Roof Harvested Rainwater in the Adelaide Region, South Australia

by

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SUMMARY

In the context of this thesis, rainwater is defined as any rain that falls on building rooftops and is collected and stored for future use. Rainwater differs from stormwater, which is water that has runoff from land surfaces into waterways and includes non-harvested roof rainwater. Rainwater is part of a complex hydrological system which acts like a filtration system removing impurities. However, during collection and storage, rainwater can become contaminated from the catchment areas (contaminants on roofs and gutters) and the associated plumbing systems (pipes and taps, etc., leading to and from the rainwater tanks). This study investigated the level of contamination in rainwater that is being preferentially used as primary source of drinking water by many households in the Adelaide region. Sampling corridors were selected across the metropolitan area based primarily on land use. Samples collected from rainwater tanks in the sampling corridors were tested for microorganisms and trace metals to assess against the Australian Drinking Water Guidelines. The capacity of filters to remove microorganisms and metals from rainwater was also assessed. Finally, householders' motives to drink potentially contaminated rainwater when they have access to clean municipal water supplied by water utilities was investigated.

Irrespective of rainwater's clean appearance, indicator microorganisms and metals were detected in rainwater samples collected in the Adelaide region above permissible levels in drinking water. Lead was found to be the predominant metal found in rainwater samples at concentrations above the drinking water guidelines. In 47 out of a total 53 tanks investigated, lead was found above the NHMRC threshold of 0.01 ppm for drinking water. Similarly, 28/53 tanks investigated were found to contain *Escherichia coli*. *E. coli* should not be detected in a 100 mL sample of any water intended for drinking. The level of *E. coli* and lead in rainwater samples collected in the Adelaide region was consistent with the results of other studies carried out on rainwater in urban and rural Australia.

A relationship was found between rainwater harvesting environment (hanging tree canopies and TV roof mounted antennas), and *E. coli* presence in stored rainwater. The study found similar trends in microorganism numbers in rainwater in summer and winter months, and a decline in microorganisms after a prolonged dry period. The tank materials, water pH, the presence of first flush diverters, and the bottom tank sludge drainage were found to have no relationship with rainwater microbial content. However, a relationship was found between building roof structure material and lead concentration in stored rainwater. In tanks that had filters attached, filtered and unfiltered samples showed that filters were not successfully removing *E. coli*, nor trace metals such as lead and zinc, although a slight reduction of metals was observed in filtered water. In contrast, an experimental water filtration unit installed in the laboratory removed *E. coli* from contaminated rainwater samples to 0 MPN/100 mL, the standard required of drinking water, but the filter became blocked at less than half the filter cartridge's advertised lifespan. It was evident from this study that filters' capacity to remove metals from rainwater was low. The difference between the laboratory study and field samples could be due to improper maintenance or installation of filters or recontamination of the faucet after filtration.

This study also investigated the drivers that cause an important fraction of the public to preferentially drink potentially contaminated rainwater when they have clean municipal water supplied. It was found that taste was a primary determinant,

and parameters like the addition of fluoride and/or chlorine to municipal water were central in people's preference for rainwater over municipal water, even when they were aware it may contain contaminants.

There have been previous epidemiological studies that have indicated that drinking rainwater containing *E. coli* is not likely to cause health effects. However, there is a need for future epidemiological studies to assess the health effects of drinking rainwater that contains elevated levels of lead. Other future studies arising from this work, include the assessment of different filters' capacity to remove metals in rainwater to acceptable drinking water standards, and the assessment of blood lead of householders who primarily drink rainwater with elevated lead concentrations to determine whether the levels in rainwater consumed are of biological significance.

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STATEMENT OF AUTHENTICITY

I certify that this thesis does not incorporate without acknowledgement and material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Emmanuel C Chubaka

STATEMENT OF CO-AUTHORSHIP

The following people have contributed to the publication of the work undertaken as part of this thesis. The co-authors are listed in the order that the co-authored publications appear in the thesis.

Assoc. Prof. John Edwards
Dr Harriet Whiley
Dr Kirstin Ross

All above listed contributions equated to no more that 25% of the work that was required for publication of research manuscripts.

Emmanuel Chubaka
Dr Harriet Whiley
Dr Paul Arbon & Dr Malinda Steenkamp

All above listed contribution equated to no more that 25% of the work that was required for the publication of research manuscript listed in the Appendix.

Emmanuel C Chubaka

PUBLICATIONS

Chubaka, C.E., Whiley, H., Edwards, J.W. and Ross, K.E.

A review of roof harvested rainwater in Australia (2018)

Journal of Environmental and Public Health.

Q2 rated Journal, impact factor of 2.145

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Chubaka, C.E., Whiley, H., Edwards, J.W. and Ross, K.E., 2018.

Microbiological Values of Rainwater Harvested in Adelaide (2018)

Pathogens, *7*(1), p.21. Q1 rated journal, impact factor of 2.93

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Lead, Zinc, Copper, and Cadmium Content of Water from South Australian Rainwater Tanks (2018). *International Journal of Environmental Research and Public Health*, *15*(7). Q2 rated journal, impact factor of 2.608

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WIT Transactions on Ecology and the Environment, *216*, pp.299-311.

https://doi.org/10.2495/WS170291.

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Journal of Emergency Management (Weston, Mass.), *16*(3), pp.183-190.

Q2 rated Journal, impact factor of 0.29, https://doi.org/10.5055/jem.2018.0367

ACRONYMS AND ABBREVIATIONS USED IN THE THESIS

$	Dollar
%	Percentage
<	Less than
>	Greater than
≤	Less than or equal to
≥	Greater than or equal to
®	Registered mark
°C	Degree Celsius
µg/dL	Micrograms of lead per decilitre of blood
µg/L	Micrograms per litre
µm	Micrometre
AAS	Atomic absorption spectrophotometer
ABC	Australian Broadcasting Corporation
ABS	Australian Bureau of Statistics
Abs	Absorbance
ACT	Australian Capital Territory
ACT-PLA	ACT Planning and Land Authority
ADP	Adelaide desalination plant
ADWG	Australian drinking water guideline
AGR TPS	Australian Government Research Training Program Scholarship
AMU	Atomic mass unit
ANZECC	Australian and New Zealand Environment and Conservation Council
Apr	April
ARID	Australian Rainwater Industry Development

ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AS/NZS	Australian/New Zealand Standard
Assoc. Prof.	Associate Professor
Aug	August
BASIX	Building Sustainability Index
BCA	Building Codes of Australia
BDCM	Bromodichloromethane
BHP	Broken Hill Propriety Company Ltd
C_2H_2	Acetylene
CA	California
$[Ca\ (ClO_2)]$	Calcium hypochlorite
$CHBr_3$	Bromoform
CHBr 2Cl	Dibromochloromethane
$CHCl_2Br$	Bromodichloromethane
$CHCl_3$	Chloroform
CAP	Car Assembly Plant
CCA	Copper chrome arsenate
CFU/mL	Colony-forming-unit/ millilitre
CI	Confidence interval
CL	Confidence level
ClO_2	Chlorine dioxide
Co	Company
CO_2	Carbon dioxide
CoAG	Council of Australian Governments
CommSec	Commonwealth Securities
Conc	Concentration
Cr III or Cr^3	Trivalent chromium

Cr VI or Cr^6	Hexavalent chromium
$C_6H_8O_7$	Citric acid
Cu	Copper
CUPDR	Committee on Uniformity of Plumbing and Drainage Regulations in NSW
DAEC	Diffusely adherent *Escherichia coli*
DBCM	Dibromochloromethane
DCC	Australian Government, Department of Climate Change and Energy Efficiency
Dec	December
Dr	Doctor
E	East
E	Expected value
E. coli	*Escherichia coli*
EAEC	Enteroaggregative *Escherichia coli*
EIEC	Enteroinvasive *Escherichia coli*
EPA	Australian Environmental Protection Authority
US EPA	United States Environmental Protection Agency
EPEC	Enteropathogenic *Escherichia coli*
Eqn	Equation
ESRI	Environmental Systems Research Institute
ETEC	Enterotoxigenic *Escherichia coli*
Exp	experiment
F	Fluoride
FSANZ	Food Standards Australia New Zealand
FAO	Food and Agriculture Organisation
Feb	February
GBC	Grey-Bartlett-Charlton

GIS	Geographical Information System
GL	Gigalitre
GL 2005	Guideline 2005
GMH	General Motors Holden
GPS	Global Positioning System
h	Hour
H_2SiF_2	Aqueous fluorosilicate acid
HIV	Human immunodeficiency virus
HMW	High molecular weight
HNO_3	Nitric acid
HRW	Harvestable roof water
IARC	International Agency for Research on Cancer
IBM	International Business Machines
IBM	International Business Machine
ID	Identification
i.e	That is to say
IJERPH	International Journal of Environmental Research and Public Health
IL	Illinois
Inc	Incorporated
Int'l	International
IQ	Intellectual quotient
Jan	January
Jul	July
Jun	June
KBW	Kilburn-Blair Athol-Wingfield
kL	Kilolitre
KCl	Potassium chloride

L/S	Linear least through zero
L/S	Litre per second
LMW	Low molecular weight
Ltd	Limited
m^2	Square metre
MAC	Mycobacterium avium Complex
Mar	March
May	May
MDPI	Multidisciplinary Digital Publishing Institute
mg/L	Milligrams per litre
mL	Millilitre
mm	Millimetre
$MnSiO_3$	Manganese silicate
MPMSAA	Master Plumbers and Mechanical Services Association of Australia
MPN	Most Probable Number
MSDS	Material Safety Data Sheet
N/A	Not applicable
N°	Number
Na_2SiF_6	Sodium fluorosilicate
NaCl	Chlorine
NaF	Sodium fluoride or inorganic fluoride
NaOCl	Sodium hypochlorite
NATA	National Association of Testing Authorities, Australia
NDA	Data not available
NHMRC	National Health and Medical Research council
Nov	November
NHO_3	Nitric acid

NOAA	National Oceanic and Atmospheric Administration
NRM	Natural Resource Management
NSECHR	National Statement on Ethical Conduct in Human Research
NSS	National Statistical Service
NSW	New South Wales
NT	Northern Territory
NTLG	Northern Territory Land Group
NWCW	National Water Commission Waterlines
NWI	National Water Initiative
NY	New York
O	Observed value
Oct	October
PAHs	Polycyclic aromatic hydrocarbons
PAWPP	Port Adelaide Waterfront Redevelopment Project
PFAS	Per-and polyfluoroalkyl substances
pH	Potential of hydrogen
PhD	Doctor of Philosophy
ppm	Parts per million
PQL	Practical Quantitation Limit
Pty	Proprietary Limited
PubMed	Public/Publisher Medline
QBS	Queensland Building Sustainability
QDC MP 4-2	Queensland Development Code, Mandatory Part 4-2
QLD	Queensland
R^2	Linear regression
RAAF	Royal Australian Air Force
RapidPlas	Rapid Plastic

RC	Runoff coefficient
RD	Rainfall depth
RFDS	Royal Flying Doctor Service
RHRW	Roof harvested rainwater
ROM	Reverse osmosis membrane
rpm	Rotation per minute
RSD	Relative standard deviation
RSE	Relative standard error
S	South
SA	South Australia
SA Water	South Australia Water Corporation
SBREC	Social and Behavioural Research Ethics Committee
SEIFA	Socio-economic indexes for areas
Sep	September
spp/L	Species per litre
SPSS	Statistical Package for the Social Sciences
TAS	Tasmania
Tel	Telephone
TEQ	Toxic Equivalent Quantity
THMs	Trihalomethanes
TV	Television
TWI	Tolerable weekly intake
™	Trademark
UDI	Urban Development Industry
UL FLI	Unimutual Limited, Flinders University
US	United States of America
USA	United States of America

UV	Ultraviolet spectrophotometer
v/v	Volume of solute/volume of solution x 100
VIC	Victoria
VTEC	Verocytotoxigenic *Escherichia coli*
v/w	Volume/weight percentage concentration
WA	Western Australia
WC	Washington, District of Columbia
WD	Water drinker
WFI	Water for Future Initiative
WIT Press	Wessex Institute of Technology Press
WHO	World Health Organisation
X^2	Chi-square
Zincalume	Steel that is coated with a mix of zinc and aluminium

This thesis is based on published manuscripts, therefore some repetition between chapters occurs

CHAPTER 1. GENERAL INTRODUCTION

1.1. Rainwater and stormwater

Rainwater is defined as rain that falls onto a building's roof and is collected and stored for future use (Woodcock and Shackel, 2013). Rain comes from the continuing passage of water through different physical stages of the hydrological cycle, which makes it clean (Hubbart and Pidwirny, 2011). This differs from stormwater, which is rain that has run off from land surfaces into waterways and groundwater (Perth Region NRM, 2016). All unharvested rooftop rainwater ends up in drains, becoming stormwater. Rainwater is considered as a naturally occurring public good (Lawn, 2000) and its consumption is governed by the law of non-rivalry and non-excludability (Malkin and Wildavsky, 1991). As such, no one can prevent another from the benefit associated with rainwater harvest.

1.2. Rainwater harvesting

In the building and plumbing industry, rainwater harvesting systems refer to building rooftops (also called catchment areas), gutters and downpipes, storage facilities, and water redistribution systems (Ling and Benham, 2014). Screens, first-flush diverters and filters are additional devices included in rainwater harvesting systems, usually to improve rainwater standard and suitability for potable use. On catchment areas, commonly used roofing materials include corrugated galvanised steel, and terracotta or concrete tiles. In Australia, standards for roofing materials manufacture and design are based on the Australian/New Zealand (AS/NZS) Standards (SaiGlobal, 2011). Standard AS/NZS 1562.1-1992 applies to galvanised roof material design and installation, and Standard AS/NZS 2049-2002 is for terracotta and concrete roof tiles (SaiGlobal, 2011).

A range of tanks are used to store rainwater and include a number of installation requirements (Figure 1). The most popular tank material is corrugated galvanised steel, which is a cost effective material and is easier to install than concrete and fibreglass tanks (enHealth, 2010). Corrugated galvanised tanks are considered iconic to the Australian suburban landscape (Block, 2011), however high grade polyethylene tanks are becoming more popular across Australia (enHealth, 2010). Concrete and fibreglass tanks are also available. In many cases, concrete tanks are used for underground storage. Fibreglass tanks, which are stronger than corrugated and concrete tanks, are less popular due to their high engineering cost (enHealth, 2010). The volume of the rainwater that can be annually harvested depends on the catchment size area, and the area's annual mean rainfall.

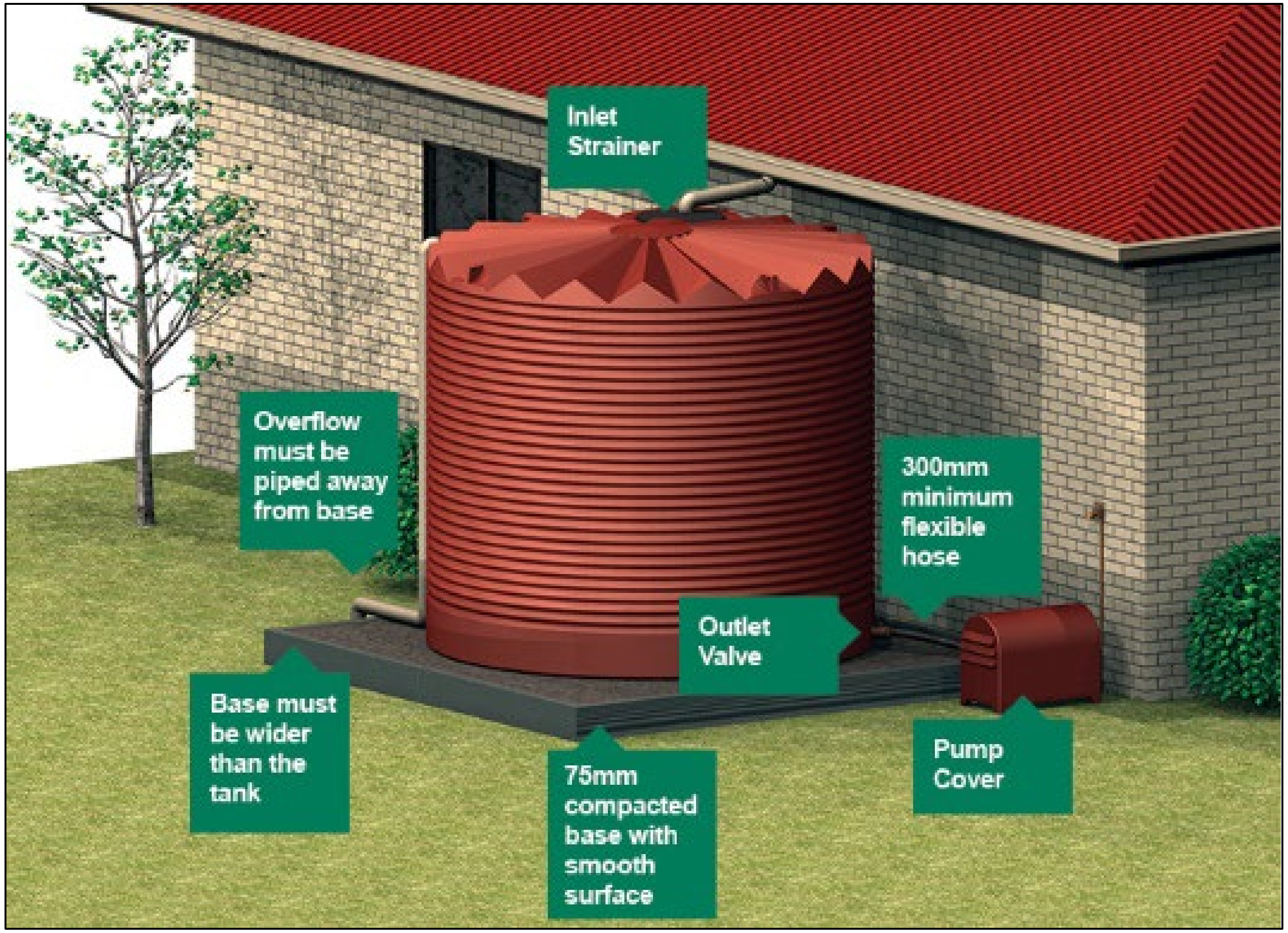

Figure 1. Polyethylene above ground rainwater harvesting system.

Source: RapidPlas Pty Ltd (2018).

A small proportion of the volume of harvestable rainfall is lost through first flush diverters, and by absorption by dust and microflora on poorly maintained catchments (Doyle, 2008). Water loss does not generally include tank overflow. A rough estimate of harvestable rainwater that incorporates water loss can be calculate using a runoff coefficient of 0.9 (Government of South Australia, 2010a). This can be calculated using the following function:

$$HRW = (CA \times RD) \times RC$$

Where: HRW = harvestable rainwater in L or kL,
CA = the catchment area in m^2
RD = rainfall depth in mm, and
RC = runoff coefficient

A review of literature on rainwater harvesting in Australia is presented in Section 1.3 of this chapter, which is a published journal article. This section discusses water sustainability for Australia, the regulatory framework around rainwater harvesting, Australian federal government incentives to help households purchase and install rainwater harvesting systems, the quality of rainwater that is being harvested in different locations across Australia, and the health risks linked to the consumption of potentially contaminated rainwater. Incidents of illness and disease outbreak because of drinking rainwater are also discussed. The paper did not cover all aspects related to rainwater harvesting and use in the Adelaide region. These aspects are presented in Section 1.4 (below) and Chapters 3, 4 and 5.

The rationale to conduct this study was that in the Adelaide region, data on rainwater contamination by microorganisms and trace metals were limited, and the drivers to giving preference to rainwater by a fraction of the public were poorly understood, particularly in a region where clean municipal water is supplied by water utilities.

1.3. Aims and objectives

The work presented in this thesis investigated rainwater in the Adelaide and greater Adelaide regions. This included an examination of the reasons why a fraction of the public who have access to clean municipal water preferably drink untreated rainwater. In addition, the investigation assessed the extent of contamination of rainwater samples collected in the Adelaide region and in South Australia, and underlying factors to the contamination.

1.3.1. Aims

The aims of the study were:

- To investigate microbiological and metal contaminants present in rainwater collected from South Australian rainwater tanks and risk factors influencing their presence.

- To identify households' attitudes towards rainwater and the drivers that influence these attitudes, particularly in areas where the public have access to clean municipal water.

1.3.2. Objectives

To achieve the study aims, this research undertook to:

- Quantify *E. coli* and total coliform content in rainwater from South Australian rainwater tanks,

- Quantify lead, zinc, copper and cadmium content of rainwater from South Australia tanks;
- Investigate the association of tank and roof materials, presence of first flush devices, rainwater pH, sampling region and sampling time with faecal indicator organisms and metals;
- Assess how factors linked to the environment around rainwater harvesting systems like the presence of overhanging tree canopies, the presence of mounted TV antennas on catchment areas, and the presence of rainwater filtration systems influence the quality of water;
- Assess a commercially available water filtration system's efficacy in removal of microorganisms and metals from rainwater;
- Investigate households' drinking water preferences and their understanding of drinking water quality, and the perception of quality of drinking water by members of the public.

This thesis contains eight chapters. Four of these chapters, and a section in the appendix, have published manuscripts incorporated in them. The first chapter (the introductory chapter) is an overview on rainwater harvesting in Australia. The chapter reviews current regulatory frameworks of rainwater harvesting in Australia. The chapter also reviews government incentives to rainwater harvesting, rainwater microbiology and toxicology, and presents a health risk assessment as a result of drinking untreated rainwater.

