the maintenance, losses were high – 198 liter/hour on average; after the maintenance, the MNF was reduced by an average of 28%. In total, R1.22 million was spent (more than the instructed R5000 per school), and an immediate aggregate monthly saving of R1.90 million was achieved. As such, the median return on investment for schools where savings were achieved was five weeks at the prevailing rate. As such, maintenance projects should be an integral part of school planning and management.

Chapter 6

Influence of affluence on school water use

The hypothesis for the third phase was that the SES (Socio-Economic Status) of the community surrounding the school influences the school's water usage, and in turn, the equity of the distribution of water resource. Following this, the research objectives for this phase were to: (1) identify the general trends in school water usage using the water usage and funding variables; and (2) characterise the influence of a school's SES on their water usage. This phase was done in collaboration with a research group from Queensland University of Technology. The research outcomes were expected to empower schools primarily, and their communities with sustainable water management by reducing water usage and the related expenses.

The data pre-processes were presented first. Thereafter, a discussion of the results followed. Finally, a summary concluded the chapter.

6.1 Methodology and theoretical framework

6.1.1 Data pre-processing

The dataset used for this study was made up of minutely water usage data for each participating school. This dataset of 242 schools was first screened based on the continuity of water usage. As such, water usage over a period of at least 720 hours (30 days) or more was considered. This reduced the dataset to 163 schools, further, the schools that had zero water usage were eliminated. Accordingly, the final dataset included 156 schools. From this dataset of 156 schools, several variables were identified and used for the data analysis. Daily water usage for each school was split up into daily, week day, Saturday and Sunday usage. The week day usage was further divided into different times of the day, which were chosen based on school operating times and activities. These were: before, during and after school hours, extra mural activities and evening hours. This was done because the dataset was made up of different types of schools, and these schools had different school hours, different extra mural activities and hence different water needs. For example, poorer schools often had feeding schemes, which required additional water usage compared to schools with no feeding schemes. Another common example was that some schools rent the school hall in order to augment governmental funding. Once again, this resulted in additional water usage for these schools. Furthermore, schools with staff members who live on the school grounds, have different usage patterns to those who do not. This residential water usage means that school will have usage during hours that normally would have little to no water usage.

At a governmental level, a school's level of affluence is predominantly determined by the socio-economic status of the community surrounding the school. As such a particular school's Quintile Grouping along with its Section 20/21 classification define its affluence level. For our study, affluence refers to the financial resources a school has at its disposal for expenses. It should further be noted that Quintile Grouping is categorised by whether or not the school charges school fees. Hence the two variables of interest for affluence level is S20/S21 and Fees or no Fees. Therefore, for this chapter, the aim was to classify the effect of school's affluence level on its daily water usage behaviour. This was achieved by conducting a Bayesian analysis using the above mentioned variables along with other variables that affect water usage behaviour, namely; number of students and educators and water usage on different days and at different times of the day. The variables that were used to represent water usage were V_{0508} to V_{2205} as well as V_t,V_s,V_{st} and V_{su}. All the variables used for the Bayesian analysis are shown in Table 6.1. The table further shows the other variables used for the Bayesian analysis; St, Edu, Fees and S21. As such, the Bayesian analysis was used to derive a new affluence level which would be compared to current affluence level; that is based only on whether the school pays school fees and its Section 20/21 classification. These two levels of affluence, the current and the new, were then compared to determine whether the two funding policies has been successful in mitigating the pre-independence unjust and unfair policies.

6.2 Results and analysis

This section presented and examined the results of Bayesian model. Initially, the general patterns of school water as identified by the Bayesian model will be discussed. Secondly, the impact of a school's SES on water demand will be described.

With regard to water usage, Figure 6.1 shows several outliers consistently for different classifications of water usage. These could potentially be due to the over-usage, rather than any measurement errors. The classifications with the most noticeable outliers, i.e. V_w, V_{0814} and V_{1417}, also have the largest

Table 6.1: Data types and classification.

Variable	Data type	Classification	
		Primary	Secondary
Water usage	Quantitative(vol/hr)	Total weekday usage (Vw)	Usage during 0500 – 0800 hrs (V0508)
			Usage during 0800 – 1400 hrs (V0814)
			Usage during 1400 – 1700 hrs (V1417)
			Usage during 1700 – 2200 hrs (V1722)
			Usage during 2200 – 0500 hrs (V2205)
		Usage during Saturdays (Vst)	
		Usage during Sundays (VSu)	
		Total usage (Vt = Vw + Vst + VSu)	
Number of students (St)	Quantitative		
Number of educators (Edu)	Quantitative		
State of charges (Fees)	Qualitative (Yes/No)		
State of affluence during apartheid (S21)	Qualitative (Yes/No)		

Table 6.2: Interrupted time series analysis (Prais-Winsten first order autocorrelation regression -AR(1)) of the events in question, with evaluation using the Durbin-Winston statistic.

Scenario			Number of Schools	Description
No.	S21	Fees		
1	No	No	27 (17%)	Poor during and after apartheid
2	No	Yes	12 (8%)	Poor during apartheid, but now affluent
3	Yes	No	44 (28%)	Affluent during apartheid, but now poor
4	Yes	Yes	73 (47%)	Affluent during and after apartheid

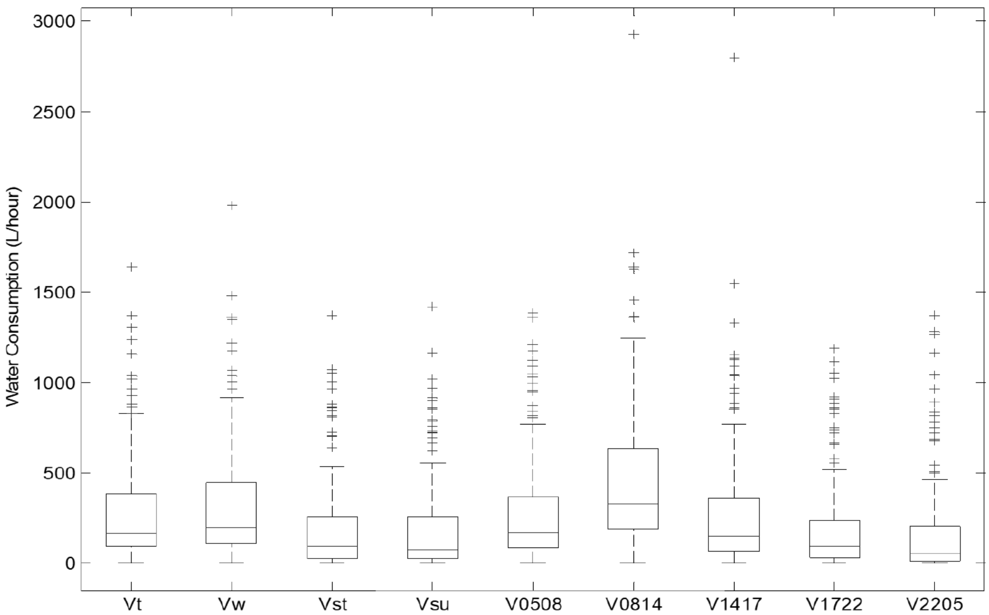

Figure 6.1: Distribution of the water usage by schools in Western Cape, South Africa.
Note: V_t - total water usage; V_w - weekday usage; V_{st} - Saturday usage; V_{su} - Sunday usage; V_{0508} - week day usage during 0500:0800 hrs; V_{0814} - week day usage during 0800:1400 hrs; V_{1722} - week day usage during 1700:2200 hrs; V_{2205} - week day usage during 2200:0500 hrs; S21 - state of affluence during apartheid, Fees - state of charges.

variance. This was unsurprising as the schools differ greatly in their water needs. On the contrary, the classifications with less variance and outliers were V_{1722} and V_{1417}. Once more, this was also expected. These classifications represented water usage between the hours of 1700 and 0500 , which was a period when most schools did not have any water activities. The lack of outliers could also be attributed to the maintenance that was executed at each of the schools as part of the #SmartWaterMeterChallenge campaign (see Chapter 5).

6.2.1 General trends in water usage by schools

Table 6.2 shows the state of affluence of schools and the distributions of water usage. Accordingly, of the 156 schools studied, 85 (55%) were currently categorised as affluent, while 71 (45%) schools remained impoverished after the country's Independence in 1994. Most notably, only 12 (8%) schools have become (or were facilitated to become) affluent after apartheid, and 44 (28%) schools, which were previously affluent, have become impoverished. A reason for this could be the migration patterns within the province that have changed, causing previously affluent areas to be populated with impoverished families. Consequently, Quintile groupings, which is based on the SES of the community that surrounds the school, had not been updated according to migration patterns (Longueira, 2016). Therefore, the results could be showing that these schools, which were previously surrounded by affluent communities, were now surrounded by impoverished ones. The results further showed that effects of the pre-independence regime were still significantly evident in schools within the province. This was also seen in that 17% of the schools which were impoverished have remained so, even after new policies were introduced. Furthermore, schools that were affluent previously had now deteriorated to poverty. Conversely, the policies introduced after the advent of democracy were only successful in reversing the unfair and unjust effects of the post Independence regime in 12 of the 156 schools. Therefore, it is evident that a school's SES is central the school's water demand. This can be attributed to the fact that the affluence level of a school determines the available funding for managing and maintaining water systems. Secondly, the affluence level establishes whether or not a school is self-governing and the above results have pointed to the notion that schools that are not self-governing, which means government settles their water bills, tends to use more water in general. In light of this, a school's Quintile Grouping and Section 20/21 classification are strong indicators of the general water usage behaviour of a school.

6.2.2 Characterising the influence of school affluence on water usage

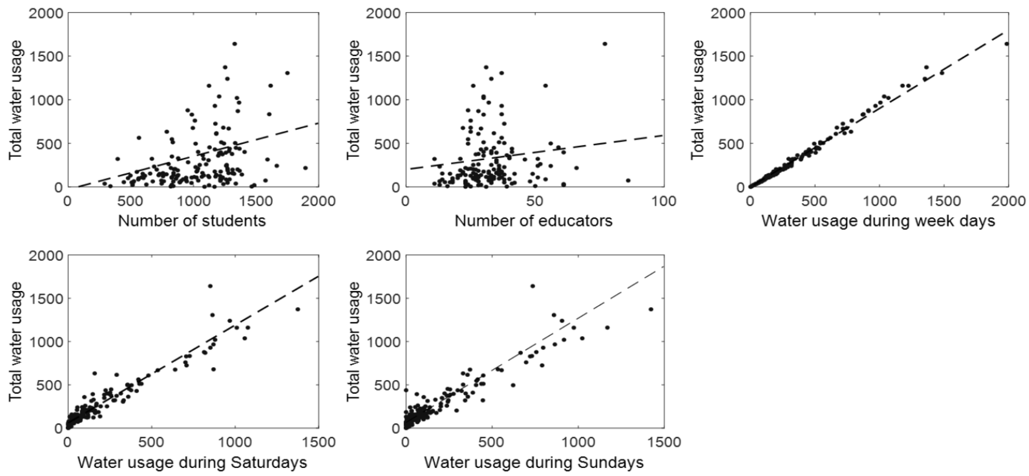

Figure 6.2: Total water usage of schools as functions of the number of consumers, usage during week days and usage during weekend. Note: all water usages are given in volume/hour.

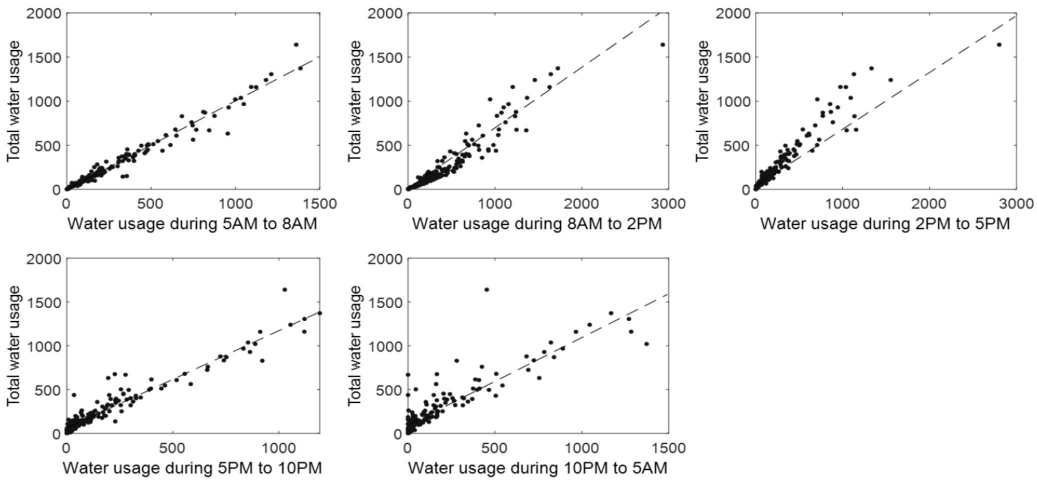

Figure 6.3: Total water usage of schools as functions of the number of the usage during different periods of time in week days. Note: all water usages are given in volume/hour.