The second chapter presents the methodological approach to the research. The chapter describes the methods used in the selection of sampling locations, sample collection and techniques of sampling, sample processing and sample testing, the survey of household drinking water attitudes and data analysis are described in this chapter.

The third and fourth chapters respectively discuss rainwater contamination by microorganisms, and by trace metals. The fifth chapter investigates the drivers behind members of the public choosing to preferentially drink potentially contaminated rainwater in regions where treated municipal water is readily available. An overview of the public’s drinking water perceptions, and perception of water quality is also presented in this chapter.

1.4. Publication: A Review of Roof Harvested Rainwater in Australia

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A Review of Roof Harvested Rainwater in Australia

1.4.1. Abstract

To address concern regarding water sustainability, the Australian Federal Government and many State Governments have implemented regulatory mechanisms and incentives to support households to purchase and install rainwater harvesting systems. This has led to an increase in rainwater harvesting in regional and urban Australia. This review examines the implementation of the regulatory mechanisms across Australia. In addition, literature investigating the potential health consequences of rainwater consumption in Australia was explored. Studies demonstrated that although trace metals such as arsenic, cadmium, chromium, lead and iron were present in Australian rainwater, these metallic elements were generally found below the health limit guideline, except in high industrial areas. In addition, pathogenic or indicator microorganisms that include but not limited to *Escherichia coli*, total and faecal coliforms, *Campylobacter, Salmonella, Legionella, Pseudomonas, Cryptosporidium,* enterococci*, Giardia*, *Aeromonas* and *Mycobacterium avium* Complex (MAC) have been detected in rainwater collected in Australia. However, epidemiological evidence suggests that drinking rainwater does not increase the risk of gastrointestinal disease. It was also identified that there is a need for further research investigating the potential for rainwater to be a source of infection for opportunistic pathogens.

1.4.2. Introduction

Australia is the driest inhabited continental land on earth (Preston, 2009, Apostolidis et al., 2011). To mitigate drought effects on the sustainability of available water resources, many Australian states have introduced regulatory requirements and incentives for the installation of rainwater harvesting systems (Commonwealth of Australia, 2010). The primary intent of rainwater harvesting in Australia is to save on municipal water. However, in urban areas, with large impeded surfaces, rainwater harvesting is additionally used to manage surface runoff (Campisano and Modica, 2016). Rainwater, unlike municipal water, is rarely subject to multiple barriers that ensure its safety for human consumption (Plummer et al., 2010). In Australia, State Health Departments have produced guidelines suggesting that the public use municipal water for drinking and cooking (NSW Health, 2007b, SA Health, 2011). However, anecdotal evidence indicates that people are giving preference to drinking rainwater even when municipal water is available (Chubaka et al., 2017). This review examines the factors that influence the use of roof harvested rainwater in Australia and the potential human health consequences.

1.4.3. Methodology and resources

This review has retrieved journal articles, published books chapters, and grey literature. PubMed and Scopus databases, and Google Scholar were used to search resources from the Web. Google search engine (Google Inc. Mountain View, California, US) was used for grey literature search. Key words such as rainwater, contaminants, contamination, bacteria, microorganisms, *Escherichia coli (E. coli)*, faecal coliforms, trace metals, illness, gastroenteritis, outbreak, health guideline, health hazard and Australia were used for database searches.

The Flinders University Faculty Librarian Officer’s services were used to recover archived and resources removed from the internet. All documents included in the review were written in English, and no further translation was required.

Journal articles, books chapters, and grey literature resources searches were strictly limited to rainwater harvesting schemes, and rainwater consumed in Australia. There were no exclusion criteria set for resources on pathogenic microorganisms and trace metals effects in humans. All resources that did not fall in that category were excluded even when found within the scope of rainwater harvesting. A total of 480 documents were searched, and 149 papers met the inclusion criteria (Figure 2).

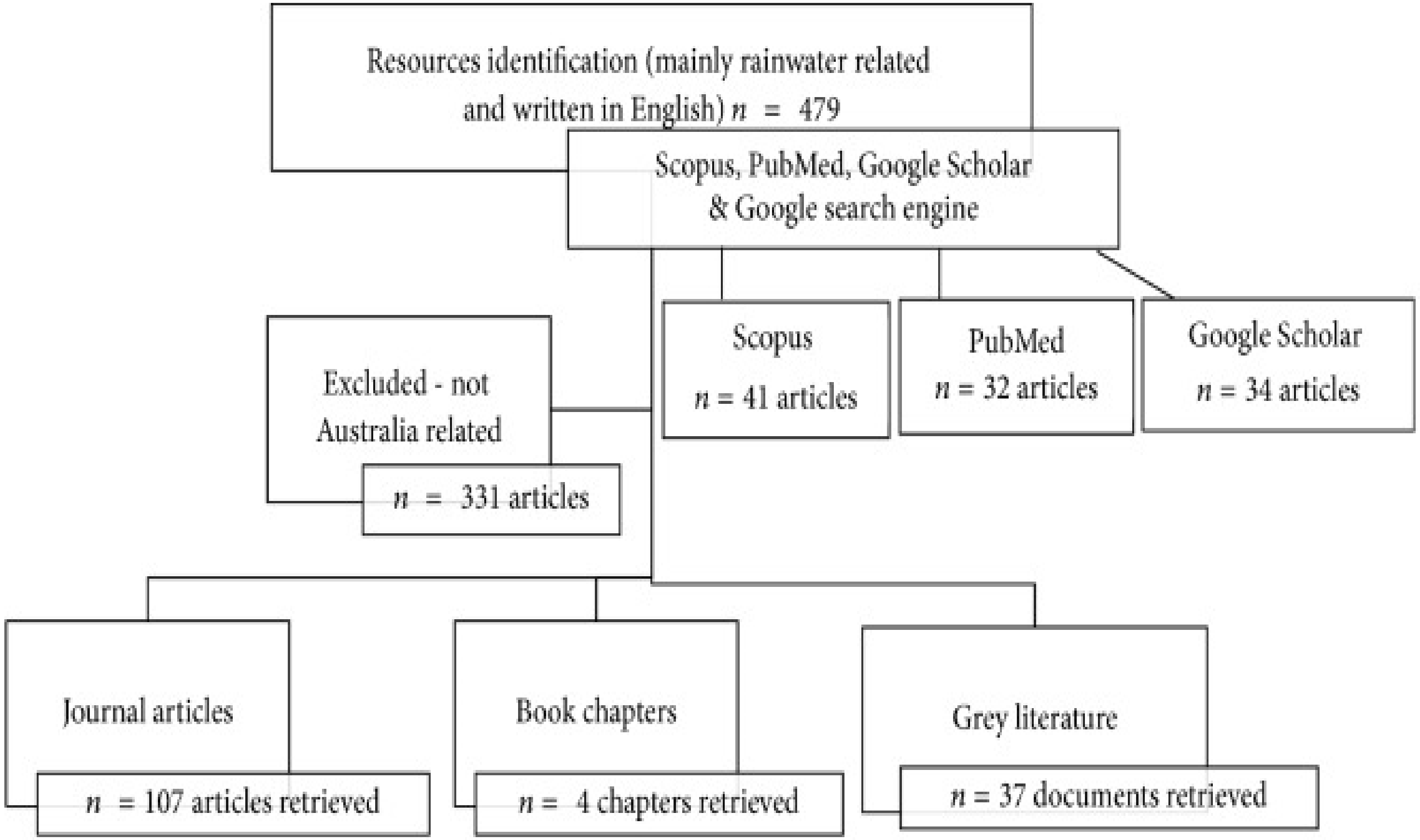

Figure 2. Methods of resources and materials search diagram.

1.4.4. Water sustainability

Climate change projections for Australia raises concerns over change in temperatures and rainfall patterns and ultimately, over sustainable supply of water resources to communities (Barker-Reid et al., 2010). In Australia, the average temperature has increased by 1°C from the middle of the 20th century (Australian Government, 2008). The trends of rising temperatures over Australia are believed to impact on groundwater renewal and aquifer recharges that support rivers perennial flow. The largest Australian perennial river, the River Murray, remains subject to drought conditions that prevail in its basin. A 2006 study indicated that in periods of drought, 75% of water flowing in the Murray is used by riparian farmers (Chartres and Williams, 2006). Another challenge for Australia is the trend in population growth (Sharma et al., 2016). In December 2016, the Australia population was estimated to be 24.3 million people and the population growth was estimated to be 1.3% (Australian Bureau of Statistics, 2017). If current water policies remain unchanged, the demand in water resources is tipped to exceed water supply capacity in major Australian cities by 2025 (Business Council of Australia, 2006).

1.4.5. Regulatory framework supporting roof harvested rainwater

Historically, in periods of drought, rainwater provided drinking water to the first European settlers and to Indigenous Australians (Engineers Australia, 2012). In rural and remote Australia, rainwater have provided drinking water to communities, and its use as source of drinking water is increasing in urban areas even though health authorities are reluctant to endorse rainwater as a safe source of drinking water (Leder et al., 2002). In times of water shortages, rainwater is a useful substitute to municipal water. In 2017, the Royal Australian Air Force

(RAAF) used harvested rainwater to supply water tanks to communities in Katherine (Northern Territory) after authorities found that municipal water was contaminated by per-and poly-fluoroalkyl substances (PFAS) (McLennan, 2017). The PFAS is cumulative and non-biodegradable chemical in human and at present, there is no strong clinical evidence that PFAS can cause cancer(So et al., 2006, enHealth, 2016), however; links exist between human exposure to PFAS and testicular, kidney and prostate cancer (Australian Government, 2017), and the decrease in bones density, and osteoporosis in women, and decrease in fecundity (Webster, 2010, Vélez et al., 2015, Khalil et al., 2016, Koskela et al., 2017).. Before 1990, rainwater harvesting was not allowed in urban areas where municipal water was accessible (Coombes, 2006). However, over time rainwater harvesting and use became an accepted practice in urban areas (Sinclair, 2007).

Under regulation, building companies in many Australian states are now required to have rainwater tanks plumbed into new properties to comply with the Urban Development Industry (UDI). This is to save municipal water and to manage surface runoff (Marsden Jacob Associates, 2009). In 2004, a regulatory framework aimed at ensuring the Building Code of Australia (BCA) and the National Health and Medical Research Council (NHMRC) requirements were complied with was created. This was focused on water tank structures and water quality parameters (Table 1) (Australian Government, 2008b). The regulatory framework, implemented by States and Territories, is managed by entities such as the National Water Initiative (NWI), the Australian Rainwater Industry Development group (ARID), the Master Plumbers and Mechanical Services Association of Australia (MPMSAA) and the National Water Commission Waterlines (NWCW) (Australian Government, 2008b). In New South Wales

(NSW), the provision of Circular 14, 2002 of the State Government requires that municipal water have connections that are separate to rainwater and that connecting pipes be labelled "*non-potable water*" with a hazard identifier sign in place (Urban Rainwater Systems, 2003). Subsequent to Circular 14, 2002, a policy on tanks plumbing was created by NSW Committee on Uniformity of Plumbing and Drainage Regulations (CUPDR) (New South Wales Government, 2006). As a result, NSW Health Guidelines of January 2005 (GL2005-033) stated that well maintained rainwater harvesting systems can provide a good source of water and suggested that adequate maintenance systems be in place when rainwater is used for potable (NSW Health, 2007b). Notwithstanding, New South Wales Health (Commonwealth of Australia, 2010) warned the public on risks associated with drinking untreated rainwater. The warning message was echoed by Queensland Health and by Western Australia Health (State of Queensland, 2006, Government of Western Australia, 2011). A study on household drinking water attitudes found that many Adelaide residents were giving preference to drinking untreated rainwater when they had high quality municipal water supplied, and the preference was based on rainwater taste rather than on water quality (Chubaka et al., 2017). A survey carried out with Currumbin residents (Gold Coast, Queensland) (n = 42) found that 100% of respondents used rainwater as source of drinking water and that 64% of households who consumed rainwater used basic sanitation practices that included water boiling, filtration and ultraviolet treatment, to improve rainwater quality (Ahmed et al., 2017). In the Gold Coast region, high quality municipal water is supplied to communities by water utilities (City of Gold Coast, 2017).

Based on the NSW Building Sustainability Index (BASIX) plans, an investigation was carried in 2011 on 52 tanks by Sydney Water (Sydney Water, 2011). The investigation found that Sydney families saved up to 38,000 L of municipal water in 2012, the equivalent of 21% of their annual water consumption (Sydney Water, 2011). In Canberra, a policy based on Australia Standards/New Zealand Standards 3500 (AS/NZS 3500) on tanks installation and plumbing, and on rainwater use was enforced in 2010 (Australian Capital Territory Government (ACT), 2010). In Queensland, Part 4.0 of the Queensland Building Sustainability (QBS) requires that Class 1 Building have a rainwater tank plumbed-in for non-potable use (Queensland Government, 2013). Subsequent to Queensland Development Code, Mandatory Part 4-2 (QDC MP 4-2), a study carried by Umapathi et al. (2012), to monitor municipal water savings in 20 households from mandated rainwater tanks found that in eleven months, families saved up to 36,1 kL of municipal water on an estimated 39.9 kL of rainwater annually consumed by households.

Subsequent to the Council of Australian Governments (CoAG) resolution of June 2003, Submission 158, the State Governments of South Australia, Victoria, New South Wales and Queensland softened their attitudes and considered rainwater as a natural supply, soft, clear and odourless; good for drinking and cooking (Urban Rainwater Systems, 2003, NSW Health, 2016). In 2007, more than 1.5 million Australian families used rainwater as source of water, the equivalent of 19% of Australian households (Marsden Jacob Associates, 2009). From 2007 onwards, the proportion of families that used rainwater as source of water steadily increased by 1% annually. In 2013, about 2.3 million families used rainwater as source of water, the equivalent of 26% of Australian households (Australian

Bureau of Statistics (ABS), 2013). In both urban and regional Australia, an estimate of 50% of rainwater harvesting systems identified were plumbed-in for indoor use (Campisano et al., 2017). In 2013-2014, about 46 GL of rainwater was consumed by Queensland households compared to 40 GL in New South Wales, 20 GL in South Australia, 10 GL in Western Australia, 0.9 in Canberra and 0.5 GL in Northern Territory (Australian Bureau of Statistics (ABS), 2015).

Table 1. Regulations and specifications for rainwater tank installation

States	Regulation	Specification	Water use	Reference
South Australia (SA)	Development Act 1993 and Development Regulations 2008 which completes the Waterworks Act 1932 and the Environment Protection Act 1993 and completed by the Waterworks Regulations 1996, the Public and Environmental Health Act 1987 and the Natural Resources Management Act 2004	Houses in new developments and house extensions greater than 50 m² must have an additional water supply to supplement municipal water. SA Water regulates the tank plumbing policy in fulfilment of the Waterworks Act 1932 and Waterworks Regulations 1996	All tanks must be plumbed for toilets flushing, hot water system and to cold water outlets in the laundry for new Class 1 buildings	Department of Planning and Local Government, 2010
Victoria (VIC)	The 5-Star Standard for all new houses in Victoria (Victoria Building Code 2005) of 1st of July	New Class 1 buildings are required to have rainwater tank of not less than 2,000 L plumbed	All tanks must be plumbed for toilets flushing. Rainwater	Victorian Building Authority, 2014

	2005 requires that new houses to have a rainwater tank plumbed to the house. Regulations 2008, Version 013, S.R. № 136/2008, in fulfilment of Part 12A of the Building Act 1993	for toilet flushing. The roof area shall be greater than 50 m^2 to meet the tank plumbing requirements and maximize the harvest.	must be separated from municipal water supply and the overflow directed into storm water drainage system	
New South Wales (NSW)	The New South Wales Health Guidelines of 2005 (GL2005_033 of January 2005) which completes the Building Sustainability Index (BSI) requires that new residential houses in NSW use less municipal water.	The installation of tanks of capacity greater than 10,000 L requires Sydney Water approval to avoid infringing on Sydney Water structure or easement.		Department of Energy Utilities and Sustainability, 2006, NSW Health, 2007a
	The Queensland Building Regulation 2006 (QBR 2006),	The QDC-MP 4-2 in place from 2007 recommends that new	Tank plumbed-in for toilet flushing, clothes	State of Queensland,

Queensland (QLD)	Subordinate Legislation 2006 № 227 under Division 2. The QDC-MP 4-2 of 2007 regulates rainwater tank installation.	houses from 100 m^2 roof area to have rainwater tank of 5 kL installed by builders at a cost of $4,000 paid by homeowners	washing and an external tap to save municipal water use up to 70 kL annually and 42 kL for detached houses.	2006, Gardner and Vieritz, 2010
Western Australia (WA)	No governing policy in place.	The Health Department advises the public to limit rainwater for non-drinking purposes.	Gardening, toilet flushing, clothes washing and hot water systems.	Government of Western Australia, 2011
Tasmania (TAS)	No governing policy in place.	A local council plumbing permit approval is required for tank installation. Works must be carried out by an accredited plumber.	Essentially outdoor use.	Australian Government, 2008

Northern Territory (NT)	The Building Code of Australia, National Plumbing Code (AS/NZS 2003b; DCC 2007). The plumbing guideline is governed by the Northern Territory Land Group (NTLG).	No mandatory requirement.	Toilet flushing, laundry use, gardening for outdoor use, firefighting, cooling tower, cold water use.	Australian Government, 2008
Australia Capital Territory (ACT)	The AS/NZS 3500 Section 4 regulates the installation of rainwater tank on a residential property. Tanks must be installed at least 3 m from the rear boundary and 1.5 m from the side building boundary.	Tanks of less than 17 kL installed at 2.4 m above ground level do not need council approval. Larger thanks require approval from the ACT Planning and Land Authority (ACT-PLA) or building approval from a private certifier or both.	Toilet flushing, laundry use for indoor use and gardening, firefighting, cooling tower for outdoor use.	Australian Government, 2008

1.4.6. Incentives to rainwater harvesting

For the government, the primary aim of the incentives to rainwater harvesting was to save municipal water in a period of drought. Reports indicate that rainwater harvesting resulted in the reduction in water bills for many households (Australian Government, 2015). During the survey of household drinking water attitudes however, no respondent referred to water bill reduction as their primary reason to install rainwater harvesting systems to their properties. Rainwater is not metered nor integrated into water utilities' treatment and distribution supply chains.

Under the Water for Future Initiative (WFI), the Australian Federal Government introduced a rebate scheme in 2009 to help families purchase and install new rainwater harvesting systems for non-potable purpose (State Government Victoria, 2013). A total of 14,625 rebates, the equivalent of $7 million, were offered to families by the Federal Government. The program ended in June 2011 (Australian Government, 2011). Out of 14,625 rebates led by the Federal Government, 55% of rebates were offered to families in New South Wales with 18.2% offered to families in South Australia, 13.7% offered to families in Victoria and 0.3% offered to families in Tasmania (Australian Government, 2011).

The government rebates were offered in terms of discount on tank purchase and the money was paid to tanks suppliers or to builders. No rebate was offered to families in Northern Territory. In addition to the Federal Government rebates, many Australian State governments have developed regulatory mechanisms to promote rainwater harvesting plans (Table 2). Because of the rebates policy, 32% of families with houses that met the standard requirements installed rainwater harvesting systems (Australian Bureau of Statistics (ABS), 2013). The number of new installed tanks increased in capital cities more than in regional Australia. Hence, 47% of Adelaide households installed new tanks followed by Brisbane households (44%) and Melbourne (Queensland Government, 2013) (Australian Bureau of Statistics (ABS), 2013). Likewise, 86% of Hobart households plumbed-in their tanks for non-potable use followed by Melbourne household (23%) (Moglia et al., 2014). The reason to install new tanks differed from households. It was reported that 60% of Melbourne households installed tanks to save municipal water while 38% complied with in place water restrictions, and 24% to make savings on water bills (Moglia et al., 2014).

Table 2. Requirements for rebates on rainwater tank systems

State	Fund allocation	Reference
South Australia	Up to $1,000 granted by SA Water to purchase tank and get them plumbed for non-potable use. Program ended in March 2013	Marsden Jacob Associates, 2009, Australian Government, 2008
Victoria	Rebates from $500 to $1,500. Program ended 30 June 2015	State Government Victoria, 2013
New South Wales	Up to $1,500 for tanks not installed under the BASIX regulation. Up to $500 offered by Sydney Water to schools to purchase tanks with an extra $500 to get them plumbed-in for non-potable use. Program ended 30 June 2009	Marsden Jacob Associates, 2009, Australian Government, 2011
Queensland	Rebates up to $1500 for a 3000 L tank or larger if plumbed-in for non-potable use. Program ended 31 December 2008	Australian Government, 2008, Marsden Jacob Associates, 2009

Western Australia	A rebate up to $600 for tanks larger than 2,000 L if plumbed-in for non-potable use. Program ended 30 June 2009	Australian Government, 2008, Marsden Jacob Associates, 2009
Australian Capital Territory	From $750 to $1,000 for new tanks if plumbed-in for non-potable use. $600 to plumb-in an existing tank. Program ended in 2008	Australian Government, 2008
Tasmania	In Hobart, up to $170 for outdoor use, $220 if plumbed-in for non-potable use for tanks of at least 600 L capacity. Program ended 30 June 2008	Australian Government, 2008
Northern Territory	No rebate scheme was granted	

1.4.7. Contamination of rainwater and quality assessment

As with surface water, rainwater can be contaminated with coarse and fine particulate matters, chemicals, micro-organisms, metals and ionic elements, and which may detrimental health effects (Khemani and Murty, 1968, Areerachakul et al., 2009). Previous studies have suggested that the human health consequences associated with rainwater are low in intensity and are linked to the type of rainwater harvesting systems design and maintenance (Evans et al., 2006, World Health Organisation (WHO), 2011). It has also been suggested that many people can develop immunity to rainwater pathogens or that they suffer from asymptomatic infections of minor infection with mild symptoms that go unnoticed (Macomber, 2001).