Prior to investigating the interdependencies between water usage and influential factors using BNs modelling, it was necessary to evaluate the basic trends between water usage and each influential factor. This is because BNs considers each relationship to be linear. Accordingly, Figure 6.2 and 6.3 show the correlation between total water usage of all schools and the number of consumers, usage during week days, usage during weekend, and usage during different periods of time on week days. From this, it was evident that the total water usage showed the strongest linear relationships with the water usage based on the day/time of the week. However, there was considerable variability in the relationship between total water usage and the number of students and educators.

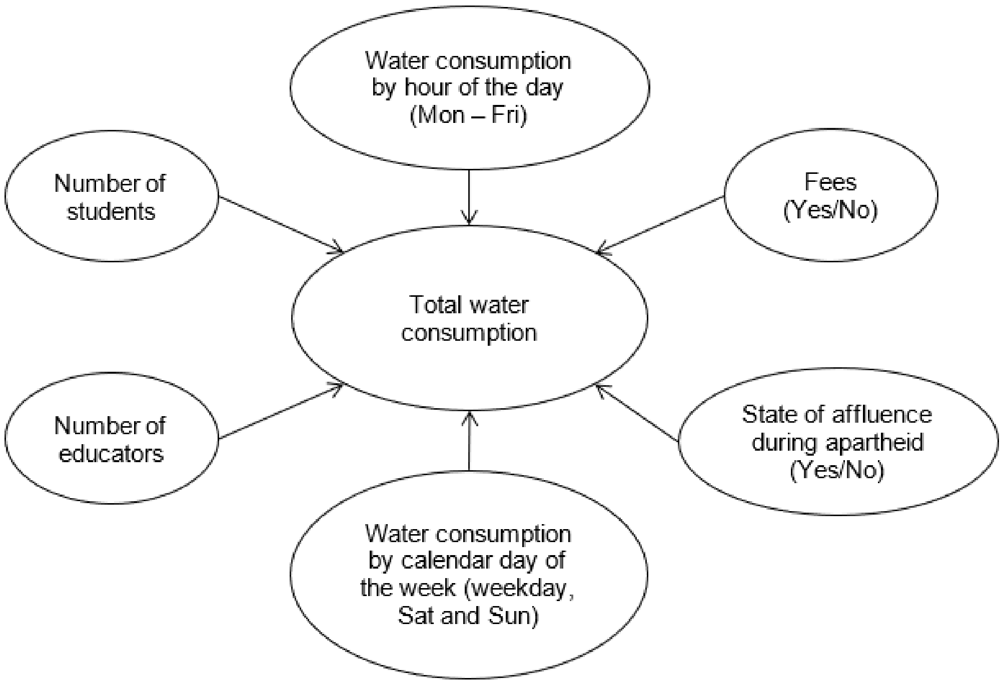

Figure 6.4: Bayesian Networks (BNs) model of water usage of schools with different socio-economic status.

Table 6.3: Estimated conditional regression coefficients(conditional Gaussian distribution, log transformed data) for total water usage (Vt) and relative influence of influential factors.

Variable	Scenario							
	1		2		3		4	
S21	No		No		Yes		Yes	
Fees	No		Yes		No		Yes	
	[b]C	[c]I (%)	[b]C	[c]I (%)	[b]C	[c]I (%)	[b]C	[c]I (%)
Edu	0.00839	0.724	0.270	10.473	-0.0582	-4.430	0.0127	1.170
St	-0.00608	-0.524	-0.350	-13.572	0.0776	5.904	0.0154	1.422
V_{0508}	-0.00580	-0.50	-0.207	-8.002	0.101	7.679	0.113	10.463
V_{0814}	0.0195	1.681	-0.0828	-3.206	-0.0838	-6.374	0.200	18.429
V_{1417}	-0.0458	-3.953	-0.103	-3.987	-0.00485	-0.369	0.0805	7.433
V_{1722}	0.0485	4.186	-0.0373	-1.445	0.0258	1.965	0.0502	4.632
V_{2205}	-0.0163	-1.402	-0.0209	-0.808	-0.00242	-0.184	-0.000251	-0.023
V_{st}	0.132	11.359	0.186	7.183	0.0247	1.879	-0.0253	-2.340
V_{su}	0.0158	1.366	-0.00467	-0.181	0.00356	0.271	0.0233	2.148
V_w	0.862	74.306	1.321	51.145	0.933	70.947	0.563	51.939

[a] Conditional density: $V_t = S21 + Fees + Edu + St + V_{0508} + V_{0814} + V_{1417} + V_{1722} + V_{2205} + V_{st} + V_{su} + V_w$

[b] probability density function of Vt, given the parent variables

[c] probability density function of Vt, given the parent variables

[d] relative influence of each factors (variable) calculated by dividing the magnitude of each conditional regression coefficient by the sum of the magnitudes of all coefficients(Note: negative sign indicates negative influence)

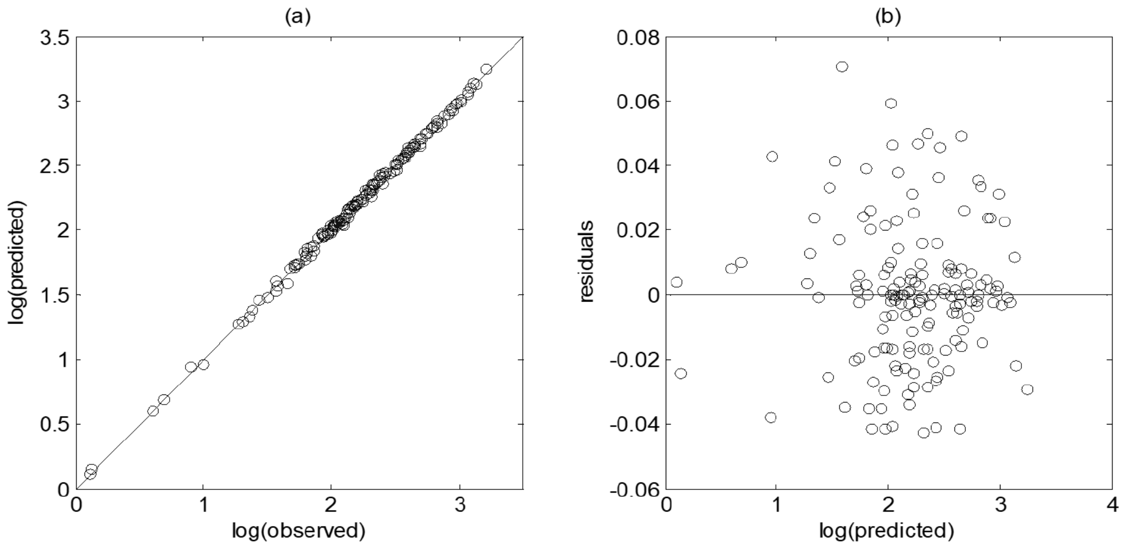

Figure 6.5: Predictive performance of the Bayesian Network (BNs) model: (a) observed vs predicted plot; (b) residuals plot.