1.4.7.1. Trace metals in rainwater stream

There are twenty-three metals known to be toxic to human (Malassa et al., 2014). Out of these metals, arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin, uranium and titanium are classified highly toxic (World Health Organisation (WHO), 2011). Trace metals naturally occur in earth crust and in many environmental matrices (Tchounwou et al., 2012). These metals are believed to spread in the environment from metal smelters and wastes processing plants (World Health Organisation (WHO), 2011), or from mining and industrial discharge, air pollution fallout, urban runoff and sewage effluent, and traffic emissions (Morais et al., 2012). In rainwater, contamination with trace metals may come from the catchment and storage structures (Mendez et al., 2011, Gikas and Tsihrintzis, 2017) or can be carried and deposited on the roof by the wind and washed into the stored rainwater (Chance et al., 2015). A study that involved the survey of 34 tanks in subtropical Australia (Queensland) found that

65% of ionic contaminants and trace metals detected in rainwater were collected in the atmosphere by water during rainfall events, with the remaining 35% linked with corrosion on structure materials, paints and lead flushing (Huston et al., 2012). Case studies have also indicated that rainwater with a pH lower than 6.5 can be corrosive on structures and dissolve metals and leach them in stored rainwater (World Health Organisation (WHO), 2011). In Australia, studies on rainwater contamination by metals are still limited in scope. In the studies that have been done, often samples were found positive to metals but generally within accepted health guidelines (Kandasamy et al., 2016). However, in former industrial corridors and raw material export terminals, studies found metals above health limits in rainwater samples (Table 3).

Table 3. Trace metals found in rainwater in key Australian towns and cities (in ppm)[1]

Aesthetic only for zinc, lead - total lead

Location	Metal concentration	Health limit	Times above limit	Reference
Adelaide, SA	15.8 – zinc	3*	5.2 times higher	Rodrigo et al., 2011
Port Pirie, SA	0.06 – lead [2]	0.01	6 times higher	Sinclair et al., 2005
Adelaide, SA	0.03 – lead*	0.01	3 times higher	Rodrigo et al., 2010
	16.1 - zinc	3*	5,3 times higher	
Melbourne, Vic	0.42 – lead	0.01	42 times higher	Magyar et al., 2008
	0.1 – chromium	0.05	2 times higher	
	0.17 – nickel	0.02	8.5 times higher	
Melbourne, VIC	0.5 – lead	0.01	50 times higher	Magyar et al., 2014

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[1] Appendix 10. Table 3 revised

[2] The value of 0.06 ppm has been changed to 0.6 ppm.

Newcastle, NSW	0.02 – cadmium	0.002	10 times higher	Morrow et al., 2010
	0.14 – arsenic	0.01	14 times higher	
	0.81 – chromium	0.05	16 times higher	
	15 – copper	2	7.5 times higher	
Newcastle, NSW	0.21 – chromium	0.05	4.2 times higher	Martin et al., 2010a
Sydney, NSW	0.55 – arsenic	0.01	55 times higher	Sinclair et al., 2005, Kandasamy et al., 2016
	2.78 – lead	0.01	278 times higher	
	0.33 – lead	0.01	33 times higher	
Esperance, WA	0.01 – lead	0.01	1.2 times higher	Heyworth and Mullan, 2009
	0.03 – nickel	0.02	1.5 times higher	
Karumba, QLD	0.006 – cadmium	0.002	3 times higher	Gulson et al., 2016
	0.10 – lead	0.01	10 times higher	
	10.8 – zinc	3*	3.6 times higher	

Brisbane, QLD	0.85 – lead	0.01	85 times higher	Huston et al., 2012
	0.03 – arsenic	0.01	3 times higher	
	0.009 – cadmium	0.002	4.5 times higher	
	26 – zinc	3*	9 times higher	

In Newcastle (NSW), a study found seasonal variations in trace metals load in rainwater (Martin et al., 2010a) (Table 4). In the summer months, lead was detected 1,050 times above health limit with zinc detected 241 times, manganese 164.6 times higher, nickel 136 times higher, cadmium 85 times higher and arsenic detected 55 times higher. The study did not determine the origin of these metals however; the detection of lead and manganese in higher proportions in Newcastle rainwater samples would have links with high industrial activity. Until the 1950s, silicate manganese ore ($MnSiO_3$) was mined in New England and processed in Newcastle by Broken Hill Proprietary Company Ltd Steelworks (BHP Steelworks Ltd) to make alloys (Crivelli and Butlin, 1955). It should be noted that in many ore deposits, silicate manganese occurs with lead, nickel, zinc, and copper (Graham, 2015).

Years after the mine closure and with time and weathering, the mine remaining overburden breaks down and during summer months, the drier conditions enable dusts bearing manganese to be released into the environment. Similarly, the excess amount of lead found in Newcastle rainwater samples may be from the same source as BHP Steelworks Ltd used coal as fuel (Crivelli and Butlin, 1955). It has been reported that lead occurs at low level with black coal mined in the Hunter Valley adjacent to Newcastle (NSW Minerals Council, 2012). In addition, Newcastle is Australia largest terminal coal export (Higginbotham et al., 2010). . Like in Newcastle, a study conducted in Brisbane (Queensland) found that lead, cadmium and iron were generally detected above accepted health limits in rainwater samples collected in drier months (Huston et al., 2009).

Table 4. Trace metals seasonal variability in rainwater harvested in Newcastle [3] (Martin et al., 2010a) (in ppm).

		Site 1		Site 2	
Parameters	Health limit	Winter	Summer	Winter	Summer
Silver	0.1	0.032	0.009	0.047	0.014
Cadmium	0.002	0.18	0.17	0.05	0.10
Lead	0.01	2.78	10.5	3.59	5.77
Uranium	0.017	0.003	0.003	0.002	0.002
Manganese	0.5	20.0	82.3	6.95	12.1
Chromium (Cr^6)	0.05	0.09	0.21	0.03	0.05
Arsenic	0.01	0.25	0.55	0.08	0.09
Zinc	3*	518	725	77.2	150
Copper	2	0.08	0.25	0.10	0.16
Nickel	0.02	0.29	0.16	1.47	2.72

*Aesthetic only for zinc

Three studies conducted in Melbourne found that lead was a major contaminant of rainwater (Magyar et al., 2008). Study 1 involved the analysis of water samples from 6 small tanks collected from glazed tile rooftops of 0.1 m^3 storage capacity each. Study 2 involved 9 normal sized tanks and Study 3 investigated 40 tanks. It was reported that Study 1 detected lead 50 times above health standards. Out of 40 tanks investigated in Study 3, samples from 11 tanks contained lead above health limit. Lead flushing along with roof structure and tanks materials were

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[3] Appendix 11. Table 4 revised

believed to be source of rainwater lead content. Study 2 recorded a pH of between 4.3 and 4.9, making rainwater acidic and eventually corrosive on structures.

A study which investigated dusts impact from the Port Adelaide Waterfront Redevelopment Project (PAWRP) at Lefevre Primary School in Adelaide detected antimony, arsenic, barium, cadmium, chromium, lead, and manganese in relatively high concentrations (SA Health, 2008). Samples were collected in Classroom 13 (Site A) and in the Gymnasium (Site B). It should be noted that metals found in the classrooms could also be found in dusts on building rooftops and in event of rainfall, they would make their ways in stored rainwater should buildings in the area be fitted with rainwater harvesting systems as noted by Gikas and Tsihrintzis (Gikas and Tsihrintzis, 2017). The source of these metals was not otherwise identified. However, Lefevre Primary School is located at the edge of Port Adelaide former industrial precinct. In the area, General Motors Holden (GMH) operated a Car Assembly Plant (CAP) in Birkenhead waterfront, few meters away from the school location before it moved to Woodville in 1923 (Renewal SA, 2013). Thus, metals found at Lefevre Primary School might have been sourced by dusts blown from the former industrial precinct, given its proximity with the school.

1.4.7.2. Potential for human exposure

Metals in human have limited beneficial effects (Morais et al., 2012). At high intake, hexavalent chromium (chromium VI or Cr^{+6}), arsenic, cadmium, mercury, lead and barium are toxic metals (Morais et al., 2012). At lower intake, copper, cobalt, trivalent chromium (chromium III or Cr^{3}) and nickel are essential nutrients in human (Mandal and Suzuki, 2002, World Health Organisation (WHO), 2011).

While trivalent chromium is an essential nutrient for sugar balance and fat metabolism in human, long-term exposure to hexavalent chromium is poisonous (World Health Organisation (WHO), 2009, Tchounwou et al., 2012). Cadmium is a cumulative toxin which affects kidneys, deforms human reproductive organs and endocrine systems and disturbs bones metabolism (Mudgal et al., 2010). Lead is as noxious as cadmium and hexavalent chromium. Studies have found that lead contamination can trigger to mental and personality disorder in children until late puberty (Martin and Griswold, 2009, Rossi et al., 2012). In adults, long-term exposure to lead can cause anaemia, damage the human Intelligence Quotient (IQ) and the reproductive organs in males (Rossi et al., 2012). In pregnant women, longer exposure to lead can trigger to miscarriage (Rossi et al., 2012). At high intake, arsenic can impair the human cardiologic system, damage the liver and the central nervous system (Mandal and Suzuki, 2002). In pregnant women, lead can freely pass from the mother to the child and trigger to lead prenatal contamination (World Health organisation, 2010).

The review identified no incident of illness caused by drinking rainwater contaminated by trace metals. However, the lack of evidence could not conclude the absence of disease linked with drinking rainwater contaminated by metals in the community, given the number of Australians who are using rainwater as source of drinking water. Incidents of illness may exist in the community, but not be reported to health authorities. Metal poisoning side effects are cumulative in scope and it takes time for the symptoms to appear, making incidents of metals poisoning hard to diagnose in a timely manner (Oregon Health Authority, 2016). Nevertheless, studies indicate that incidents of illness caused by metals poisoning through other routes are recorded in the community (Baghurst et al., 1992, Tong et al., 1996, Ernst, 2002).

1.4.7.3. Microbiological contamination

The likelihood of rainwater to contain microorganisms is high (Evans et al., 2006). Generally, microorganisms found in rainwater are assumed to be from birds and small mammals that live around suburban areas. This is supported by a study carried by Ahmed et al. (2012b) on 22 rainwater tanks in Brisbane and in the Gold Coast region, where suburban birds and possums were found to be the vectors of all *E. coli* strains that were isolated from rainwater. Likewise, faecal matter that contain these microorganisms can also be carried with the dust and windstorms and be deposited on catchment areas and get discharged into harvested rainwater (McFeters, 2013). In underground tanks, faeces of large animals and humans collected by surface runoff can enter improperly designed, damaged or unsealed tanks (Pathak and Heijnen, 2004). This review found no study carried out on underground tanks in Australia.

Table 5 shows that microorganisms such as *E. coli*, total and faecal coliforms, *Campylobacter, Salmonella, Legionella, Pseudomonas, Cryptosporidium,* enterococci*, Giardia*, *Aeromonas* and *Mycobacterium avium* Complex (MAC) have been detected in rainwater harvested in Australia. Commonly detected bacteria are *E. coli* and enterococci. In considering the degree of *Enterococcus spp*. virulence and its observed level of prevalence in rainwater, the bacterium is also used as faecal indicator organism in the determination of rainwater microbiological quality, in addition to traditional *E. coli* (Manero and Blanch, 1999) (Ahmed et al., 2012c). In an earlier study, Ashbolt et al. (2001) argued for the need to use enterococci in the determination of recreational water quality. In line with this proposal, it was suggested that rainwater be subject to reasonable sanitation works, if rainwater is to serve as source of drinking water (Ahmed et al., 2011b).

Case studies have shown that rainwater harvested in many locations of Australia is generally of poor microbiological quality (Barker-Reid et al., 2010) . A study that involved the quantification of microorganisms of faecal origin in rainwater harvested in Queensland detected *E. coli* in the range of < 1 to 3060 ± 456 CFU 100 mL whereas, enterococci and *C. perfringens* were detected in the range of < 1 to 3400 ± 700 CFU 100 mL (Ahmed et al., 2010a). In southeast Queensland, study on the assessment of health risks linked with rainwater used for potable and non-potable purpose found that 10.7% of samples contained *Salmonella*, with 9.8% of samples found positive to *Giardia lamblia*, 5.6% positive to *Legionella,* and 0.4% of samples were found positive to *Campylobacter jejuni* mapA genes (Ahmed et al., 2010b). The study tested 214 samples collected from 84 tanks.

While epidemiological evidence links *E. coli* and incidents of gastroenteritis illness, Tobias et al. (2015) and Heusinkveld et al. (2016) studies have shown that not all strains of *E. coli* are pathogenic, although some can cause gastroenteritis, haemorrhagic colitis and kidney failure, which can be fatal (Griffin and Tauxe, 1991, Gould et al., 2013). Enterococci typically causes a gastrointestinal illness but can also cause urinary tract and blood infections (Bennett et al., 2014). A study carried on rainwater microbial content have found that in Australia, 60% of tanks surveyed contained *E. coli* (Chapman et al., 2008).

Another study conducted in Queensland detected *E. coli* in 15 tanks over 35 tanks and enterococci in 21 tanks over 35 tanks. The rate of prevalence was 48.5% for of *E. coli* and 60% for enterococci (Ahmed et al., 2012a).

A survey of 72 rainwater tanks in Brisbane and Gold Coast (Queensland) detected *E. coli* and enterococci in 74% and 94% of tanks respectively. Another study carried in 2015 in Brisbane on rainwater detected *E. coli* and enterococci in similar proportions (Hamilton et al., 2016). The colony-forming-unit of organisms count (CFU/100mL) ranged from 0.3/100 mL organisms and 3.7/100 mL organisms (Hamilton et al., 2016). In water, *E. coli* can survive between 15°C and 18°C for 3 months (Edberg et al., 2000). In harsh environment, *E. coli* lifespan can sharply vary from some days to few hours (Edberg et al., 2000). It should be noted that in water, *Enterobacteriaceae* bacteria have very similar lifespan to *E. coli* (McFeters and Stuart, 1972).

Until early 1900_s, total coliforms and *E. coli* were believed to naturally occur with faeces and the detection of total coliforms implied the presence of *E. coli* (Edberg et al., 2000). Gradually, the detection of total coliforms in the absence of faeces became evident (Tallon et al., 2005). Since total coliforms can grow in the environment without reference to faeces, the bacteria are no longer surrogate indicator of water faecal contamination. The bacteria have since been replaced by *E. coli* and enterococci (Stevens and Ashbolt, 2003). In Australia, the water quality standard for potable water is 0/100 *E. coli* CFU/mL(National Health and Medical Research Council (NHMRC), 2011). The guideline extends to faecal coliforms and these bacteria. Like *E. coli*. It is recommended that all strains of faecal coliforms be 0/100 CFU/mL for all points in the drinking water treatment and supply chain (Gleeson and Gray, 2002).

Campylobacter and *Salmonella* are typically considered foodborne illness causative agents, but other environmental sources including water can play a role in disease transmission (Whiley et al., 2013, Jokinen et al., 2015). *Campylobacter* is the causative agent of campylobacteriosis and the leading cause of gastrointestinal illness in Australia (Altekruse et al., 1999, Moffatt et al., 2017) . *Salmonella* is the causative agent of salmonellosis a gastroenteritis which has been increasing in incidence in Australia over the last decade (SA Health, 2016, Department of Health, 2017). A study conducted in southern Queensland detected *Campylobacter spp*. and *Salmonella spp* in 7 tanks over 35 tanks tested (Ahmed et al., 2012a). *Campylobacter* is shed in the faeces of infected humans and animals and the bacteria cannot replicate outside a host (Ternhag et al., 2005). However, *Campylobacter* has been shown to survive between 29 and 120 days in environmental water sources (Rollins and Colwell, 1986, Buswell et al., 1998), and *Salmonella* can replication outside a host and have been shown to survive in water source with minimal carbon content for at least 63 days (Cevallos-Cevallos et al., 2014).

Legionella and MAC are opportunistic pathogens (Falkinham III, 2013). *Legionella* is the causative agent of Legionnaire’s Disease, an atypical pneumonia infection and Pontiac fever, a mild febrile illness (Guyard and Low, 2011). MAC can cause a range of infections including musculoskeletal infections, respiratory disease, lymphadenitis, skin and soft tissue infections (Akram and Attia, 2017). *Legionella* can easily grow in potable water distribution systems, in freshwaters and thermal waters, in compost and potting mix, and the bacteria optimal living temperature is in the range of 20 and 45 degrees Celsius (Akram and Attia, 2017). Likewise, MAC are ubiquitous in the environment and can grow in soil and water sources including potable water distribution system (Falkinham III, 2013). When MAC are exposed to harsh environmental conditions, the bacteria enter dormancy lifecycle and its lifespan can become longer (Chaves et al., 2015).

Table 5. Prevalence of organisms in rainwater collected in key Australian cities[4]

Location	Organisms	Occurrence (%)	Count (CFU/100 mL)	Reference
Adelaide, South Australia	*Legionella spp*	17	840,000	Chapman et al., 2008
	E. coli	42	250	
	Salmonella spp	8	*	
	enterococci	67	450	
	Aeromonas	33	1700	
Brisbane, Queensland	*E. coli*	36	260	Chapman et al., 2008
	E. coli	*	2,420	Ahmed et al., 2016
	C. perfringens	100	55	
	enterococci	70	19	
Broken Hill, New South Wales	*Legionella spp*	70	73,000	Chapman et al., 2008
	enterococci	70	37	
	C. perfringens	70	16	
	Aeromonas	10	22	
Canberra, Australian Capital Territory	*E. coli,*	50	9,200	Chapman et al., 2008

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[4] Appendix 12 with Table 5 revised

	enterococci	100	32,000	
	Campylobacter spp	10	43	
	Legionella spp	10	20,000	
Newcastle, New South Wales	*Pseudonomas spp*	60	15,200	Evans et al., 2006
	E. coli	*	17	Martin et al., 2010b
Southern Queensland, Queensland	*E. coli*	63	89	
	Campylobacter spp	60	50	Ahmed et al., 2012a
	enterococci	92	91	
	Salmonella spp	4	700	
	Giardia lambilia	30	580	
Sydney, New South Wales	enterococci	100	199	Chapman et al., 2008
	E. coli	100	3,900	
	C. perfringens	33	16	
Wollongong, New South Wales	*E. coli*	100	100	Chapman et al., 2008
	enterococci	92	30,000	
	C. perfringens	42	27	
	Aeromonas	33	*	

* No data available

1.4.8. Epidemiological evidence

Since incidents of illness caused by drinking untreated rainwater may be limited to small numbers of people, it is difficult to identify individuals with infections linked with drinking rainwater in the community by means of epidemiological tools (Sharma et al., 2015). As such, real incidence of infections linked with drinking rainwater may be underreported or simply not reported (Ahmed et al., 2011a). A quantitative microbial risk assessment carried in Queensland by Ahmed, Gardner (Ahmed et al., 2011a) reported that over 1,000 people who annually drink rainwater daily, the chance to develop an infection was estimated for *Giardia lamblia* to 44 - 250 individuals, and for *Salmonella spp* to 85 - 520 individuals. Irrespective to the findings, the assessment concluded that in Queensland, risks of infections linked to drinking untreated rainwater were exaggerated. In Australia, there are limited epidemiological studies on rainwater consumption and incidents of gastroenteritis (Ahmed et al., 2009). A study conducted by Rodrigo et al. (2011) on 300 families that used rainwater as source of drinking water found that rainwater consumption did not extensively contribute to gastroenteritis incidents. Later, Rodrigo et al. (2010), and Hamilton et al. (2017a) highlighted the lack of strong epidemiological evidence that links gastroenteritis and rainwater consumption, albeit case control have indicated a relationship between drinking untreated rainwater and the illness[5]. A study by Heyworth, et al. (Heyworth et al.,

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[5] *Note: In the study, reference was made to cervical lymphadenitis and disseminated infection from drinking rainwater that contains bacteria from the group Mycobacterium Avium Complex (MAC). These risks were drawn from laboratory experiments, rather than epidemiological studies. Therefore, Hamilton *et al* (2016) recommend that further studies be carried out.

2006) indicated that in South Australia, children who drank rainwater were not found to have a higher level of gastroenteritis incidents, compared to their peers who drank centralised municipal water. The observation was later supported by Dean and Hunter (2012) and Abbott and Caughley (2012) argued that in South Australia, 42% of households drink untreated rainwater with limited gastroenteritis risks.

While the emphasis in the study by Hamilton and Ahmed was on *Legionella* and *Mycobacterium avium* complex (MAC), Hamilton et al. (2017b) indicated that drinking untreated rainwater would cause a cervical lymphadenitis in children and lead to disseminated infections in immune compromised adults. These authors suggested that rainwater be limited to car and clothes washing. [6]The review has identified three incidents of disease outbreaks linked with drinking untreated rainwater in Australia. The first outbreak caused by *Campylobacter* was identified in Queensland (Merritt et al., 1999), with a second linked to *Salmonella* identified in Victoria (Franklin et al., 2009), and a third caused by *Giardia lambilia* identified in New South Wales (Baldursson and Karanis, 2011) (Table 6). Incidents of illness were recorded in aged care facilities and holiday camps (Dale et al., 2010).

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[6] Note. In areas where rainwater is to be used for potable purposes in non-domestic settings (food cooking in restaurants, hospitals and aged care facilities, schools, recreational parks), enHealth (2004) and SA Health (2017c) advise that regular water testing be carried out to ensure the water meets the standards for drinking water as specified in the Australian Drinking Water Guidelines.