Figure 6.4 shows the directed acyclic graph (DAG) of the proposed BNs model incorporating the factors that could influence the water usage at schools. This model was fitted with observed data (see Section 2.2) using the 'bnlearn' package in the R statistical computing platform (Scutari, 2016). Table 6.3 shows the estimated influence exerted by each factor on schools' water usage. Further, Table 6.3 provides different sets of conditional regression coefficients corresponding to different scenarios of the state of affluence of schools (see Table). Additionally, the performance of the proposed model was assessed using the leave-one-out cross validation. This resulted in a Root Mean Squared Error (RMSE) of 0.0269, and observed vs predicted plots and residuals plots (Figure 6.5), which also confirmed that the model performance was satisfactory.

As can be seen in Table 6.3, the influential factors have both positive and negative (inverse) relationships with total water usage. The positive relationships indicated that the increase in those factors would result in an increase in total water usage, while the increase in the factors that have inverse relationships would contribute to limiting the water usage. As such, in schools that belong to scenarios 1, 2 and 4, educators contributed more to the water usage than students. A plausible reason for this was that educators drank hot beverages throughout the day, resulting in dish washing and also consequent usage of the restrooms. For affluent schools, specifically those in Section 21, the SGBs were responsible for the overall allocation of governmental funding and therefore were incentivised to adopt behaviour that reduces the school's water bill. In contrast, at less affluent schools, particularly those in Section 20, the educators do not directly influence the school's budget expenditure, especially the utility bills, as these were settled by the government. Hence, there may be a general lack of awareness around water conservation and the educator's specific contribution to total water usage. Across all schools, irrespective of the state of affluence, the weekday usage (V_w) contributes the most towards total water usage, which in fact, was unsurprising. Table 6.3 further shows that for schools belonging to scenarios 1 and 2, the second highest contributing factor to total water usage would be Saturday water usage (V_{st}). These schools were in section 20 and hence were less affluent. Consequently, high water usage on Saturdays could be expected as schools allow other community members and churches to use the school grounds for additional income. On the other hand, for schools which belong to scenarios 3 and 4, V_{0508} (7.7%) and V_{0814} (18.4%), respectively were found to be the second highest contributors to total water usage. The period from 5AM to 2PM in the day was in fact, before and during the school hours, when students and educators were at the school. Further, these schools fall into the Section 21 group of schools, where educators are part of the SGBs. It follows that educators were likely to have a better awareness of water conservation as it directly impacted the budget for which they are responsible. Also seen in these scenarios was that the students either contributed equally or more to the total water usage. Therefore, this awareness was reflected in the fact that the majority of the water was used predominantly during school hours.

6.3 Summary

The primary objective of this phase of the research study was to understand how a school's affluence level affects school water usage patterns. The underlying assumption was that the policies put in place by government after the country's independence in 1994, affected water activities differently based on a school's Quintile grouping and Section 20 or 21 placement. The results presented in this chapter showed that these policies had not been successful in creating a fair and just education system post the Independence of the county. The evaluated variables, namely Section 20/21 placement and Quintile grouping, strongly suggested that these policies have not fully improved the unfair and unjust education system. This was mainly because the school teachers and SBGs (Section 20 schools) were not directly involved in the distribution of funds and hence not incentivised to ensure conservation of school funding.

Chapter 7

Randomised controlled trial

Water usage feedback from water councils to schools is an important aspect as it allows for self-monitoring. In order for schools to test and adopt new water usage habits, regular feedback from water councils is vital. Accordingly, the objective of this fourth phase was to evaluate the impact of regular and accurate water usage feedback data to schools. Therefore, the hypothesis was that given regular, accurate, understandable and timely water usage feedback information, schools will be more likely to reduce their water usage. The hypothesis was tested by quantifying the effects of two treatments using the difference-in-difference method.

This above objective was achieved by conducting a RCT (randomised controlled trial). A RCT was chosen as it has proven successful, in numerous studies, in establishing cause-and-effect relationship between a treatment and outcome(s) [1, 3, 30, 47].The trial was conducted in collaboration with a research group from the University of Cape Town. I was personally involved in contacting the schools, planning and executing the interventions, while the data analysis was done by the researchers at the University of Cape Town .

This section reports on the trial in a brief manner, while the full details can be obtained from the publications of Professor Martine Visser's research group at the University of Cape Town **??**. The methodology used is presented first, which provides the details of the participants and the interventions employed.