Table 6. Incidents of illness and diseases outbreak linked with drinking rainwater * declared outbreak

Year	State	Micro-organisms	Place	Incidents	Evidence	Reference
1981	New South Wales	*Clostridium botulinum*	Home location	3	High	Murrell and Stewart, 1983
1997	Queensland	*Campylobacter*	Nursing home	23 *	High	Merritt et al., 1999
1999	Queensland	*Salmonella spp*	Working camp	28	High	Taylor et al., 2000
2001	Queensland	*Salmonella spp*	Nursing home	3	High	Kirk et al., 2011
2004	Queensland	*Salmonella spp*	Nursing home	8	High	Kirk et al., 2011
2004	Victoria	*Campylobacter*	Nursing home	7	Suspicion	Dale et al., 2010
2005	Queensland	*Salmonella spp*	Nursing home	8	High	Dale et al., 2010

2005	New South Wales	*Giardia lambilia*	Not specified	*	High	Baldursson and Karanis, 2011
2006	Queensland	*Campylobacter*	Holiday camp	46	High	Dale et al., 2010
2006	South Australia	*Cryptosporidiosis*	Home location	19	High	Cooke, 2011
2007	Victoria	*Salmonella*	School camp	27 *	High	Franklin et al., 2009
2009	Queensland	*Campylobacter*	Island resort	29	High	Cooke, 2011

1.4.9. Conclusion

To mitigate growing concerns over the sustainability of water resources supply to communities, the Australian Federal Government and many State Governments have developed regulatory mechanisms and incentives to support families purchase and install rainwater harvesting systems to supplement municipal water. Increasingly, rainwater harvesting has become more common in Australian capital cities and in regional Australia. Guidelines on rainwater harvesting and use and on tanks installation are in place in most Australian States and Territories. A mandatory rainwater tank plumbing policy on houses in new developments is enforced in South Australia, Victoria, New South Wales and in Queensland and having a rainwater tank on large extensions has become mandatory. Many Australians are using untreated rainwater as source of drinking water.

In comparison with municipal water supplied to communities, rainwater harvested in Australia can be of poor quality. Contamination with trace metals is generally low, except in some locations with large industry pollution. Contamination with microorganisms is common; but there is limited epidemiological evidence to suggest that exposure to gastrointestinal pathogens in rainwater results in an increase likelihood of gastrointestinal illness. However, there is a need for more research investigating the risk posed by opportunistic pathogens, particularly in susceptible populations. Notwithstanding increasing support to the industry, the Australian Federal Government and all States Health Departments recommend the public to exclusively limit rainwater use for non-potable purposes to avoid risks of contamination.

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Conflict of interest

The authors have no known conflict of interest to declare. All authors have agreed with the submission.

1.4.10. Reference

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1.5. Water resources and rainwater harvesting in South Australia

This section presents aspects that are related to water resources and rainwater harvesting and use in South Australia, and in the city of Adelaide.

1.5.1. South Australia, the driest state

South Australia is Australia's driest state (Tait et al., 2005). South Australia's capital city, Adelaide, is at the edge of isohyet 500 (Fawcett et al., 2006). Data on standard rainfall indicate that Adelaide receives an average of 563.1 mm annually (Australian Bureau of Meteorology, 2018). The Adelaide region has high variability in rainfall over time, and many years have a rainfall below the annual average (Figure 3). In 2014, South Australia's rainfall dropped below the historical level, to 206 mm (Australian Bureau of Meteorology, 2015a). Based on the Bagnauls and Gaussen classification (Nikolova and Mochurova, 2012), Adelaide's drier period with lower potential to harvest rainwater in tanks extends from November to March (Figure 4).

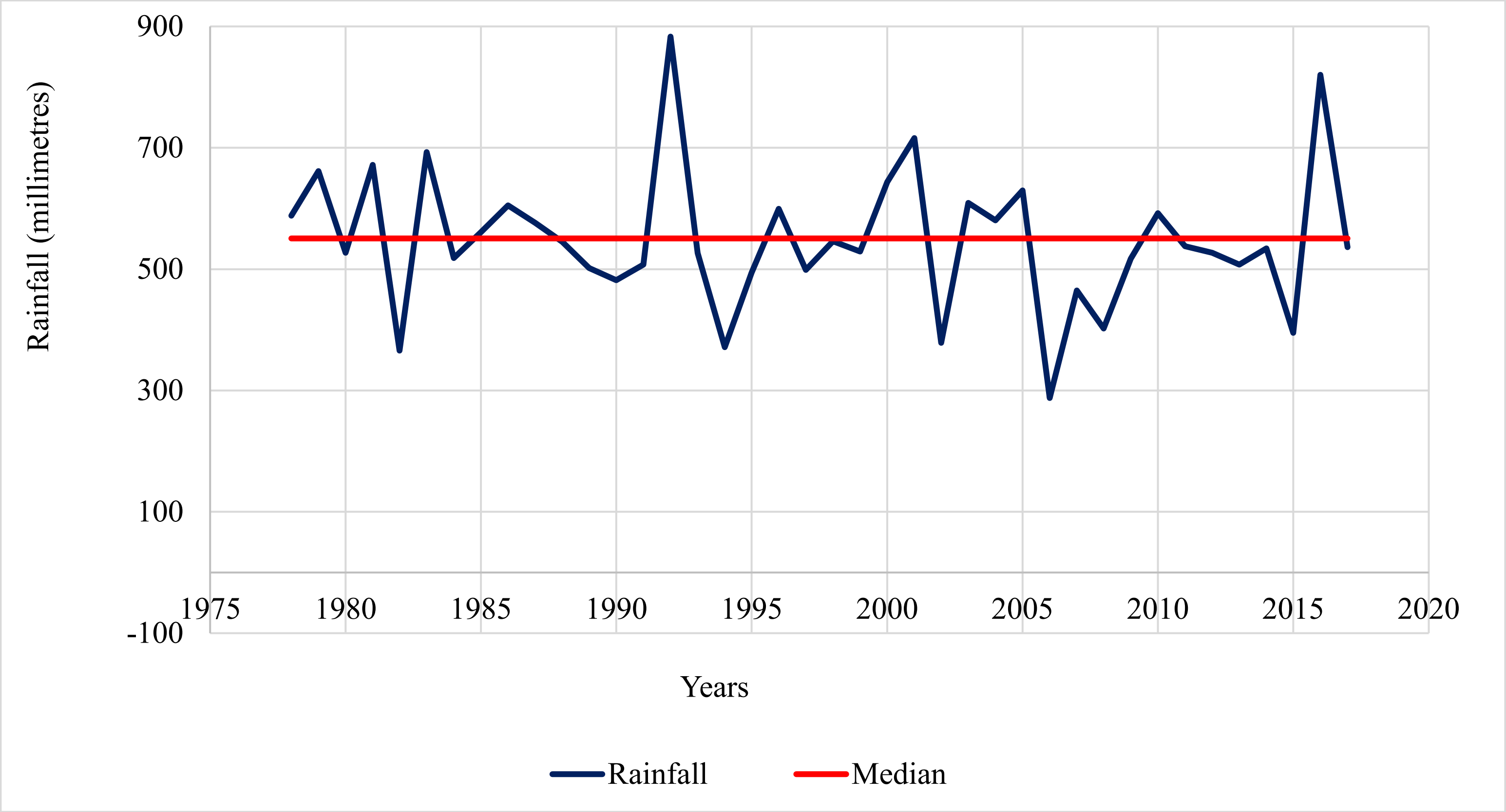


Figure 3. Adelaide annual mean and median rainfall: 1978-2017 (Kent Town – Station code: 02 3090).

Australian Bureau of Meteorology (2018)

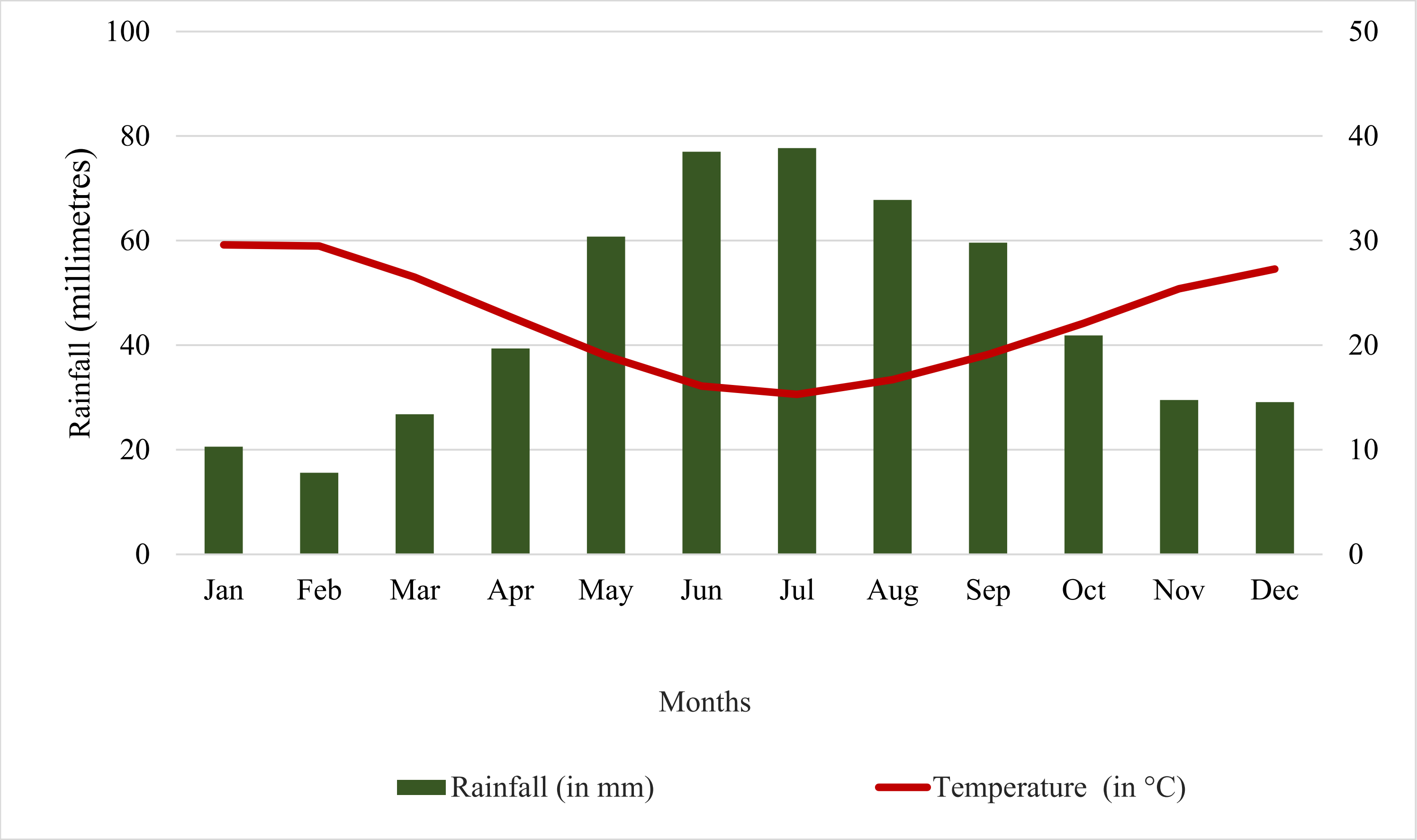


Figure 4. Adelaide mean rainfall and temperature 1978-2017 (Kent Town)

Source: Australian Bureau of Meteorology (2018)

In Australia, a small house roof is classified as having an area of 100-150 m^2, a medium house has a roof area of 150-200 m^2, and a large house has a roof area of 200 m^2 or greater (enHealth, 2010). In Adelaide, a free-standing house built in 2016/17 had an average roof size of 245.5 m^2 (CommSec, 2017). Using the formula described in 1.2, Adelaide's annual mean rainfall and average roof size, the annual volume of water potentially harvested by an average household in Adelaide is 124,316 L (124.3 kL). The average annual consumption of municipal water for a Adelaide house hold is 190.1kL (Australian Bureau of Statistics, 2011c); as such, a household could potentially replace 65% of its annual municipal water consumption with rainwater.

1.5.2. Sources of water for Adelaide and regional South Australia

Water supplies to Adelaide and regional South Australia come from four main raw water sources. The ratio of supply changes on an annual basis, but on average 59% comes from surface water, 33% from the River Murray, 6% from groundwater, and 2% from seawater (SA Water, 2017d). The Murray River is the only perennial river in South Australia that is capable of supplying water resources to the city of Adelaide all year round without incurring higher risks in terms of water supply (CSIRO, 2008). However, the water from the river has many upstream users under different authorities, hence reliability of flow is constantly compromised (Murray-Darling Basin Authority, 2010, McCarthy and Somerville, 2017). The watersheds in the area are subject to seasonal rainfall variability, posing a risk to resource base renewal and making the harvest of the required volume of water to supply the city of Adelaide in water resources together with supporting the farming activities in the Adelaide Hills unsustainable (Government of South Australia, 2010b). A desalination plant was built in Lonsdale (south of Adelaide) in 2011 to reduce dependence on the River Murray and to improve Adelaide’s water security (SA Water, 2017d). Set to desalinate 100 GL of municipal water annually, the Adelaide desalination plant (ADP) operates at 10% of its initial installed capacity (SA Water, 2018a). Thus, lower ADP water output mean that primarily water is still pumped from the River Murray, or harvested from Mount Lofty Ranges region watershed (Figure 5) (Adelaide Hills Council, 2013).

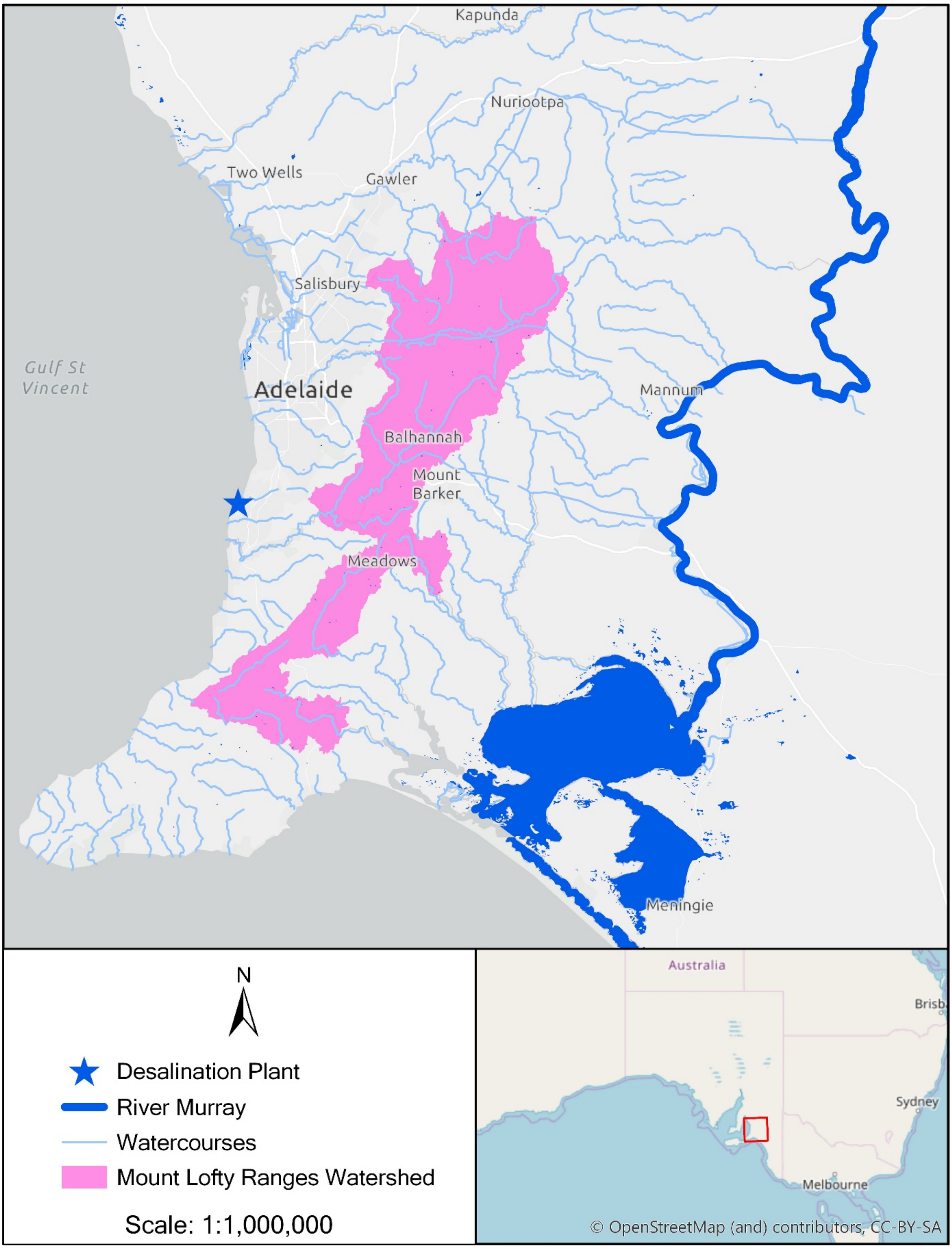


Figure 5. Map of the Mount Lofty Ranges watershed and the River Murray.

Source: adapted from the Department for Environment and Water (2005)

In South Australia, mandatory water restriction was implemented in 2003 in suburbs and towns in the Greater Adelaide region supplied by River Murray water and Myponga Reservoir (Figure 6). The policy intended to address the problem of water shortages in periods of drought, or following increasing demand for water that would exceed the environment regenerative capacity (Government of South Australia, 2010b). The policy required that recreational green areas, nurseries and sports grounds be watered by hand using hand held hoses, buckets or watering cans (Department of Planning and Local Government, 2010). From the December 2010, these restrictions ended in South Australia and were replaced by 'Water Wise Measures', permanent guidelines to reduce water use long term (Todd, 2010). Under this policy, households are not to use sprinklers for garden watering between 10 am and 5 pm, not hose paved areas and are required to use hoses that have trigger nozzles for car and boat washing and dust suppression (Department of Planning and Local Government, 2010). At the time of writing, there have been no substantial changes to South Australia water restriction measures as outlined in the policy of 2010 on the advised time for plant watering, and the tools to use for watering. The Water Wise measures are still in place.

When water restrictions are not in place, South Australia annually uses 1,200 GL of water (Government of South Australia, 2010b). This includes 163 GL used by greater Adelaide, 50GL used by regional South Australia and the remaining 950 GL supporting the farming industry or used for recreational purposes. Plans to harvest alternative sources of water (stormwater recycling and wastewater reuse) are in place to mitigate effects of future droughts (Government of South Australia, 2010b). The plans include additional investment in new stormwater harvesting and wastewater recycling projects and the desalination plant. (Government of South Australia, 2010a). Fully implemented, these plans could add an extra 150

GL of water to SA Water production, the equivalent to 75% of SA Water supplies to metropolitan Adelaide (Government of South Australia, 2010b). Challenges exist with these plans in terms of both funding and regulations as the implementation requires the support from different levels of government (state and federal governments) that regulate the water industry (Rabone, 2006).

Rainwater harvesting is increasing Australia wide, particularly in urban and rural South Australia (Sinclair et al., 2005). In South Australia, changes made to the Building Code under the Development Act 1993 that require mandatory plumbed rainwater tanks for Class 1 buildings in South Australia (Government of South Australia, 2002) have resulted in increased rainwater harvest and use.

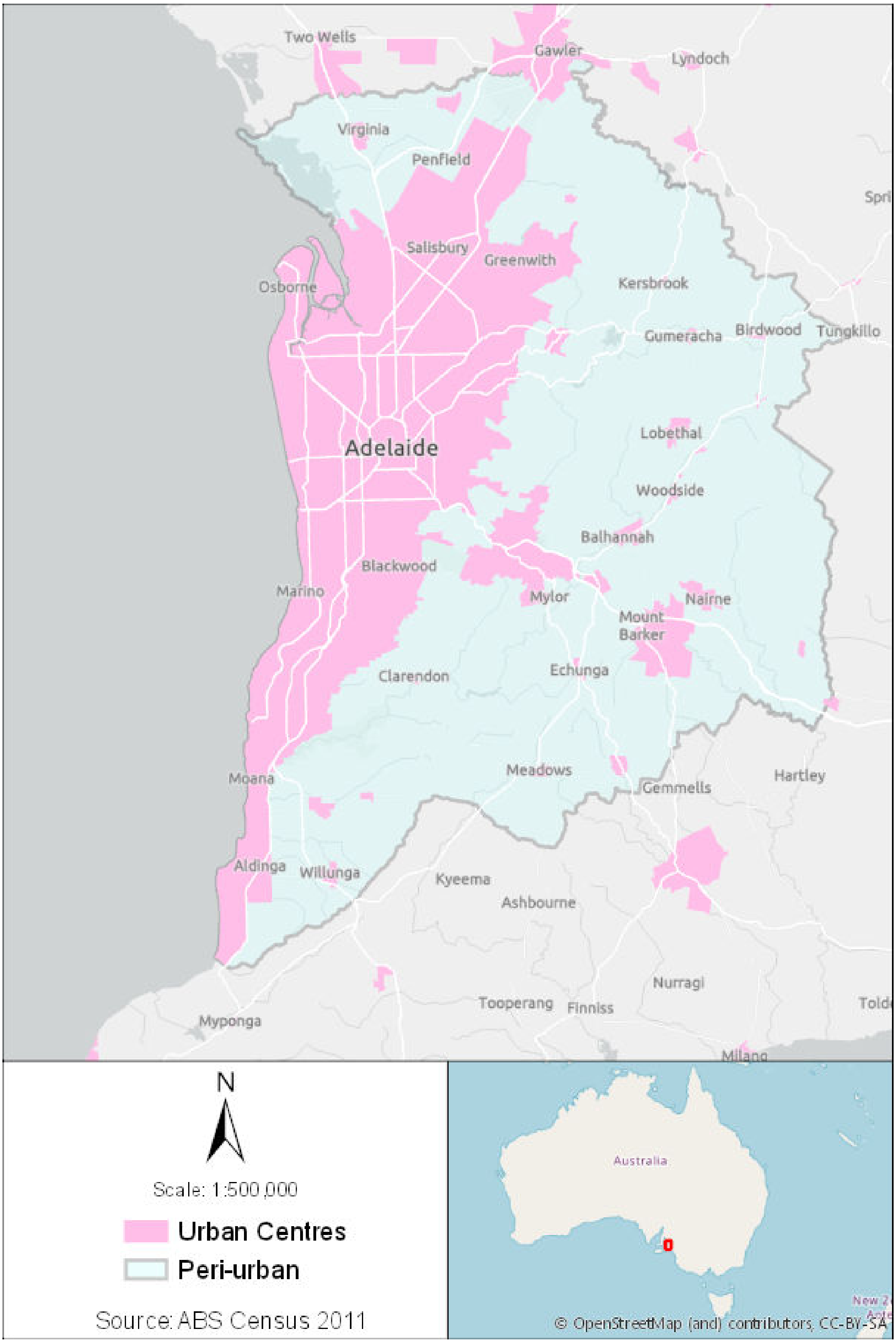


Figure 6. Map of the greater Adelaide region, South Australia.