7.1 Methods

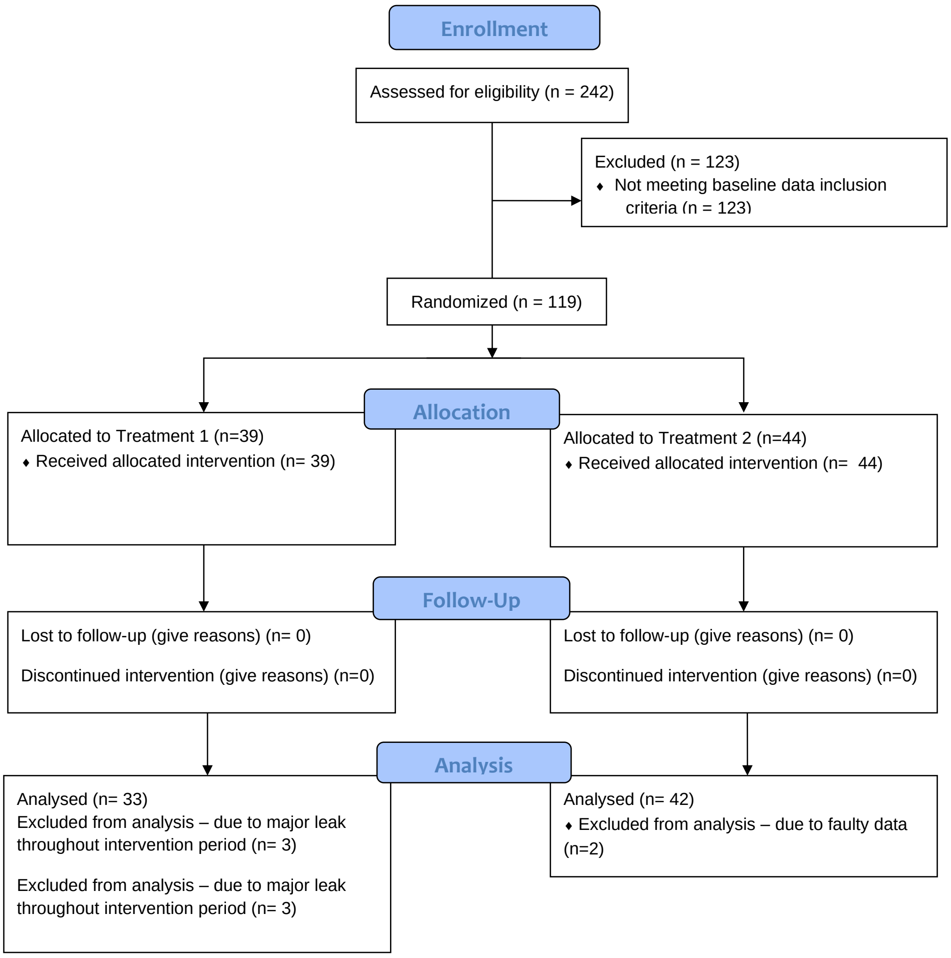

Figure 7.1: Participant flow diagram for the Ramdomised Controlled Trial.

7.1.1 Participants and interventions

A sample of 242 schools was drawn from the schools that were enrolled in the #SmartWaterMeterChallenge campaign in the Western Cape province of

South Africa at the start trial. From these only 119 schools that were eligible to participate in the study. Schools were eligible on the basis of firstly, having a water meter installed that was smart-meter-ready, on their premises. Secondly, the school had to have the maintenance aspect (M1 and M2 mentioned in Chapter 5) fully completed. Finally, the available baseline water usage data needed to be reliable. The baseline period was defined as two weeks after maintenance was fully completed. The data was deemed reliable if the data set of the school for a day was available and complete. As such, the trial population was limited to schools that met all three criteria. Refer to Figure 7.1 for the full participants flow diagram.

The eligible schools were randomly placed into three groups: Treatment 1, Treatment 2 and a Control group. The first treatment, an *Information Only* behavioural intervention, was a weekly report of the school's water usage. The report detailed the weekly water usage volume and the equivalent cost. Secondly, an hourly average day's water usage was given, highlighting the hours of high water usage. Therefore, the objective of the first treatment was to allow each school to self monitor their water usage. A sample of this *Information Only* report can be found in Appendix C, Figure C.1. The second treatment, a *Social Norm* behavioural intervention, involved a comparative element in the form of a competition. As such, the report specified the particular school's reduction from the previous week as well as their reduction over the past month. Further, water usage reduction of the top three schools were given. From this, schools in Treatment group 2 had the ability to compare their water usage reduction to that of the top three performing schools in the study. The *Social Norm* behavioural intervention can be found in Appendix C, Figure C.2. The final group was a control group, which received no treatment. The treatments were mainly sent to schools via email. It should be noted that schools in the study had significantly different levels of affluence which meant that not all schools had access to the internet or email. Therefore, text messages and posters were introduced to account for this. Figure 7.2 shows examples of the two posters send to each treatment group. Additionally, feedback information was also embedded in each email to account for those participants who might not open their pdf report attachments. Appendix C, Figure C.3 shows a sample of this, which was also send via text messages. In summary, the trial used four different mediums to send out the interventions to the participating schools; posters, pdf reports, text messages and emails.

Figure 7.2: Treatment 1 (the scoreboard) was applied to the competition group and Treatment 2 (on the right), was applied to the information feedback group. They were placed at each school where all school members could easily see them.

7.1.2 Randomisation

Notably, all the Smart Water Meter installations and maintenance projects were not executed at the same time because schools joined the #SmartWater-MeterChallenge project at different times. This lead to schools having different baseline dates and as such, schools entered the trial on different dates and in different waves, as in refer to Table 7.1. During the baseline period, schools were classified according to their average weekly water usage as low, medium or high users. Thereafter, each school was assigned a random number and these were ranked and used for the randomisation process. Consequently, schools were randomly allocated to the three groups, with a total of 36, 39 and 44 schools in the Control, Treatment 1 and 2 group respectively. Groups were then balanced on the basis of the school size, number of pupils and educators and location of the school. These variables were obtained from the Western Cape Education Department database. A snippet of this database can be found in Appendix B, Figure B.2. The random assignment of the schools to the groups was based on their average weekly water usage in their baseline period. The RCT included 119 schools and the study period was from February to October of 2018.

Table 7.1: Waves and schools per treatment arm

Wave	Start of Baseline	Start of Treatment	Control	Treatment 1	Treatment 2
1	12 February 2018	15 April 2018	12	13	15
2	16 April 2018	3 June 2018	18	18	20
3	21 May 2018	22 July 2018	6	8	9
			36	39	44

7.2 Results and analysis

During the balance tests of the randomisation process, it was imperative to ensure that high water using schools were evenly distributed across all the three treatment groups. However, the balance tests, could not account for unusually high water usage, which is related to events such as pipe bursts or major leakages. As such, several schools were dropped before the analysis process. Subsequently, these schools were omitted from the analysis due to three main reasons: having a median water usage volume grater or equal to 300l/30min; lack of observations prior to the application of treatments as well as having erratic usage over the entire baseline period. In total, 14 schools were omitted from the analysis phase. Accordingly, the schools were as follows: 6, 6 and 2 schools were dropped from the Control, Treatment 1 and 2 respectively.

Table 7.2 shows the resulting effects of the two treatments on the participating schools' water usage. The results show that overall, Treatment 1 lead to a higher percentage change in water usage compared to Treatment 2. The first treatment resulted in a reduction of 23.96%, which was 2.04% more than that of the second treatment. Subsequently, this was a daily volume reduction of 163.20 litres for all hours of all the days considered. Further, the highest influence of Treatment 1 was seen in night hours water usage, which was reduced by 57.78%. It should however be noted that this high reduction could also be attributed to the water saving efforts from the individual schools due to the severity of the water shortages at the time of the study. The results point to an improvement in the general management and maintenance of schools' water systems.

On the other hand, Treatment 2 showed superiority in affecting daily water usage habits during school hours compared to Treatment 1. Hence, for school hours, the second treatment performed better than the first. This highlighted the benefit of self-monitoring in changing everyday water usage behaviour.

Noticeably, both treatments' highest effects were seen in night hour usage. This was unsurprising for Treatment 1 as the maintenance study, seen in Chapter 5, underlined that water wastages and leakages are most discernible during early morning hours between 01h00 and 04h00. This is the time period when schools are expected to have little or no water activities. Interestingly, the highest daily water volume savings were not seen during night, but during school hours. Therefore, although night hours reported the highest percentage reduction, school hours had the highest daily water volume savings. This was possibly because the maintenance project had already addressed most of the issues that lead to night time wastages.

Moreover, also seen in Table 7.2, the savings per learner were similar to daily savings. For example, overall, the first treatment had higher reductions per learner and both treatments had their highest percentage changes during night time hours.

These results clearly suggests that the *Information Only* intervention had a higher effect on the schools' overall water system management and maintenance. On the other hand, the *Social Norm* intervention affected daily water usage behaviour. These results were consistent with that those observed in previous research, where the social comparison interventions had a lower impact on water usage reduction than information feedback interventions [1, 43]. Conversely, a study on up-scale households had contradicting results and the social comparison treatment had the least influence on water usage reduction compared to the information feedback and persona identity interventions [44]. Therefore, it was evident that behavioural interventions have the ability to affect water usage reductions and they have similar effects in the non-residential as in the residential sector of urban water demand.

7.3 Summary

The aim of this chapter was to test the efficacy of two behavioural interventions using a RCT. From the results, the two interventions were showed significant success in changing water usage behaviour. Interestingly, the *Information Only* treatment, which targeted self-monitoring, affected night time water usage more than the *Social Norm* behavioural intervention. The latter was effective in reducing water usage during school hours. These findings were consistent with what previous researchers found using behavioural interventions on residential water demand. Therefore, it was clear information feedback interventions are beneficial for improving the general management and maintenance of school water systems and managing the general demand.

Table 7.2: Difference-in-difference regressions

	All hours	All hours	School hours	Night hours
	All Days	All Days	School Days	All Days
	00:00-24:00	00:00-24:00	07:00-14:00	00:00-24:00
Single Spike data issue	SS obs	SS obs	SS obs	SS obs
High erratic consumption		HE drop	HE drop	HE drop
		med_vol>=250	**med_vol>=250**	**med_vol>=250**
Dependent variable: Water usage (L/30min)				
1,treatment1#1,Post	-24.78	-26,01**	-22,79*	-30,90**
	(15.63)	(12.98)	(13.14)	(12.94)
1,treatment2#1,Post	-21,38**	-15,15**	-25,58***	-11.39
	(10.31)	(7.440)	(8.527)	(8.371)
Observations	739,723	679,649	124,964	99,120
R-squared	0.372	0.378	0.274	0.391
Number of School_ID	112	105	105	105
Baseline mean vol	119.8	106.6	255.7	53.48
% Change T1	-20.68%	-24.40%	-8.91%	-57.78%
% Change T2	-17.85%	-14.21%	-10.00%	-21.30%
Litres per day saved T1	1189.44	1248.48	319.06	247.2
Litres per day saved T2	1026.24	727.2	358.12	91.12
Dependent variable: Water usage per learner (L/30min)				
1,treatment1#1,Post	-0,0266*	-0,0290**	-0,0253*	-0,0339***
	(0.0140)	(0.0125)	(0.0138)	(0.0114)
1,treatment2#1,Post	-0,0243***	-0,0200***	-0,0285***	-0,0158**
	(0.00867)	(0.00688)	(0.00961)	(0.00673)
Observations	739,723	679,649	124,964	99,120
R-squared	0.360	0.368	0.241	0.393
Number of School_ID	112	105	105	105
Baseline mean vol	0.111	0.101	0.246	0.0505
% Change T1	-23.96%	-28.71%	-10.28%	-67.13%
% Change T2	-21.89%	-19.80%	-11.59%	-31.29%

Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Control variables included: week, month, p_holiday, s_holiday, afterhours, weekend, leak, night_flow Single Spike data issue: Schools with a one-time dramatic spike in usage (due to a leak). Can either drop just the observations over the period (SS observation drop) of the spike or can drop the entire school (SS variable drop). High erratic usage: Schools with high usage. There are 6 schools that have high consumption that fluctates.

Chapter 8

Conclusions and recommendations

8.1 Conclusions

Educational institutions are important contributors to urban water usage, hence their water demand management is vital to reducing urban water demand. However, these institutions are rarely the focus of water conservation campaigns, especially in developing countries such as South Africa. With freshwater sources becoming more scarce as a result of over population, urbanisation and pollution, managing freshwater demand has becomes increasingly crucial. Schools in developing countries are often under financial constraints as governments in these countries are not always equipped to cater for the schools' financial needs. Moreover, when natural disasters like droughts hit these countries, schools experience additional financial pressures.

During the Western Cape provincial drought for example, water rates were increased, which further intensified the financial struggles of schools in the province. This lead to higher water bills and therefore extra financial loss. As such, this research study proposed solutions that used real-time water usage data in order to assist schools in reducing their water usage and the related expenses. These solutions first sought to understand and classify school water usage behaviour, using a pilot study. Secondly, they targeted both daily and night time usage reduction using behavioural interventions and the MNF metric respectively. Therefore, this give schools an opportunity to reallocate these finances to their primary objective, namely academic excellence.

Initially, a pilot study was conducted at a primary school in Stellenbosch, namely Stellenbosch Primary School, where several hypotheses were tested on a small scale. These were later developed into the main objectives of this research study. Hence several lessons that were learned from the pilot study allowed for a comprehensive approach to the objectives of the research study. Firstly, a lack of effective maintenance plans were found to be the main contributor of unusually high water wastage, especially during night time hours. Secondly, there was a delay in feedback of water usage from water utility companies to schools, due to a lack of accurate water usage data. Furthermore, there was a clear distinction between affluent and impoverished schools, particularly in night time water usage, a time commonly associated to leakages.

What followed was an investigation of the influence of socio-economic variables on the water usage demand of the non-residential sector using a case of school water usage in South Africa. The research outcomes of this phase highlighted flaws in the current governmental education funding policies. The two policies, the Quintile Grouping and the NNSSF, were found to be outdated and hence inefficient in eradicating the effects of the pre-independence regime. The education system was found to be unjust and unfair during this regime.