Source: adapted from the Australian Bureau of Statistics (2011a)

1.5.3. Rainwater as a source of water

Rainwater harvesting is a widespread practice in regional Australia, and increasingly in urban areas to save municipal water. In many small towns in outback Australia, rainwater may be the only available option to communities (Australian Bureau of Statistics, 2013). In 2008, it was estimated that 45.4% of South Australia households used rainwater as a source of water compared with 22.1% in Queensland and 21.4% in Tasmania (NHMRC, 2011). South Australia had the highest proportion of households that used rainwater for drinking (22%), compared with 14.9% in Tasmania and 13.2% in Queensland. There were no data available for the Northern Territory (NT) or the Australian Capital Territory (ACT) on the proportion of households that used rainwater for drinking (Figure 7).

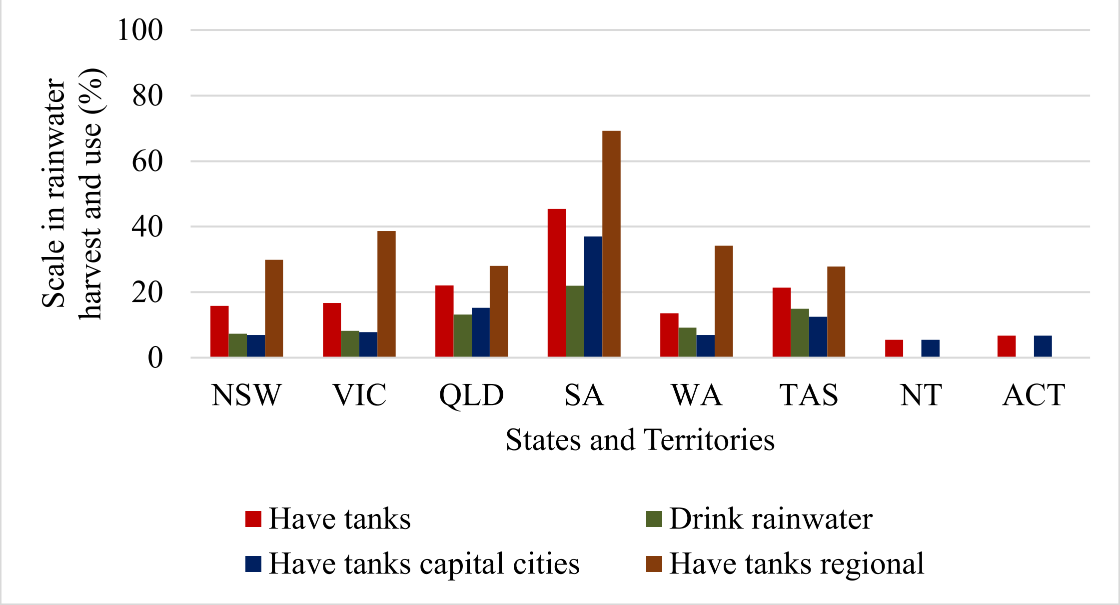


Figure 7. Rainwater as source of water in Australia, 2007 - 2008.

Source: enHealth (2010)

A federal government stimulus to support household purchase and install rainwater tanks was introduced in 2009 (Commonwealth of Australia, 2015). In South Australia, SA Water support to households ranged from $200 to $1000 for tanks of at least 1,000 L capacity, for tanks plumbed into the house, with the water to be used for clothes washing and toilet flushing (Australian Government, 2008). As a policy outcome, it was reported that from 2009 to 2013, 46% of South Australian households used rainwater as a source of water (Australian Bureau of Statistics, 2013). It was found that indoors, rainwater supplies were predominantly connected to hot water outlets rather than to toilets and laundry outlets. Interestingly, in capital cities that have higher rates of water supply connection to hot water outlets, there are fewer households using rainwater as a source of drinking water (Department of Health, 2011) (Figure 8).

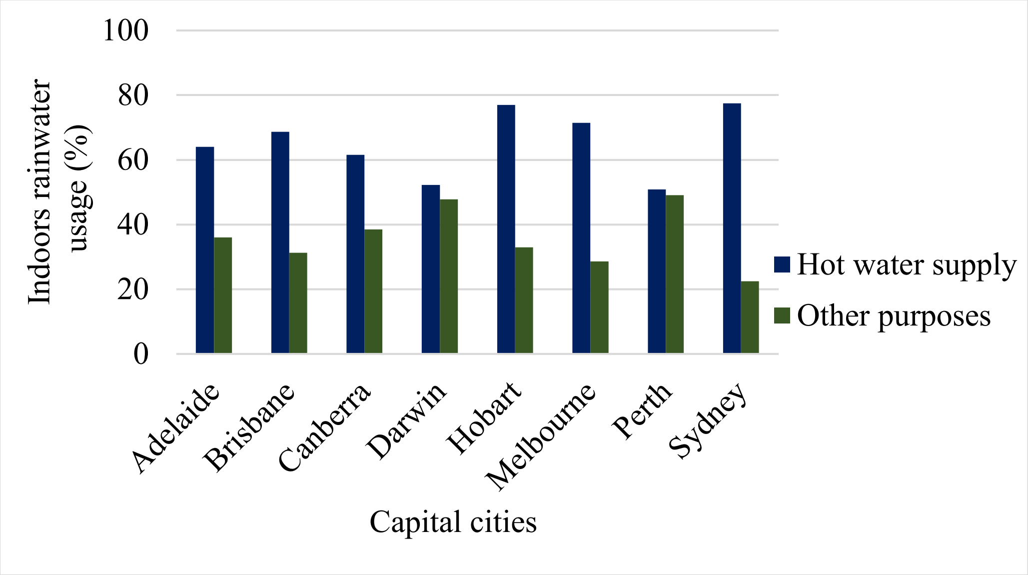


Figure 8. Indoor use of rainwater in urban Australia.

Source: Department of Health (2011)

The reasons that households install tanks vary. From the government's perspective, incentives to harvest rainwater were intended to help households reduce the use of municipal water during periods of severe droughts (Australian Government, 2015). In addition to complying with water restriction measures and with the provision of the Development Act 1993 and the Building Code 2006, it was found that many households installed tanks to make savings on water bills, and because they prefer rainwater (Australian Government, 2015). A study from Melbourne (Moglia et al., 2014) found that 60% of households installed rainwater tanks to save municipal water, 38% wanted to comply with water restrictions, and 24% used rainwater to make savings on water bills. Rainwater is also popular for non-potable uses, and used predominately for garden watering compared with other purposes (Figure 9) (Department of Health, 2011).

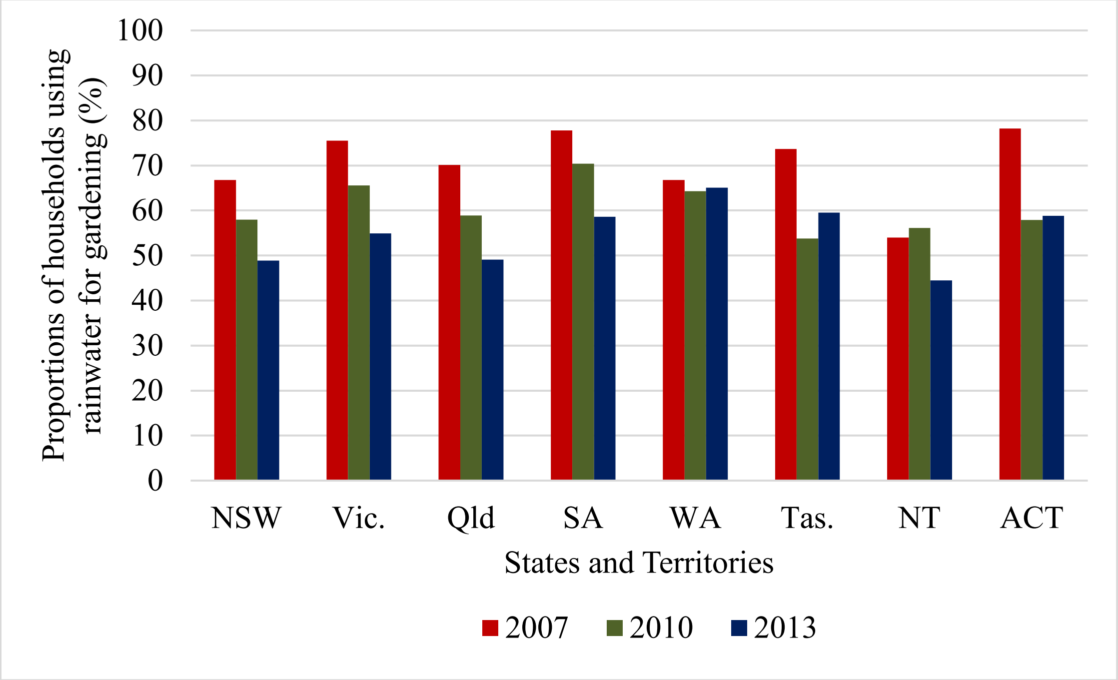


Figure 9. Trends in rainwater outdoor use in Australia.

Source: Australian Bureau of Statistics (2013)

In addition, dissatisfaction with municipal water within a community can contribute to increased numbers of households installing rainwater tanks. Data on rainwater consumption (enHealth, 2010), and on municipal water community satisfaction (Australian Bureau of Statistics (ABS), 2013) indicate that Australian states and territories that have lower municipal water community satisfaction have a higher proportion of households that use rainwater as a source of water (Figure 7 and Figure 10). In 2013, South Australia and Adelaide had the lowest satisfaction level in municipal water quality (57%) compared with other Australian major cities (Figure 10) (Australian Bureau of Statistics, 2013). While in some areas of Australia, municipal water community satisfaction is related to water physical qualities (NHMRC, 2011), water taste was a major issue of concern in Adelaide (Heyworth et al., 1998). Historically, an unpleasant odour and taste, as well as salinity, were major contributors to community dissatisfaction with Adelaide municipal water (Heyworth et al., 1998, EPA South Australia, 2008).

Perceived dissatisfaction has resulted in many households becoming reliant on rainwater for drinking (Heyworth et al., 1998). The quality of municipal water supplied to communities in Adelaide was improved through the installation of filters in 1977 to improve the physical appearance of the water, but the culture of drinking rainwater has remained in the community (Heyworth et al., 1998, EPA South Australia, 2008). A recent SA Water report (SA Water, 2017a), indicates that the major contributors to community dissatisfaction with supplied municipal water is that it is dirty (59%), has poor taste and odour (32%) and caused soiled washing (5%). In addition, many small towns in the Adelaide Hills and foothills have limited access to centralized public municipal water supplies, making rainwater the only available option.

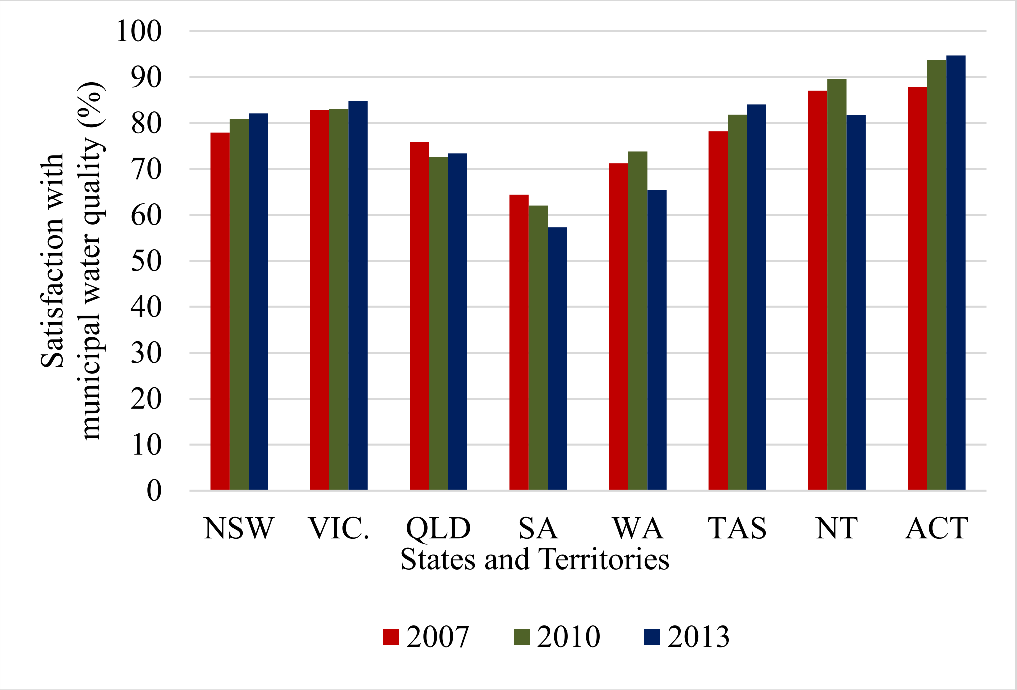


Figure 10. Municipal water quality community perception across Australia.

Source: Australian Bureau of Statistics (2013)

1.5.4. South Australia rainwater harvesting regulations

In addition to incentives, the Development Act 1993 [SA] and the Building Code of Australia (BCA) 2006 stipulate that houses in new developments and house extensions greater than 50 m² must have an additional water supply to supplement mains water (Planning SA, 2006). The policy emphasises that rainwater tanks shall be plumbed to the house and used for toilet flushing, hot water systems and to cold water outlets in the laundry (Planning SA, 2006). Further to the Development Act 1993, SA Water indicated that:

> *"From July 2006, most new homes in South Australia will be required to have a rainwater tank plumbed into the house for some domestic uses, to significantly lead to greater use of rainwater, and to annually reduce high demand on municipal water supply in the Adelaide region by an estimated*

> *4,000 mL by 2025, with further savings in many other South Australian communities"*
>
> Government of South Australia (2010a).

It was specified that the water be used indoors for toilets flushing or be connected to hot water outlets, and to the laundry for clothes washing (enHealth, 2010). Implicitly however, the regulation might encourage the use of rainwater for potable use, should an outlet tap be installed inside the house. The requirement does not specify that households not use rainwater for food preparation, and for drinking, and since it is suggested by health authorities that rainwater can be used for food preparation and drinking if it does not smell, has little taste and is clear, and harvested from well-maintained catchment area, and collected from clean storage facilities (enHealth, 2010), this directive might have increased the number of households using rainwater for potable purposes.

CHAPTER 2. GENERAL METHODOLOGY

This chapter presents the methodology and operation of apparatus used in the research presented in this thesis. This includes the procedures used for selecting sampling locations (section 2.1), sample collection and processing (section 2.2), sample analysis for bacteria quantification and metal determination (section 2.3), and methods of data statistical analysis (section 2.5). The chapter also outlines the selection of participants to the survey of households' drinking water attitudes, and the design of the survey questionnaire (section 2.4). As this thesis contains published material, there may be some duplication of methods in subsequent chapters. The methodology presented here includes greater detail than that presented in published manuscripts. The study was approved by Flinders University Social and Behavioural Research Ethics Committee (SBREC Number 6782 and SBREC 6782 - Modification 2) in accordance with the National Statement on Ethical Conduct in Human Research (NSECHR) (NHMRC, 2015) (Appendix 1).

The first application for ethics approval (SBREC N° 6782) allowed the researcher to contact potential participants to the study and obtain their consent to access to their properties and to their rainwater tanks facilities to later, collect water samples for laboratory testing. During initial contact, the researcher gave the documentation with details on the scope of the study to households, the initial questionnaire, and the researcher letter of introduction. The questionnaire was developed in collaboration with academic staff and was piloted before use by three colleagues in Environment Health, College of Science and Engineering, Flinders University to ensure comprehensibility, prior to being taken to the general public. To carry out the survey, the researcher applied for and obtained the approval of an additional study (SBREC 6782- Modification 2), to allow contact with members of the public to assess household drivers for their sources of drinking water. The project was funded by the Australian Government Research Training Program Scholarship (AGRTPS), and supported by the Health and Environment group, College of Science and Engineering, Flinders University.

2.1. Selection of rainwater sampling locations

Three residential sampling locations were identified in the Adelaide region (Figure 2.1). Parameters like vegetation cover and land use were determining factors in the selection of sampling corridors. In the Adelaide plains for instance, the corridor Port Adelaide-Outer Harbour, and the triangle Kilburn-Blair-Athol-Wingfield via Regency Park are semi industrial precincts with some residential areas. In contrast, the residential areas of the Adelaide foothills and the peri-urban region of the Adelaide Hills are characterised by increased vegetation cover and reduced industrial activities.

In this study, sampling locations for the Adelaide plains comprise the semi-industrial hub that goes from Port Adelaide to Outer Harbour in Lefevre peninsula, and the semi-industrial triangle that extends from the suburbs of Kilburn – Blair Athol – Wingfield via Regency Park. The Adelaide foothills comprise the suburbs of Belair, Glenalta and Blackwood in the City of Mitcham. The Adelaide Hills sampling corridor is a vast peri-urban area that extends from One Tree Hill to Paracombe via Kersbrook, Gumeracha and Cuddlee Creek (Figure 11).

The selection of sampling locations was based on land use and vegetation cover. Within the selected sampling corridors however, the selection of tanks to survey was based on whether there was a tank and whether the owner was willing for the water to be sampled. Given these restrictions, the selection choice could not consider the geographical location within the sampling location, the tank material, the building roof material, whether the tank had a first flush diverter and/or filter installed, and to whether the tank was plumbed to the house or not, although these factors were noted and included in the study (detailed below). Water samples were collected from houses that had rainwater harvesting systems installed.

Contact with homeowners and those responsible for public buildings that had rainwater harvesting facilities installed was made through door knocking. At the time, a short briefing on the study objectives was given to householders, if at home. Each householder was given an information letter, a consent form and a reply-paid envelope and were instructed to return the consent form to the researchers if they were willing to be part of the study. In the cases of residents not being at home at the time of the initial contact, an information letter, a consent form, a reply-paid envelope, and details on the research objectives were left in the homeowner’s letter box. Residents who agreed to participate in the project received a briefing on the project, outlining confidentiality and anonymity as required by Flinders University Social and Behavioural Research Ethics Committee (SBREC). Then participants were informed that:

- Their participation was a commitment on a voluntary basis which could be withdrawn at any time and that terminating the participation would not affect the participant in any way;

- Opinions and personal views would be treated and dealt with confidentiality;
- There would not be any audio recording of personal opinions and views;
- Under no circumstances would the names of participants or identification of the houses of participants appear in the final dissertation of this thesis or publications arising from the research;
- Responding to the researcher's questions was not an obligation;
- The results of samples analysis from individual tanks would not be made publicly available.

Details on these aspects are outlined in the Information Sheet and Consent Form contained in Appendix 2 and 3.

On initial contact, residents were asked whether they had a rainwater tank and whether they would be willing to allow a sample to be taken of their rainwater tank water, and subsequent samples to be taken at monthly intervals, or following a significant rainfall event, and whether they preferred to be home when samples were collected (Appendix 12, Table 22). Observations of the following were made during sampling visits to premises: storage tank and catchment characteristics (tank and building roof materials), whether the tank was plumbed in the house, whether the tank had a first flush device and a water filtration system installed, if there were a TV antenna mounted to the roof or the presence of overhanging tree branches over the catchment. Rainwater samples were primarily collected from tanks installed on private residential properties A few samples (16 samples out of 365 samples) were collected from tanks installed on public buildings. There were no samples collected from tanks installed on commercial buildings as all businesses that were approached refused to allow access to their properties for sample collection.

After agreeing to participate, participants were asked a few questions about their water tanks and water use. These questions included questions about maintenance activities, including bottom tank sludge drainage, gutters and downpipes and tank cleaning and additional questions about tank age, whether there were first flush devices installed, whether there were filters installed and whether they were maintained, whether the tanks were plumbed directly into the house and what the water was primarily used for. Additional details on tank and roof structure materials were made by observation.

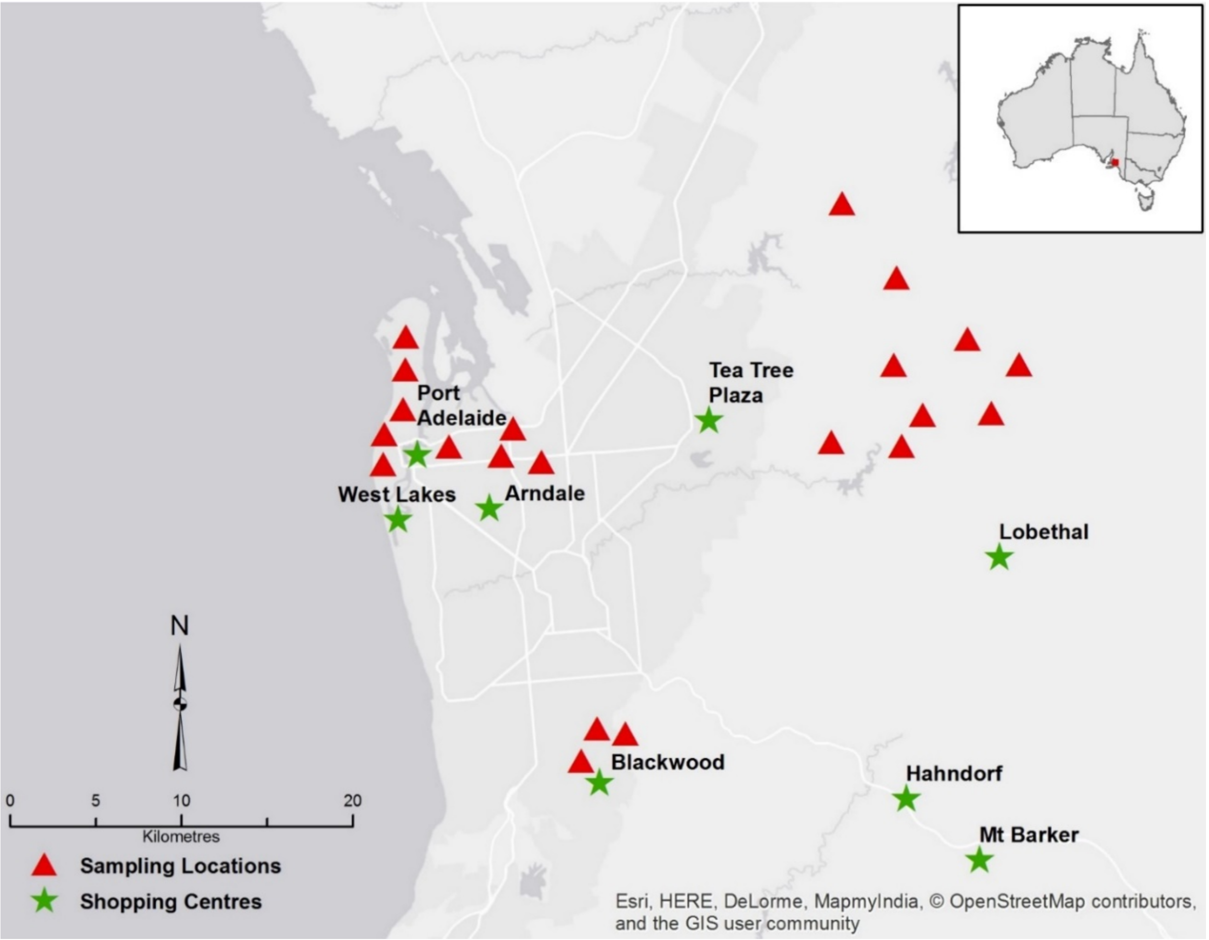


Figure 11. Study area in the Adelaide region showing the rainwater sampling locations and the shopping malls where surveys were conducted (Esri Map, 2017)

To relocate every tank, geodetic coordinates of properties were recorded by Garmin GPS 64s (GPSMAP, Garmin International Inc., Kansas, 66062, USA). Due to anonymity requirements, geodetics coordinates of tanks are not disclosed in this thesis. The questionnaire and a letter of introduction are contained in the Appendices (Appendix 4 and 5).

2.2. Sample collection and techniques of sampling

Rainwater samples were collected from July 2015 to August 2016. In this region most rainfall occurs in winter months (Murphy and Timbal, 2008). Sample collection was extended to two winter seasons. Samples were collected in 1 L rinsed, acid-washed polyurethane bottles. Samples were collected from the water tank tap, generally installed near the bottom and above the tank sludge zone. In tanks that did not have outlet taps, water samples were collected from the tank water top inlet. A ladder to step on, and a sterile polyurethane bottle of 1 L attached to an extendable Mighty Gripper® cylindrical telescopic rod (John Morris Scientific Pty Ltd, Whangarei 0140, New Zealand) were used to collect samples from inside the middle of the tank.

For tanks that had filtration systems installed, and the tanks plumbed into the house, homeowners were asked to provide a sample of water from an indoor tap. For such tanks, an additional unfiltered sample was directly collected from the tank. As with samples collected from unplumbed tanks, samples from plumbed-in outlets were collected in sterile polyurethane containers of 1 L. In all cases (plumbed and unplumbed tanks), samples were collected by the researcher. Both filtered and unfiltered samples were tested for bacteria and metals.

To collect samples, water was left to run for several seconds prior to collecting. Once collected, water samples were transported back to the laboratory in a storage container on ice and processed immediately on arrival. Alternatively, samples were stored in the dark at 1°C and 4°C and processed within the next 24 hours. Parameters such as water pH and water temperature were taken in the field by a digital pH-618 Pen-Type Automatic Calibration IP65 Waterproof pH Meter (Shenzhen Handsome Technology Co., Ltd. Guangdong, China, Walcom Int'l Industry Ltd., Hong Kong, China).

A total of 365 rainwater samples were collected in the Adelaide region from 53 different tanks. Of these samples, 120 samples were collected from 18 tanks in the Adelaide plains, with 97 samples collected from 15 tanks in the Adelaide foothills, and 148 samples collected from 20 tanks in the Adelaide Hills. Samples were collected on a monthly basis or after a significant rainfall event that occurred between two sampling periods.

During the study period, events of significant rainfalls occurred in early autumn. Significant events included 17 mm and 18 mm of rainfall recorded at Blackwood (Wittunga) rain gauge station in the foothills on March 7 and March 10, 2016 respectively, after a prolonged drier period (Australian Bureau of Meteorology, 2018). In the Adelaide Hills, 14.6 mm and 21.6 mm of rainfall were recorded at Gumeracha rain gauge station, respectively on March 3 and March 11, 2016. At Kersbrook rain gauge station, event of significant rainfall (23.4 mm) occurred on March 10, 2016 (Australian Bureau of Meteorology, 2018) (Table 7).

Table 7. Rainfall at rain gauge stations closest to sampling sites (rainfall in mm)

Months	Adelaide Hills		Adelaide foothills		Adelaide plains	
	Gumeracha*	Kersbrook*	Belair*	Blackwood*	Seaton*	Kilburn*
June 15	29.8	28.8	44.8	41.0	26.2	39.6
Jul 15	96.8	91.6	54.8	97.2	49.2	31.0
Aug 15	92.2	85.4	26.6	79.6	36.6	21.0
Sept 15	50.8	45.6	42.8	42.6	19.1	34.8
Oct 15	14.2	13.4	38.6	11.4	8.0	13.2
Nov 15	11.6	16.6	50.6	17.6	17.0	20.0
Dec 15	0.0	13.8	51.6	12.0	0.0	71.8
Jan 16	43.2	43.2	58.6	57.3	32.1	22.4
Feb 16	13.2	18.2	18.0	23.2	15.6	20.0
Mar 16	45.2	48.4	49.8	61.4	40.0	38.2
Apr 16	10.8	11.0	11.2	12.4	9.0	32.6
May 16	198.4	146.4	125.6	112.8	71.0	25.8
Jun 16	115.0	108.8	121.2	108.2	69.0	29.6
Jul 16	175.8	153.2	145.8	151.0	90.4	31.0
Aug 16	90.8	96.8	79.0	84.4	52.4	21.0

Source: Australian Bureau of Meteorology (2018)

* Gumeracha. Station number: 23719, latitude: 34°82’S, Longitude: 138°89’E

* Kersbrook. Station number: 23877, latitude: 34°79’S, Longitude: 138°87’E

* Belair St Johns. Station number: 23890, Latitude: 35°00” S, Longitude: 138°62” E

* Blackwood. Station number: 23839, Latitude: 35°02” S, Longitude: 138°61’E

* Seaton. Station number: 23024, Latitude: 34°90’S, Longitude: 138°51’E

* Kilburn: Station number: 23134, Latitude: 34°85’S, Longitude: 138°59’E

Many tanks did not have water for sampling in summer as the water had been used by the household and drier conditions prevail in the region in summer, so sampling was not carried out in these times. After collection, rainwater samples were transported back to the laboratory in a storage container on ice. On arrival, the samples were immediately tested for microorganisms. For trace metals, the samples were acidified with nitric acid and then stored in a cold room at 4ºC until testing.

2.3. Sample processing and testing

2.3.1. Total coliforms and *Escherichia coli* quantification

The quantification of *Escherichia coli (E. coli)* and total coliforms was based on the Colilert IDEXX Quanti-Tray®/2000 water testing method (IDEXX Laboratories, Inc., Westbrook Maine 04092, USA). The method uses two enzyme substrates which are included with the Colilert®- a chromogen that reacts with the enzymes found in total coliforms, and a fluorogen that reacts with an enzyme found in *E. coli* (Ohio Water Microbiology Laboratory, 2013). A Colilert®-18 reagent was added to undiluted and unfiltered 100 mL rainwater in a 100 mL sterile polyurethane container. After settling, the sample was transferred in a Quanti-Tray®/2000, a semi-automated total coliform and *E. coli* enumeration method based on the Most Probable Number (MPN) for water bacterial analysis (Ohio Water Microbiology Laboratory, 2013). The Quanti-Tray®/2000 was sealed in a Quanti-Tray®/2000 Sealer, Model 2X (IDEXX Laboratories, Inc., Westbrook, Maine 04092 USA). The sealed Quanti-Tray®/2000 was incubated for 24 hours at 37 °C in an Air-Jacketed Automatic CO_2 Incubator, Model NU-5100 (Plymouth, Minnesota 55447, USA). After the incubation period, Quanti-Tray® wells positive to total coliforms (yellow), and to *E. coli* (blue fluorescent) under 6-watt, 365 nm long-wave ultraviolet lamp (Model VL-215L, Vilber Lourmat, Marle la Vallée, France) were counted (Figure 12). The Idexx Quanti-Tray®/2000 MPN Table has 49 large wells and 48 small wells. Bacteria numbers are estimated by means of the Most Probable Number (MPN) estimate. In the MPN Table, numbers range from 0.0 MPN and >2419.6 MPN/100 mL.

Figure 12. Image of a Quanti-Tray®/2000 containing a rainwater sample. The yellow wells are positive for total coliforms and the blue fluorescent wells are positive for *E. coli*.

2.3.2. Assays for trace metal determination

Samples for metal analysis were collected into 1 L acid-washed polyurethane bottles and filtered through 22 µm pore size filters (Whatman® ashless filters Grade 541, Whatman, London). A filtered sample of 100 mL was stored in a 100 mL polyurethane bottle prior to analysis. Samples were filtered to reduce the amount of suspended matter associated with the sample, to reduce the risk of obstruction in the instrument capillary tubing. Studies indicate that paper filters can contain quantities of dissolved metals that can be leached in the sample matrix during water filtration, as samples to filter are usually acidified (Matoug, 2013, d'Halluin et al., 2017). The metals that can be found in paper filters include, but are not limited to, chromium, zinc, copper, magnesium, barium and molybdenum (Hedberg et al., 2011, Matoug, 2013) . Thus, filters were tested for chromium, copper, lead and zinc before use. To do this, deionised water was run through Whatman® paper filters, and the water tested for metals. This blank was run before each assay.

Each 250 mL rainwater sample was acidified using 2.5 mL nitric acid (NHO_3) at 1% concentration. There are several reasons for acidification; to bring the sample pH<2, for sample conservation; to minimise metal precipitation and adsorption on the surface of the water container walls; to stop the growth of microorganisms in the water; and to convert trace metals into the same oxidation state (Batley and Gardner, 1977). After acidification, samples were stored in a cold room at 4°C, prior to analysis. The initial sample analysis used a Grey-Bartlett-Charlton 902 atomic absorption spectrometer unit (GBC 902 AAS) (GBC Scientific Equipment Australia Ltd, Dandenong, Melbourne, Australia). These analyses were hindered by an equipment calibration problem. The unit uses an outdated SavantAA Windows® software package for calibration and data analysis. Therefore, subsequent analyses were undertaken using a GBC 933 AAS (Figure 13). Samples were analysed for total cadmium, total copper, total lead and total zinc. The unit uses acetylene (C_2H_2) and air as the oxidant to ignite the atomic flame, and Avanta Software for Windows® 95 for the equipment calibration and data analysis (GBC Scientific Equipment Australia Ltd, Dandenong, Melbourne, Australia).

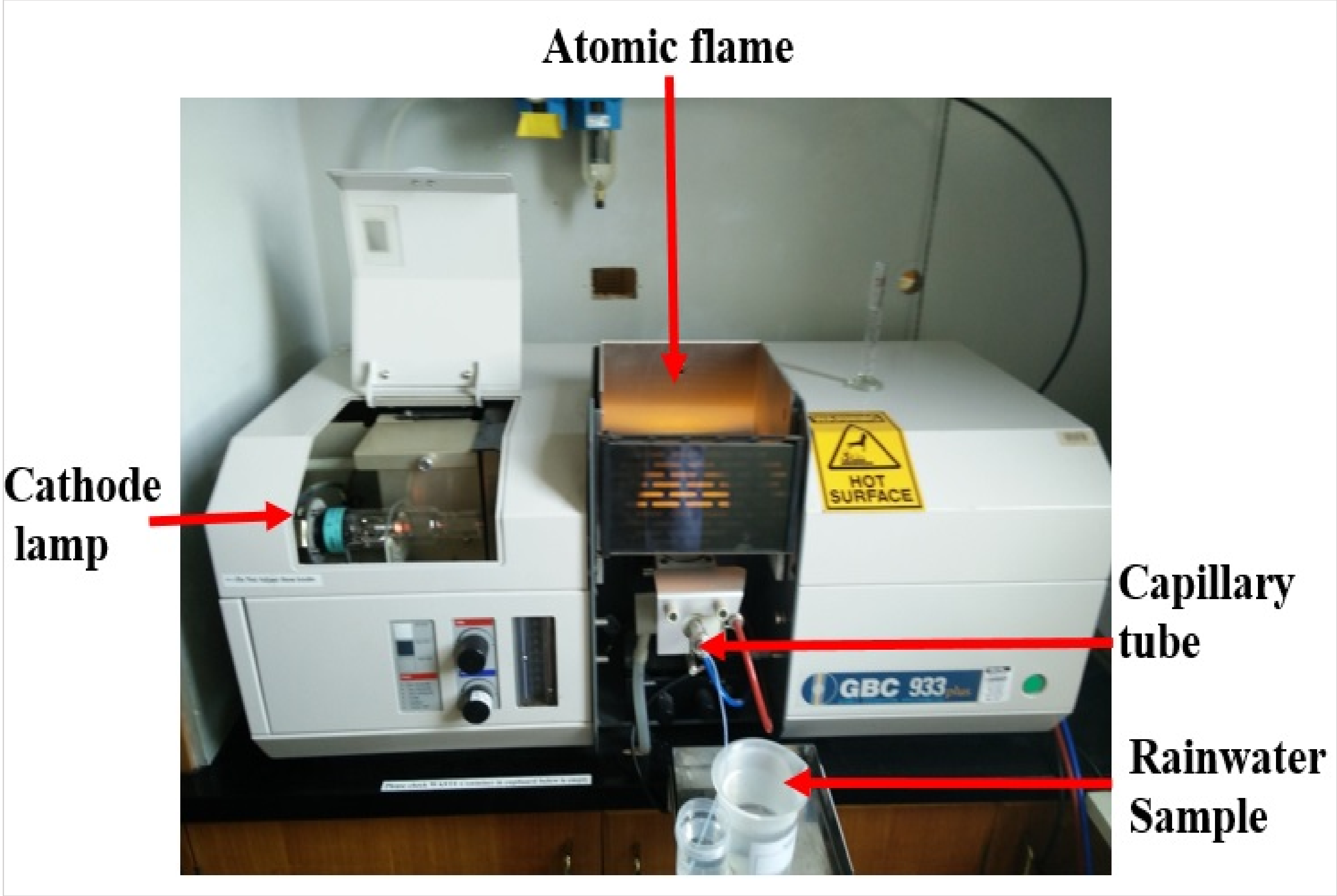


Figure 13. GBC 933 AAS showing hollow cathode lamp and the atomic flame

The GBC 933 AAS uses cableless Photron Coded Hollow Cathode Lamps for common elements as the source of radiation to excite free atoms into the atomic flame (Photron Ptd Ltd, Narre Warren, Victoria, Australia 3805). Working ranges are presented in Table 2.1. Also presented are health standards set by the National Health and Medical Research Council of Australia (NHMRC), as outlined in the Australian Drinking Water Guidelines (NHMRC, 2011), and the GBC 933 AAS detection limit as specified in the flame methods manual for atomic absorption by GBC Scientific Equipment Pty Ltd (2002).

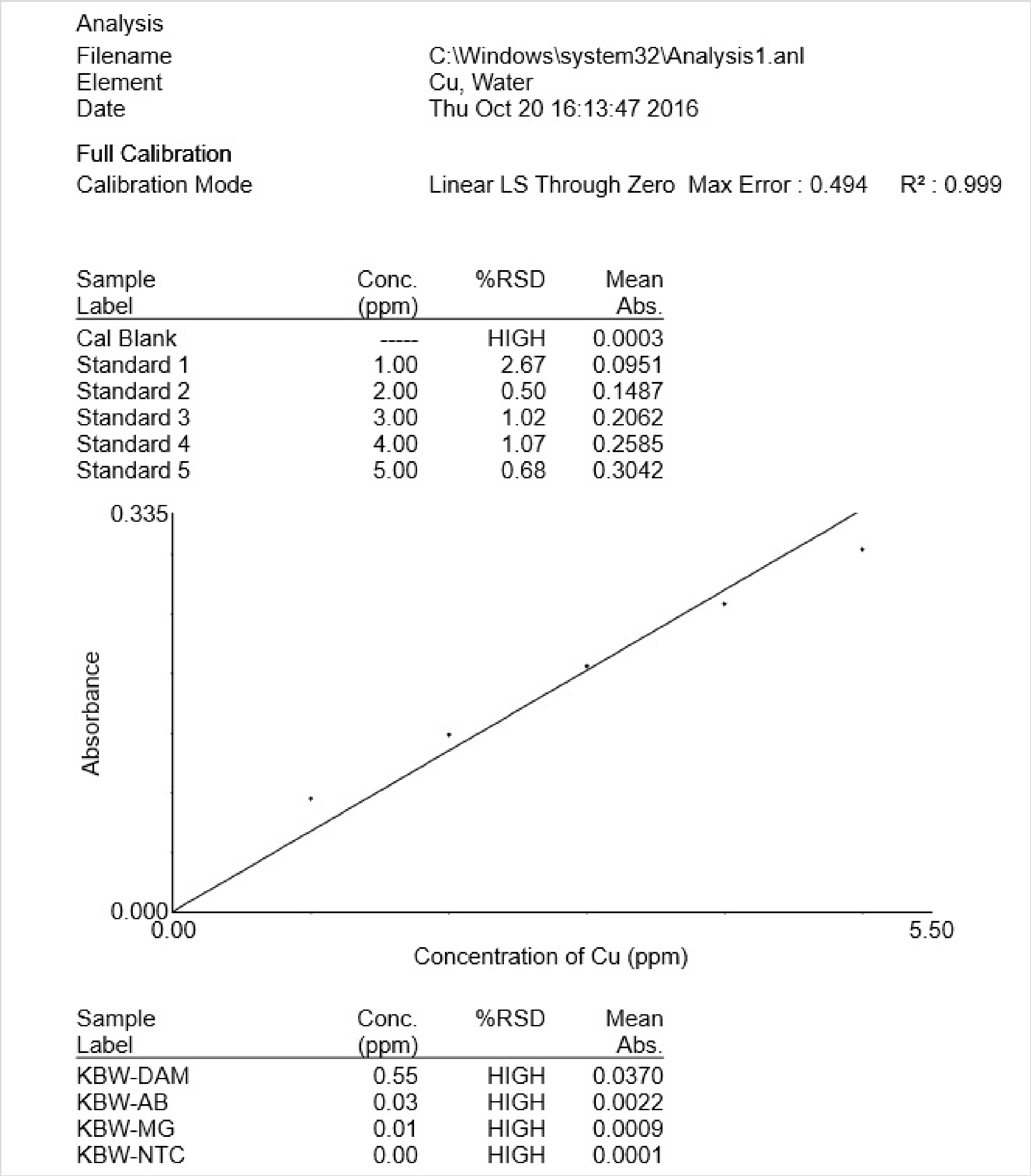
Table 8. Working ranges and NHMRC guideline concentrations

Element	Working ranges (μg/L)	Detection limit (μg/L)	NHMRC guideline (μg/L)
Cadmium	0.01 – 2.00	0.009	20
Copper	1.00 – 5.00	0.025	2000
Lead	0.01 – 2.00	0.06	10
Zinc	0.50 – 10.00	0.008	3000

Sources: GBC Scientific Equipment Pty Ltd (2002).