Further, we found that the schools' socio-economic status greatly affected water usage patterns. The schools with higher socio-economic status displayed a higher awareness of water usage conservation than schools that have low socio-economic status. This was largely due to the school governing boards having direct influence on the school fund expenditure, for the more affluent schools. This, however, was not the case for impoverished schools, for which school materials and utility bills are settled by the government.

The results indicated that it would be beneficial to both policy makers and schools, to configure education funding and management policies that cater to schools' needs based on their SESs. Additionally, restructuring and regularly updating the Quintile grouping and socio-economic placements of each school would promote policies that cater for schools according to their SESs more effectively. For example, schools with lower SESs, where SGBS are not directly responsible for paying for school materials and utility bills, need different incentive programs with regards to encouraging resource conservation. Hence, the country would benefit greatly from investing in research that further explores the effects of policies on the overall performance of schools in the country.

Regarding the plumbing maintenance project, the main objective was to explore affordable and easily implementable fixes that could be implemented at schools within the Western Cape in order to reduce water leakages. These leakages were defined between the hours of 01h00 and 04h00 and the MNF metric was used to quantify these reductions. The water reduction results made it abundantly clear that doing even little maintenance makes financial sense, and that it should be done sooner rather than later. The project further showed that investing in the upkeep of water systems could hugely reduce expenses, leaving money free to be used for the schools' main purpose, educating children excellently. Nevertheless, without additional financial support, the overall maintenance in schools will not improve as much and as urgently as it needs to. Therefore, it is imperative that the South African government find new ways to assist schools financially, such as encouraging improved maintenance projects.

In an effort to further reduce water usage in school, a RCT was conducted at 119 schools that employed two behavioural interventions, a *Information Only* and a *Social Norm* intervention. The results showed that behavioural interventions are effective in reducing school water demand. Specifically, the *Information Only* intervention was able to substantially improve the overall management and maintenance of the schools' water systems. Conversely the *Social Norm* intervention contributed significantly to water reduction during school hours.

This research was one of the first few to study school water demand in-depth. It was evident from the results that school water demand research is urgent and lacking. Although this study achieved its objectives, there remains a significant amount of work to be done on the topic of school water demand. This study was able to collect accurate and reliable data, that can be used by future researchers to contribute to the topic. The obtained results can be used to provide a valuable point of comparison for future studies on school water usage. As such, the findings of this study contribute considerably to the growing body of literature on school water demand in South African schools.

Excellence in the South African education is unattainable without excellence in the general management and maintenance of school infrastructures.

8.2 Recommendations

The recommendations for future researchers should primarily be centered around: (i) investing time and resources in collecting additional good quality school water demand data, (ii) conducting in-depth analysis of schools water infrastructure and the related management and maintenance plans that are already in place, (iii) further in-depth analysis on school funding - in the case of South Africa, focusing on the two policies discussed in this paper, (iv) conducting further studies that employ behaviour intervention in order to change school water cultures. Further, statistical techniques can be employed on school historic data in order to model and predict the demand of school water usage. As such7, these models can be used to establish "normal" water usage patterns and allow for detection of "abnormal" usage such as leakages.

Appendices

Appendix A

School Maintenance Instructions

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School maintenance instructions:

Checklist of problem areas:

1. All bathrooms (Pupils and staff)
    a. Toilet cisterns
    b. Urinals
    c. Taps
2. Kitchen
    a. Taps
    b. Boiler
3. Geyser
4. Staff room
    a. Taps
    b. Boiler
5. Outside taps
6. Stop valve
    a. Confirm that stop-valve completely shuts off water supply

Pre-approved maintenance work:

1. Running toilet cisterns
2. Broken taps
3. Obvious leaks

Up to R 5 000 may be spent on these pre-approved items.

Scope of work to be quoted for:

1. Urinals with continues flushing to be replaced with push button flushing
2. Faulty mains stop valve to be replace or new one installed inline.
3. Obvious sources of water wastage.

Office number: 021 201 6939 Whatsapp: 083 339 1298

Figure A.1: Each plumbing company employed for the #SmartWaterMeter-Challenge was given a check list and it was up to the plumber to inpect the school and then peform maitenance that was in line with the fixes defined in this list.

Appendix B

Western Cape Province School Data Set

Serial Number	Meter Reading Type	Consumption value05.2017	Consumption value06.2017	Consumption value07.2017	Consumption value08.2017	Consumption value09.2017	Consumption value10.2017
16712720	Automatic estimation - SAP	78052	0				99321
448176	Meter reading by utility -	195	291	375	186	490	83617
103634	Automatic estimation -			41718			41914
1402	Automatic estimation -	38649		60			38796
93416180	Meter reading by utility -					8	36310
15749327	Meter reading by utility -						10263
D12UH015796	Automatic estimation -						10065
115861	Meter reading by utility -	92	1			49	9999
16712689	Automatic estimation -	97282		1948	90749	87243	6996
C-KUJ750	Automatic estimation -	14	17	15	15	17	4326
7ME68148270	Meter reading by utility -			53335	236	1142	3863
C-JJK5634	Meter reading by utility -					172	3312
120F05081	Meter reading by utility -						2994
220372	Automatic estimation -	2510	2215	2289	2141	2511	2068
701862	Meter reading by utility -			16956	1	0	1988
90101265	Meter reading by utility -	1778	1428	1443	1029	1264	1952
D17A1300072	Meter reading by utility -					2000025	1637
14805755	Automatic estimation -	5	30	1687	1800	1687	1631
16713053	Automatic estimation -	3	491	1566	1419	1589	1589
15782768	Automatic estimation -						1578

Figure B.1: A Sample of water usage values obtained from the City of Cape Town. The serial numbe is a uinique identifier for each school. This data set shows the meter reading type as well as consumption values for May to October of 2017.