Cadmium, copper, lead and zinc standards solutions were created from elemental standards stocks of 1,000 mg/L in 2% nitric acid matrix (HNO_3). Five standard solutions were created for each element. Elemental stock solutions for lead, zinc, cadmium, and copper were digested in 2% nitric acid concentration (HNO_3). A calibration blank was run before samples. To create a calibration blank for cadmium, copper, lead and zinc, 2.5-mL nitric acid (HNO_3) at 1%

concentration was transferred into 997.5 mL deionised water. Samples were analysed in triplicate. The linear regression coefficient (R^2) for the GBC 933 AAS calibration standards by means of Linear Least Squares was 0.999 for all metals (example presented in Figure 14).



```
Analysis
Filename                 C:\Windows\system32\Analysis1.anl
Element                  Cu, Water
Date                     Thu Oct 20 16:13:47 2016

Full Calibration
Calibration Mode         Linear LS Through Zero  Max Error : 0.494     R² : 0.999


Sample                  Conc.     %RSD      Mean
Label                   (ppm)               Abs.
------------------------------------------------
Cal Blank               -----     HIGH    0.0003
Standard 1               1.00     2.67    0.0951
Standard 2               2.00     0.50    0.1487
Standard 3               3.00     1.02    0.2062
Standard 4               4.00     1.07    0.2585
Standard 5               5.00     0.68    0.3042
```

```
Sample                  Conc.     %RSD      Mean
Label                   (ppm)               Abs.
------------------------------------------------
KBW-DAM                  0.55     HIGH    0.0370
KBW-AB                   0.03     HIGH    0.0022
KBW-MG                   0.01     HIGH    0.0009
KBW-NTC                  0.00     HIGH    0.0001
```

Figure 14. Copper full calibration standard by means of linear least square through zero

2.3.3. Assessment of efficacy of filters in rainwater sanitation

This section essentially focuses on filters efficacy to remove contaminants from rainwater. During the survey, the proportion of respondents who indicated treating their rainwater stated that using filters to improve their water quality. There was no reference made to water boiling practice, although the method, at scorching temperature, is efficient to deactivate microorganisms in water, although it does not remove trace metals. To evaluate the efficacy of a commercially available filter to remove contaminants from rainwater, an under bench double console Puratap® water filtration unit (Puratap® Pty Ltd, Stepney, SA 5069, Australia), with a pre-sediment cartridge (membrane cartridge) of 1 µm/pore size, and an activated carbon cartridge of 0.45 µm/pore size was installed in the laboratory. The diagram in Figure 15 shows the filtration unit design, and the running procedure. A photograph of the unit is presented in Appendix 9.

The water filtration unit was worked by a powered Cole-Parmer MasterFlex Peristaltic® L/S pump of 600 rotations/minute (rpm), Model 7553-79 and a Cole-Parmer MasterFlex L/S Modular Controller 7553-78 (Cole-Parmer Instrument Co, Vernon Hills, Illinois 60061, USA). MasterFlex tubing connectors were connected to the MasterFlex Peristaltic pump to allow the flow of water from the pump through the filter to the supplied outlet tap for collection. Working at full capacity (speed 10), a Peristaltic® L/S pump delivers 3.4 L of water every minute (Cole-Parmer, 2015). To run the experiment, samples were collected from a participant's tank known to have high *E. coli* levels. From early January 2016 to late June 2016, a total of 53 rainwater samples of 5 L each were collected from this tank, run through the filter and tested for total coliforms and for *E. coli*.

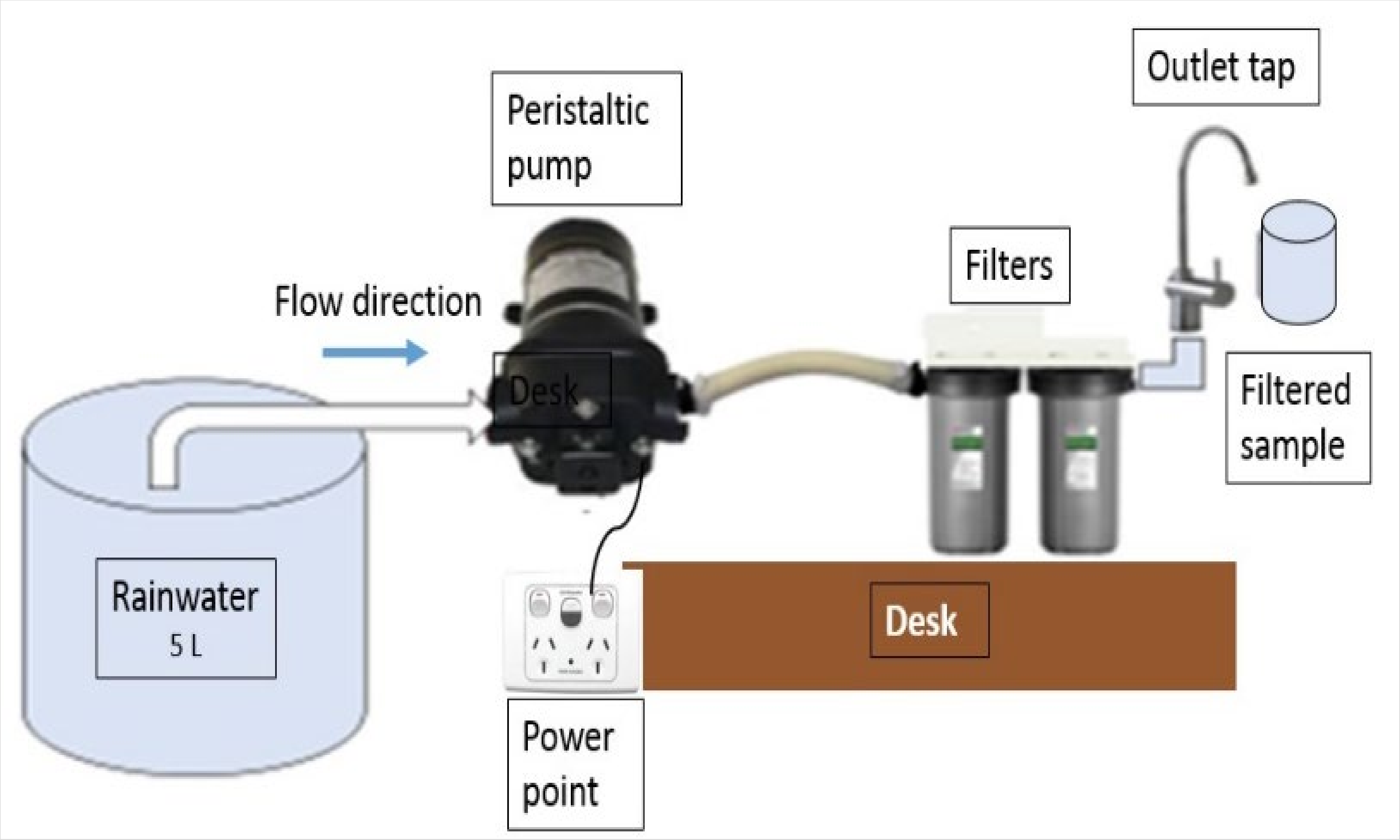


Figure 15. Diagram of the laboratory under bench mounted filtration unit

2.4. Survey of household drinking water attitudes

This section critically investigates the drive behind an important fraction of Adelaide households to give preference to potentially contaminated rainwater when treated municipal water is made readily available to the community by water utilities. An attempt to identify to which socio-economic group rainwater consumers belong to in the community will be carried.

2.4.1. Site identification and survey techniques

Areas chosen to undertake the surveys were selected to maximise the chance of reaching many households, and from all socio-economic classes, to maximise the chance of having people from all social layers of the community participate to the survey. Thus, the decision was made to carry out the survey in carparks adjacent to shopping malls during the busiest times, from 9:00 am to 3:00 pm. At times, interviews were conducted on Saturdays and Sundays to maximise the chance to meet with people who would be working during the week. An application to allow the access to survey sites and a certificate of public liability (Certificate N°: UL FLI 16) were sent to the management of shopping malls, in accordance with the provision of South Australia Trespass Act 1953 which regulates entries onto private properties (Government of South Australia, 2018) (Appendix 6). In the Adelaide region, most shopping malls are owned privately. A request to allow the access to the study area was sent by email. In event of late response or response not received, officers in shopping malls were directly contacted to obtain the approval.

The survey was conducted from March to May 2016 in five locations in the Adelaide region (Figure 2.1). Two locations were identified in the Adelaide plains, one in the Adelaide foothills and two in the Adelaide hills. Sites where the survey was conducted were West Lakes Shopping Centre (34º52’48”S, 138º29’23”E), Arndale Shopping Centre (34º52’22”S, 138º32’56”E) in the Adelaide plains, Blackwood Shopping Centre (35º1’13”S, 138º36’56”E) in the Adelaide foothills, Mount Barker Shopping Centre (35º3’57”S, 138º51’31”E), and Lobethal Shopping Centre (35º3’57”S, 138º51’31”E) in the Adelaide hills. Shopping malls geodetic coordinates were recorded by a Garmin GPS 64s. Four shopping centres that were contacted declined to allow access to their sites to conduct the survey.

The sampling method for the survey on household drinking water attitudes was convenience sampling, a non-probability sampling method that collects on data from population members who are conveniently available to participate and that meets some pre-established criteria (Etikan et al., 2016). Thus, participants were selected among people aged 18 years and over who accepted to answer the survey questionnaire, entering or leaving the shopping centre. However, the sample size was limited to the time available to conduct the surveys. The researcher only recorded the people who voluntarily accepted to participate to the study. For convenience, those who declined to answer the survey questionnaire were not recorded. It is estimated that about 30% of people who were approached accepted to participate to the study.

The survey used the National Statistical Service (NSS) sample calculator to determine the sample size, using 95% as confidence level (CL), 0.5 as proportion, 0.05 as confidence interval (CI) and 5.11 as relative standard error (RSE) (Australian Bureau of Statistics, 2016b). When the initial proportion is unknown, as a rule it is set the proportion of the population which is likely to display the attitude to 0.5 or 50%, as a conservative estimate of variance (Australian Bureau of Statistics, 2016b). The survey involved 459 respondents. The sample was representative of an estimate 562,147 households identified in Adelaide in 2016 (Australian Bureau of Statistics, 2016a). Participants were randomly[7] chosen among people entering or leaving shopping malls, and answering questions was voluntary. The survey was anonymous. A brief introduction to the survey topic, aim and objectives was made to participants prior starting the interview. A few numbers of people did not want to be approached as they believed the activity was about money raising for charities. Of 510 persons who were approached during the survey, 459 people (90%) accepted to fully participate and answered the survey questionnaire.

2.4.2. Questionnaire construction and design

This section presents the procedure that was used to design the survey questionnaire, and the survey operating mode. In the survey, closed-ended questions were asked to respondents. Similar to multiple choice questions, closed-ended questions give to the respondent the freedom to select the answers they believe most appropriate to their situation (Nardi, 2018). The questions were written and then read to respondents who had accepted to participate to the study. In turn, the replies to the questions were given verbally. The answers were recorded by the researcher, putting a tick on chosen response on the questionnaire paper for those answers that were common, and a written record of those answers that were not on the list. Five questions were put to participants. The maximum time to answer the questionnaire was estimated at three minutes. Some respondents devoted more time to expand their views on drinking water qualities. Questions asked to participants included suggested responses as prompts and allowed free responses where desired (Appendix 7). The names and

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[7] Note. The word randomly has been replaced by the word ‘opportunistically’

respondents' addresses were not recorded, to keep the survey anonymity, based on the study ethics.

2.3.4. Public discussions on drinking water quality

In this section, internet discussions boards and online platforms with discussions about drinking water were searched to obtain information on drinking water quality, perception of quality and risk perception. Text posted on these discussions boards was analysed to determine reasons for drinking water choice.

2.5. Data Statistical Analysis

Data from the study of microbial contamination of rainwater were graphed using Microsoft Excel (Microsoft Corporation, Washington, WC, USA), and analysed using IBM SPSS statistical software package (IBM SPSS Statistics for Windows, Version 23.0. IBM Corp, Armonk, NY, USA), and GraphPad Prism 7.02 (GraphPad Software, Inc., San Diego, CA, USA). The relationships between variables were tested using analysis of variance after testing for normality. Bacterial data were also transformed using a log transformation and retested. Each replicate was considered was considered in its own right, and the data were not tested as clusters.

Data from the study of metal contamination of rainwater were entered and graphed using Microsoft Excel (Microsoft Corporation, Washington, USA) and GraphPad Prism software (GraphPad Software, Inc. San Diego USA). Data were tested for normality and relationships between variables were tested using analysis of variance for metal concentrations and different roof and tank materials, presence of a first flush device, sampling corridor and pH. Before and after filtration metal concentrations were compared using a paired t-test. Each replicate was considered in its own right, and the data were not tested as clusters.

Data from the survey were entered and graphed using Microsoft Excel (Microsoft Corporation, Washington, USA) and GraphPad Prism software (GraphPad Software, Inc. San Diego USA) and were tested using Chi-squared analysis to determine whether there was a relationship between any of the variables.

2.6. Limitation to study

This longitudinal study provides insight into rainwater quality in the Adelaide region. However, it should be noted that the are some limitations of this research. The study was reliant on people being willing to allow the researcher to collect water from their tanks. Of the 500 letters sent out, only 53 responded, a very low response rate. Additionally, many people refused to participate in the survey.

Following drier conditions that prevail in the Adelaide region in summer, samples were not collected in some locations in due to lack of water to collect in many tanks. This resulted in further reduction in number of samples able to be collected. In addition, a few households living in rental tenancies who agreed to allow access to their tanks moved out and were replaced by less cooperative tenants. It is not clear whether the people exposed to high levels of lead have elevated levels of lead in their blood. The logical next step for this research wold be to test those people that are drinking rainwater that has high levels of lead to determine whether the levels they are being exposed to are high enough to cause elevated blood lead levels however this was beyond the scope of this study, but make interpretation of the results with respect to toxicological impact difficult.

CHAPTER 3. RAINWATER MICROBIOLOGY

3.1. Publication: Microbiological Values of Rainwater Harvested in Adelaide

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Microbiological Values of Rainwater Harvested in Adelaide

3.1.1. Abstract

In Australia, rainwater is an important source of water for many households. Unlike municipal water, rainwater is often consumed untreated. This study investigated the potential contamination of rainwater by microorganisms. Samples from 53 rainwater tanks across the Adelaide region were collected and tested using Colilert™ IDEXX Quanti-Tray*/2000. Twenty-eight out of the 53 tanks (53%) contained *Escherichia coli*. Samples collected from ten tanks contained *E. coli* at concentrations exceeding the limit of 150 MPN/100 mL for recreational water quality. A decline in *E. coli* was observed in samples collected after prolonged dry periods. Rainwater microbiological values depended on the harvesting environment conditions. A relationship was found between mounted TV antenna on rooftops and hanging canopies; and *E. coli* abundance. Conversely, there was no relationship between seasonality and *E. coli* or roof and tank structure materials and *E. coli*. In several tanks used for drinking water, samples collected prior to and after filtration showed that the filtration systems were not always successful at completely removing *E. coli*. These results differed from a study undertaken in the laboratory that found that a commercially available in-bench 0.45 µm filter cartridge successfully reduced *E. coli* in rainwater to 0 MPN/100 mL. After running a total of 265 L of rainwater which contained high levels of *E. coli* through the filter (half of the advertised filter lifespan), the filter cartridge became blocked, although *E. coli* remained undetected in filtered water. The difference between the laboratory study and field samples could be due to improper maintenance or installation of filters or

recontamination of the faucet after filtration. The presence of *E. coli* in water that is currently used for drinking poses a potential health concern and indicates the potential for contamination with other waterborne pathogens.

3.1.2. Introduction

Worldwide, rainwater harvesting has the potential to supplement surface and groundwater resources in areas that have inadequate water supply (Aladenola and Adeboye, 2010). In Australia, there has been an increase in harvesting rainwater to supplement municipal water. Until recently, the Australian Federal Government and many State Governments were offering financial incentives to householders to install rainwater harvesting systems (Department of the Environment and Energy, 2011). The incentives were intended to make substantial savings on municipal water, to alleviate the problem linked with water restriction measures; and to mitigate drought conditions (Department of the Environment, 2015). This resulted in 34% of Australian homes having rainwater tanks installed on their properties (Australian Bureau of Statistics (ABS), 2013). The proportion of households with tanks on their properties was higher in South Australia and in Adelaide compared with other Australian States and major cities. In that period, 76% of families in regional South Australia and 34% in Adelaide used rainwater (Department of the Environment and Energy, 2011) as their source of drinking water (Australian Bureau of Statistics (ABS), 2013).

In the community, there is a general belief that rainwater can be used for drinking with limited treatment (Hurlimann and Dolnicar, 2010), and that unlike municipal water which is believed to contain contaminants, rainwater is of higher quality as stated by rainwater users in South East of Queensland (Mankad et al., 2010). The

South Australian Health Department (SA Health) advice is that if rainwater is collected from a roof is clear and has little taste and is collected from a well-maintained catchment system and tank, it is probably safe to drink (SA Health, 2011). Like SA Health advice, recommendations from the enHealth is that drinking rainwater from a well-maintained roof catchment and tanks represents a relatively low risk of illness (enHealth, 2010). This guidance is supported by epidemiological evidence from a study of 1016 children aged 4-6 years from regional South Australia who drank rainwater which found no difference in gastroenteritis incidents compared with their peers who drank centralized municipal water (Heyworth et al., 2006). In those that drank rainwater, the frequent exposure to pathogens might have enhanced their immune system, as the system can control the pathogens before they become harmful [8](Price and Walker, 2015). However, this epidemiological evidence does not take into consideration vulnerable populations, including immunocompromised and the elderly, `who may be at greater risk (Zhu et al., 2015). Pathogenic organisms, including *Aeromonas, Campylobacter, Legionella, Salmonella, Giardia lambilia* and *E. coli*, have been found in rainwater harvested in many locations across Australia (Chubaka et al., 2018). There have also been several reported outbreaks of salmonellosis, giardiasis and cryptosporidiosis that have been linked to contaminated rainwater (Taylor et al., 2000, Franklin et al., 2009, enHealth,

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[8] Note. In people who are frequently exposed to pathogenic organisms like in those who drink untreated rainwater, their body immune system might have enhanced the mechanisms to control the pathogen before they become harmful. In their book at page 4 and page 12, Price and Walker (2015) note that the human body has an adaptor immune system that recognises and remembers specific groups of pathogens, conferring immunity after exposure.

2010). This investigation had three objectives, firstly, to determine whether the microbial content of rainwater reported elsewhere was similar in South Australia, secondly, to assess the number of householders filtering their rainwater and whether this filtration is successful and thirdly, to test whether a commercially available filtration system removed microbial contamination to an acceptable level for potable water.

3.1.3. Results

3.1.3.1. Microbiological Values of Harvested Rainwater

Total coliforms and *E. coli* were regularly detected in rainwater samples. Table 9 presents all the tanks that were positive for total coliforms or *E. coli*, the primary use of the rainwater, the tank and roof material, the presence or absence of a water filter, and factors linked to rainwater harvesting immediate environment.[9]

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[9] Note. Appendix 13, Table 23. Summary table of all tanks sampled for microbes

Table 9. Number of samples found positive to total coliforms and *E. coli* in some tanks[10] (in MPN/100/mL).

Tank Number	Rainwater Use	Filter on Tank	Positive to Total Coliforms /8 Samples	Positive to *E. coli* /8 Samples	Total Coliforms: Minimum and Maximum Detection	*E. coli:* Minimum and Maximum Detection	Roof Material	Tank Material	TV Antenna on Rooftop	Hanging Canopy
1	Drinking	No	8	6	18.5-2419.6	1.0-59.1	Galvanized	Galvanized	Yes	No
2	Drinking	Yes (before filter)	8	6	1046.2-613.1	866.4-461.1	Galvanized	Polyethylene	Yes	No
		Yes (after filter)	8	5	28.8-365.4	1.0-13.4				
3	Drinking	Yes (before filter)	7	4	58.6-≥2419.6	11.0-365.4	Galvanized	Polyethylene	Yes	No
		Yes (after filter)	5	2	42.6-866.4	1.0-5.2				

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[10] MPN/100 mL

4	Drinking	No	8	5	1.0-≥2419.6*	1.0-980.4	Galvanized	Polyethylene	Yes	No
5	Drinking	Yes (before filter)	8	7	140.8-≥2419.6*	13.2-1986.3	Tiles	Polyethylene	No	Yes
		Yes (after filter)	7	5	172.3-648.8	2.0-50.4				
6	Drinking	No	8	6	5.2-≥2419.6*	1.0-7.2	Tiles	Polyethylene	Yes	Yes
7	Drinking	Yes (before filter)	8	5	1.0-≥2419.6*	1.0-≥2419.6*	Galvanized	Galvanized	No	Yes
		Yes (after filter)	6	3	1.0-≥2419.6*	1.0-≥2419.6*				
8	Drinking	No	6	3	2.0-≥2419.6*	1.0-39.3	Galvanized	Concrete	No	No
9	Drinking	Yes (before filter)	8	3	256.5-≥2419.6*	2.0-22.8	Galvanized	Polyethylene	Yes	No

		Yes (after filter)	2	1	24.3-1553.1	<1.0-1.0				
10	Drinking	Yes (before filter)	6	3	32.7-1986.3	13.4-648.8	Galvanized	Polyethylene	Yes	Yes
		Yes (after filter)	3	2	3.0-88.2	1.0-11.0				
11	Drinking	Yes (before filter)	6	3	29.9-≥2419.6*	1.0-24.6	Galvanized	Polyethylene	Yes	Yes
		Yes (after filter)	4	1	8.6-≥2419.6*	<1.0-2.0				
12	Gardening	No	8	6	151.5-≥2419.6*	3.2-111.2	Tiles	Galvanized	Yes	Yes
13	Gardening	No	8	7	83.6-≥2419.6*	6.0-648.8	Tiles	Polyethylene	No	Yes
14	Gardening	No	6	3	4.1-1986.3	4.1-38.9	Tiles	Galvanized	Yes	No
15	Gardening	No	6	5	24.6-1203.3	1.0-33.1	Tiles	Galvanized	Yes	No

16	Gardening	No	6	4	18.5-1119.9	1.0-517.2	Tiles	Galvanized	Yes	No
17	Toilets flushing	No	8	2	22.9-307.6	1.0-2.0	Galvanized	Galvanized	No	No
18	Toilets flushing	No	8	8	14.4-259.5	1.0-27.5	Galvanized	Polyethylene	No	No
19	Toilets flushing	No	8	6	179.3-1413.6	2.0-461.1	Tiles	Polyethylene	No	No
20	Toilets flushing	No	8	6	142.1-1299.9	3.1-1203.3	Tiles	Polyethylene	No	No
21	Toilets flushing	No	8	6	165.0-≥2419.6*	1.0-1986.3	Tiles	Polyethylene	No	No
22	Toilets flushing	No	6	2	17.5-107.6	9.7-14.8	Tiles	Polyethylene	Yes	No
23	Toilets flushing	Yes	8	6	18.9-≥2419.6*	2.0-435.2	Galvanized	Polyethylene	No	No
24	Toilets flushing	No	5	1	16.4-≥2419.6*	1.0-107.1	Galvanized	Polyethylene	No	Yes
25	Toilets flushing	No	6	4	119.9-≥2419.6*	2.0-18.7	Galvanized	Galvanized	No	No

26	Toilets flushing	No	8	8	27.5-≥2419.6*	1.0-≥2419.6*	Galvanized	Polyethylene	No	No
27	Firefighting	No	6	1	5.2-1986.3	1.0-325.5	Galvanized	Polyethylene	Yes	No
28	Unused	No	6	6	13.5-1299.7	1.0-58.6	Tiles	Galvanized	Yes	Yes

* Count that exceeded the quantification limit of 2416.9 MPN/100 mL in the IDEXX Quanti-Tray*/2000 Most Probable Number Table[11]. * Not inclusive of samples that contained < 1.0 MPN/mL, and samples only positive to total coliforms.