School Name	Meter Reading Type	Consumption value05.2017	Consumption value06.2017	Consumption value07.2017	Consumption value08.2017	Consumption value09.2017	Consumption value10.2017	Monthly Consumption_Average	Meter Reading05.2017	Meter Reading06.2017	Meter Reading07.2017	Meter Reading08.2017	Meter Reading09.2017	Meter Reading10.2017
School 0	Meter reading by utility - SAP					2000025	1637	1000831					93361	1662
School 1	Automatic estimation - SAP	1307	90	999591			1076	250516	5836	5792	0			1476
School 2	Automatic estimation - SAP	985705	24	411		593	840	197515	0	11960	58242		58835	59675
School 3	Meter reading by utility - SAP	424	458	228	221	591	287	368	11225	11683	11911	12132	12723	13010
School 4	Automatic estimation - SAP	77	70	75		140	75	87	7457	7527	7602		7742	7817
School 5	Automatic estimation - SAP	95442			97323			96383	0			0		

Figure B.2: A Sample of school water usage data fro mthe Western Cape Education Department (WCED). This sample was chosen as it is a good representation of the full dataset (which incudes 270 schools).The sample shows the different methods used for meter readings and shows water usage data and meter readings from May to September of 2017

Appendix C

RCT Competition Report example

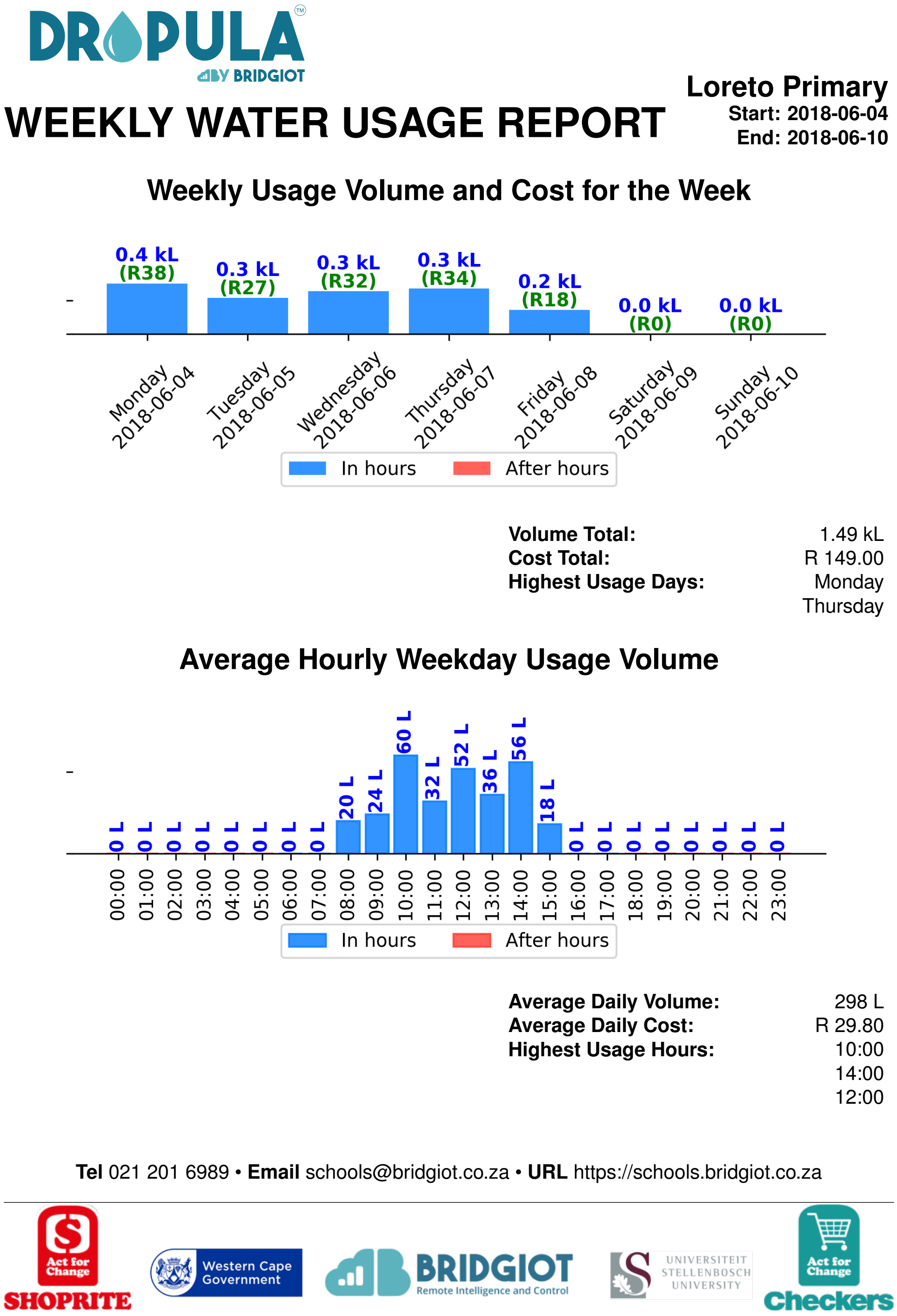

Figure C.1: A Sample of the "Information Feedback" intervention in pdf form

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COMPETITION REPORT

Loreto Primary
Start: 2018-06-04
End: 2018-06-10

Water Savers Score Board:

Your school's water usage change last week:[1]

Loreto Primary	20.5% increase

The top three schools' water usage change last week:[2]

School 1	85.0% decrease
School 2	39.8% decrease
School 3	27.7% decrease

Your schools' water usage change in the last month:

Two weeks ago	--
Three weeks ago	--
Four weeks ago	--

Schools in Competition:

Cravenby Sekondêr, Eersterivier Sekondêr, Forest Heights Primary, Grove Primary, Kalkfontein Primary, Kasselsvlei Primary, Kenridge Primary, Laerskool Mikro, Laerskool Webner Straat, Lantana Primary, Loreto Primary, Matthew Goniwe Memorial High, Nkazimulo Primary, Nomzamo High, Nooitgedacht Primary, Ravensmead Sekondêr, Rietenbosch Primêre, Robinvale High, Stellenberg High, Welcome Primary

[1] Water Savings Performance is calculated as a percentage reduction from baseline consumption before the competition started. A value of '–' indicates insufficient data was available to reliably calculate reduction.

[2] The top three schools over the entire competition will receive an award and be featured in a media release at the end of the competition.

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Figure C.2: A Sample of the "Social Comparison" intervention in pdf form

Dear LANTANA PRIMARY

WATER USAGE REPORT FOR WEEK 2018-06-04 to 2018-06-11

Total Water used: 23.31 kL
Total Cost of Water used: R2331.00
Average usage per day: 4632.00 L
Highest usage days: Monday,Tuesday

WATER SAVINGS COMPETITION

Your school's water savings from the start of the competition:
78.1% increase
Top three school's water savings:
School 1: 85.0% decrease
School 2: 39.8% decrease
School 3: 27.7% decrease

#SmartWaterMeterChallenge

Kind Regards
BRIDGIOT
021 201 6939
info@bridgiot.co.za

Figure C.3: Example of the information send out via email and text message. The first treatment arm only received the top half information, while the second arm received both the top and bottom

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