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[11] Note. Data have been log-transformed and a table is now included in the appendix (Appendix 14, Table 25). Note. Transformation did not change those parameters that had a statistically significant relationship.

E. coli was detected in 53% (28 tanks) of all tanks that were surveyed (tanks were sampled 6-9 times over the course of this study—August 2015-August 2016). Of tanks that did not contain *E. coli*, 33% (18 tanks) contained total coliforms during all sampling rounds. Water collected from fifteen tanks exceeded the count of 200 MPN/100 mL for *E. coli*. Eleven out of the fifty-three tanks were plumbed-in, and the water used as source of drinking water. This represented 21% of tanks that were surveyed. Of these tanks, seven tanks (64%) were fitted with filtration systems for water sanitation (Table 8).

Samples collected from all seven tanks that had filtration systems installed contained *E. coli* and for more than one sampling event (Figure 16). The concentration of *E. coli* in samples collected post-filtration was overall statistically significantly less than in the pre-filtration samples ($P = < 0.16 \times 10^{-5}$); however, the filters did not always completely remove *E. coli*. Four tanks that were used for drinking that did not have filters fitted often contained *E. coli*.

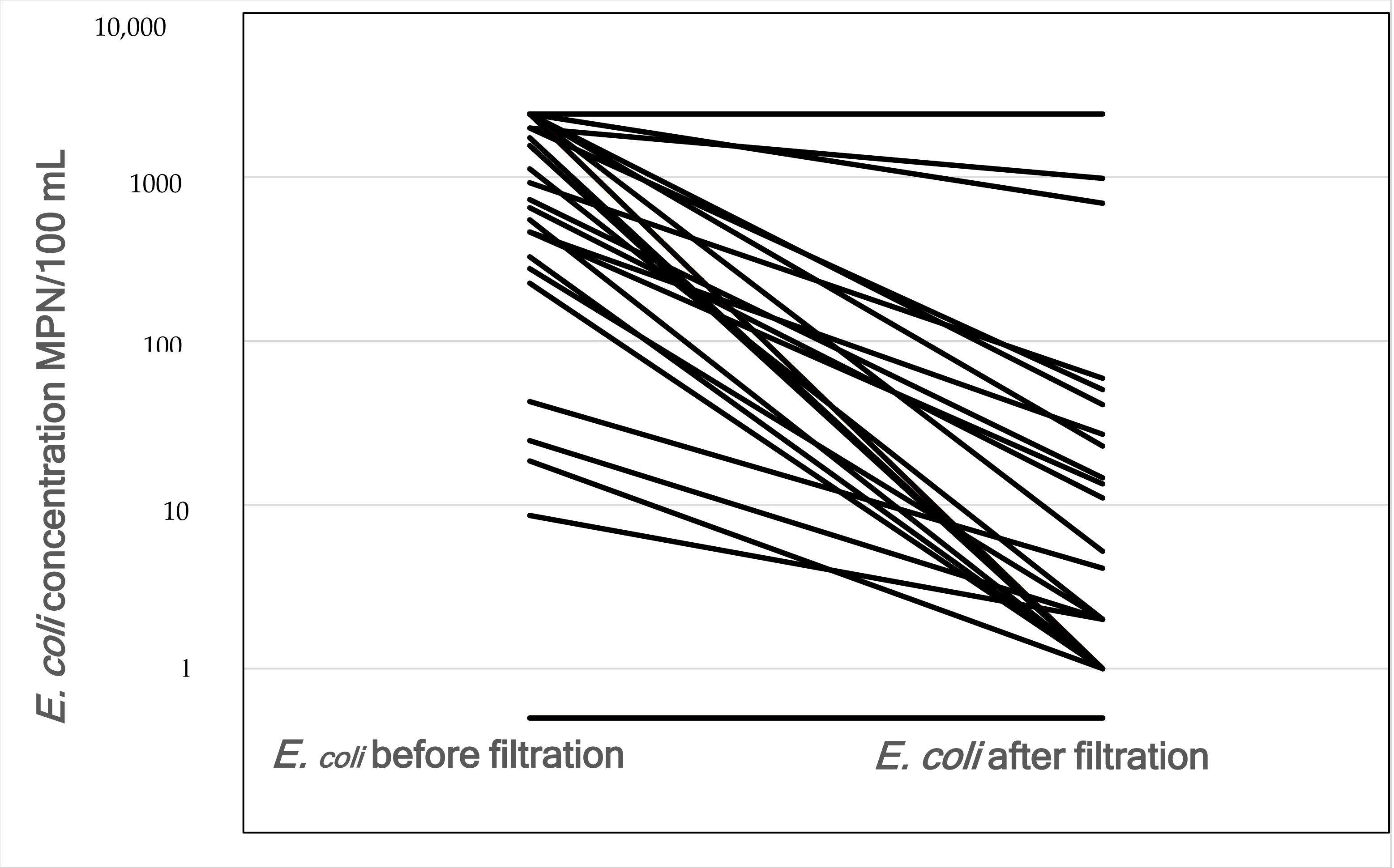

Figure 16. Concentration of *E. coli* present before and after filtration in rainwater tanks used for drinking water with filters fitted.

Water from the remaining forty-two tanks (79% of tanks surveyed) were either used for indoor purposes such as toilet flushing or for outdoor purposes, such as gardening or firefighting. It should be noted that of the twenty-eight tanks that contained *E. coli*, ten tanks (19%) were plumbed-in for toilets flushing, and water from five tanks (9%) was used outdoor for gardening. In addition, water from one tank (2%) was used for firefighting and water from another tank (2% of tanks surveyed) was not used for any purpose.

The use of coliforms as indicator organisms has been previously debated; however, this study demonstrated that there was a relationship between the total number of coliforms (MPN/100 mL) and total number of *E. coli* (MPN/100 mL). This relationship is not a surprise given that *E. coli* is a coliform. The problem with using coliforms as indicator organisms is that they are not specifically of faecal origin and are present naturally in the environment. The linear regression (R^2 = 0.145, and *p*-value <0.01) indicates there is a weak correlation with faecal contamination. The study observed no seasonality in bacteria load in samples however; a moderate relationship was observed between total coliforms and *E. coli* in samples collected during both winter and summer months. However, a difference in bacteria load was observed after significant period of no rainfall. Moreover, there was a relationship between rainwater temperature and *E. coli* abundance (R^2 = 0.321, *p*-value < 0.001). Temperature values ranged from 5.7 °C to 29.5 °C. Thus, increased rainwater temperature was associated with increased *E. coli* concentrations. Conversely, the regression analysis found no linear relationship between rainwater pH and *E. coli* abundance (R^2 = −0.005, and *p*-value = 0.17). Rainwater pH ranged from 4.5 to 8.8. Thirteen samples had a pH lower than 6.0, which is a level below which is potentially corrosive to structure materials, if the level of alkalinity is low (Rodrigo et al., 2009).

3.1.3.2. Physical Environment around Rainwater Harvesting Systems

The building materials used in the catchment areas; building rooftops, gutters and tanks downpipes, were assessed to determine whether the building materials played a role in rainwater microbial contamination. It was found that there was no relationship between building structure materials and rainwater microbial content. In addition, hanging canopies and mounted TV antennas on building rooftops were identified. Having a TV antenna impacted on bacteria abundance in rainwater samples. It was found that 19% of samples that were harvested from building with mounted TV antennas contained *E. coli*. Likewise, 12% of samples harvested from catchments partially covered by hanging canopies contained *E. coli*. The regression analysis ($R^2 = 0.025$, p-value < 0.001) indicated a weak but positive correlation between the presence of mounted TV antennas on building rooftops and hanging canopies, and *E. coli* abundance. Nearly 75% of catchment areas that were partially covered by trees canopies had mounted TV antennas installed[12]. For the fifty-three tanks surveyed, there were no maintenance works reported on catchments areas, gutters, downpipes or tanks. No relationship

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[12] Note. A weak relationship was found to exist between the temperature of the water and the presence of TV antenna over the catchment, and *E. coli* abundance. This could be interpreted as a linear relationship where, for each degree increase in temperature, the concentration of *E. coli* is expected to increase by 0.566 MPN/100 mL. However, given the weak correlation, this should be interpreted with caution.

between having a first flush device and *E. coli* and total coliform content was found ($R^2 = 0.003$, *p*-value = 0.956 and $R^2 = 0.003$, *p*-value = 0.53 respectively).

3.1.3.3. Investigating the Efficacy of a Water Filtration System to Remove Microbial Contamination

A laboratory study was conducted to evaluate the efficacy of a commercially available filter to remove microorganisms. It was found that before filtration, 93% of samples contained total coliforms and 54% contained *E. coli*. The organism count ranged from <1.0 MPN/100 mL-≥ 2419.6 MPN/100 mL for both total coliforms and *E. coli*. Filtration reduced the organisms count to 0 MPN/100 mL in all samples for target bacteria. This indicated that under laboratory conditions the filtration system is able to remove bacteria from rainwater. The filter reduced rainwater bacterial load to acceptable safety limit of 0 MPN/100 mL for *E. coli* in drinking water.

The bench mounted filtration unit reached clogging point was reached after 265 L rainwater had passed through the filter over a 6 months period (half of Puratap® cartridge's advertised lifespan). Since a little water was left in the two cartridges (1 L/cartridge) at the filter clogging point, this water was tested for bacteria. The intention was to verify whether the bacteria could still grow and be detected in the water that remained in the cartridges while undetected in filtered water. In the inlet cartridge (membrane cartridge), organisms count for total coliforms was ≥2419.6 MPN/100 mL, and 55.4 MPN/100 mL for *E. coli*. Likewise, in the outlet cartridge (activated carbon cartridge), organisms count was 178.9 MPN/100 mL for total coliforms and 48.7 MPN/100 mL of *E. coli*. This suggests that the bacteria could still be detected in the water in both cartridges while its passage through the filtration unit remained blocked, and no bacteria could be detected in rainwater collected at the top end of the connected tap.

3.1.4. Discussion

In Australia, *E. coli* guidelines for drinking water is ≤ 0 MPN/100 mL (The National Health and Medical Research Council (NHMRC), 2011). Nearly 54% (197/365) of samples tested in this study were found to be positive for *E. coli*. Of this total, 60 samples (30%) that contained *E. coli* were collected from 11 tanks. This represented 21% of tanks surveyed. These tanks were plumbed-in and fitted with filters, and the water used as source of drinking water. These findings are higher compared with the study conducted in 2007 in regional South Australia that found 30% of 974 rainwater samples collected from 325 rainwater tanks were positive for *E. coli* (Rodrigo et al., 2009).

The most significant findings from this study was the number of tanks that had filters fitted and still tested positive to *E. coli*. This is consistent with White et al. (2007) who suggests that not all filters are designed to remove bacteria from rainwater. Thus, it was found that all water samples from tanks that were fitted with filtration systems contained *E. coli*, on more than one occasion (Table 1). These results contradicted the findings from the experimental, laboratory testing of a Puratap® filter. Laboratory testing demonstrated that a Puratap® filter effectively removed all *E. coli* and total coliform contamination from the rainwater. Notably, the filter only managed 1/10 of its advertised filtration capacity before becoming blocked. In tanks with higher suspended solids, cartridge lifetime would even be shorter than the suggested period. The experimental study found that at the unit clogging point, the filter capacity to retain bacteria remained effective and no bacteria was detected in filtered water at the top end of Puratap® supplied outlet tap.

The difference in findings from field samples and the experimental study could be due to differences in flow rates and water pressures in the rainwater used in households compared to the experimental design. Alternatively, it could be indicative of inadequate maintenance of filters, which was supported by discussion with participants, many of whom indicated that the filter cartridges had never been replaced. Only one tank out of fifty-three tanks was reported to have been drained and the bottom sludge removed. Contamination could occur with cartridges that have reached the end of their factory lifetime, or in cartridge with factory faults. It should be noted that not all filters meet the standard for bacteria removal from water. Otherwise, filters may have been originally improperly fitted or the contamination could have been from the faucet, post filtration.

In some marginal cases, external factors to the tanks could have contributed to the presence of *E. coli* in filtered water. Studies indicate that strains of *E. coli* can survive and even grow in an open environment, subject to the environmental level of nutrients, and conditions such as temperature and pH (Van Elsas et al., 2011). Bacteria could be associated with rainwater droplets during rainfall events and be in connecting pipes, or water exposure to ambient air could facilitate the incursion of these organisms into filtered water (Thermo Fisher Scientific Inc, 2015). After that, the bacteria can grow inside pipes or in the faucet post filter and ultimately, be detected in filtered water at the point of collection. On the other hand, filter cartridges pore size could have been larger than *E. coli* size and allow the bacteria pass through the system unblocked and remain in the filtered water.

It should be noted that *E. coli* size vary from 0.5 µm in width and 2 µm in length (Sundaram et al., 2001). Thus, filters with cartridge pore size smaller than *E. coli* size would remove the bacteria from water, providing the filters are regularly maintained, and the cartridge replaced after the suggested factory lifetime. However, case studies have indicated that membrane cartridges of 0.2 µm - 0.22 µm are benchmarks for bacteria retention from water (Sundaram et al., 2001, Lenntech, 2012). Well maintained, these cartridges can be effective in removing *E. coli*, *Salmonella* (2µm by 0.5 µm), *Campylobacter* (0.2-0.8 × 0.5-5 µm), enterococci (0.6–2.0 µm by 0.6–2.5 µm), *Giardia lambilia* (10–15 µm), *Legionella* (2 µm by 0.3–0.9 µm) and *Aeromonas* (0.3 to 1.0 µm by 1.0 to 3.0 µm) from rainwater, but challenges remain on these cartridges capacity to remove viruses that may occur in rainwater. Viruses vary in size from 27 nm to 250 nm diameter, and a nanometer (nm) corresponds to one-thousandth of a micrometer (µm) (Weeks, 2012). Filters with cartridges of 0.45 µm pore size were accepted by Lee and Deininger (Lee and Deininger, 2004), as benchmark for bacteria retention. It should be noted that in below ground tanks, sewerage effluent can be discharged by surface runoff into poorly sealed tanks, and tanks that have cracks can allow human infectious protozoa and viruses into stored rainwater (Pathak and Heijnen, 2004). The likelihood of finding these organisms in rainwater collected from above ground tanks is low (Ahmed et al., 2011). In order to avoid virus contamination, a membrane filtration of 0.01 µm – 0,1 µm and ultraviolet disinfection can be use (New South Wales Health, 2005).

However, the cost to acquire and to maintain these highly efficient systems is high, and their small pore sizes can trigger an early blockage when applied on rainwater with high sediments (Amway, 2003). Such filters were not tested in this study. It was found that 100% of tanks (seven tanks) that had filters fitted tested positive to *E. coli* at least once, suggesting issues of filter maintenance and cartridge replacement. Only one tank (2% of tanks surveyed) was reported to have been drained for bottom sludge removal.

In Australia, incidents of illness linked with drinking rainwater are low even though rainwater collected in many areas fails to meet the Australian Drinking Water Guideline microbiological standard requirements (enHealth, 2010). Similar findings on rainwater quality were reported by Ahmed et al. (2011) and Ahmed et al. (2014) who suggested that members of the public avoid drinking untreated rainwater, particularly older and immunocompromised people. Notably, many samples collected in the Adelaide region were found to contain *E. coli* above the guideline levels for recreational water, suggesting that rainwater was not even fit for recreational use. In Australia, organism count should not exceed the threshold of 150 fecal coliforms/100 mL in recreational water for five consecutive sampling events, and sampling should be at regular intervals and extended to a period of 30 days (The Australian and New Zealand Environment Conservation Coincil (ANZECC), 2000).

The guideline for recreational water for *E. coli* is set to a more stringent limit of 126 organisms/100 mL in New Zealand. Although links existed between *E. coli* and rainwater fecal contamination, no study in bacteria speciation has been carried out to whether determine whether *E. coli* found in rainwater is Enterohemorrhagic *E. coli* O157:H7. Further research could be undertaken to assess whether it is a possibility. However, for domestic above ground tanks, the risk of detecting *E. coli* O157:H7 strain in harvested rainwater would be negligible, and associated health risks low in magnitude.

When considering the observed *E. coli* prevalence, rainwater harvested in the Adelaide region may pose a risk when used for toilet flushing or gardening without a minimum level of disinfection. During gardening or toilet flushing, incidents of contamination could potentially occur through inhalation of droplets and aerosols that contain *E. coli* or other pathogenic microorganisms. However, risks of infection through these routes are lower than those encountered through drinking (Ahmed et al., 2010). Additionally, rainwater with high *E. coli* content would not be recommended for watering fruit and vegetable plants as bacteria can colonise the roots and the leaf and on harvest spread in the food processing chain and cross contaminate other food products (Van Elsas et al., 2011). In the Adelaide region, it was found that many tanks exceeded the maximum detection limit of 200 CFU/100 mL for *E. coli,* for water intended for irrigation (Sharma and Sanghi, 2012). A less stringent limit of 250 CFU/100 mL for plants watering exists in the United Kingdom (BS8515:2008) (Richard, 2010). In Australia, water must not exceed the threshold of 10 CFU/100 mL for raw human food crop watering, 100 CFU/100 mL for grazing animal other than pigs and dairy animals, and <1000 CFU/100 mL for grazing dairy animals with a withholding period of five days (The Government of Western Australia, 2010). Alternatively, such water should not be recommended for playgrounds and school yards watering, if attended by small children as they have a high incidence of hand-to-mouth action. Freshly watered playground and school yards have higher contamination potential as bacteria can survive longer on grassy surfaces with higher moisture conditions (Stine et al., 2005). This study found a decline in the number of bacteria in samples collected after a prolonged drier period. This could be due to higher temperatures causing deposited fecal matter on structures to dry out more quickly and kill the bacteria. It should be noted that in this study, rainwater samples were collected from galvanised and tiled catchments, subject to a range of humidity parameters, and to changing ambient temperatures. Outside the host vector, *E. coli* lifespan can be compromised on dry surfaces where humidity is low. Experiments have shown a reduction in *E. coli* up to 99.9%, following 24 h direct exposure to light (Wilks et al., 2005). Moreover, *E. coli* survival may be compromised on dry surfaces after 120 min at 20 °C and 360 min at 4°C on metallic surfaces (Curtis, 1998).

To some degree, the poor record of tank maintenance might be linked with the design of the tank. All tanks surveyed had large inlets in the rainwater intake region, and overflow valves; but no tank had sludge valve for tank drainage; and tanks' outlets were limited to taps used for rainwater collection. It is suggested that the next generation of tanks have larger outlet valves in the sludge zone to allow easy tank sludge removal. This can assist households to clean their tanks and avoid the costs associated with having the water tank professionally cleaned.

3.1.5. Materials and Methods

3.1.5.1. Study Area and Samples Collection

The samples were collected from July 2015 to August 2016 in the Adelaide region (Figure 17). The study was approved by Flinders University Social and Behavioural Research Ethics Committee (SBREC N° 6782, and 6782 SBREC modification N° 2) in compliance with the National Statement on Ethical Conduct in Human Research (NSECHR). The investigation of tank water quality used a purposive sampling method Purposive sampling generally targets subjects that are of interest to the investigator, and participants are selected among those who voluntarily accept to participate to the study (Palinkas et al, 2015). Thus, participants were chosen among Adelaide households who were identified as having a rainwater harvesting system on their properties, and those who allowed access to their tanks for samples to be collected.

In total, 500 letters were mailed to households that were identified as having a rainwater tank installed on their properties, to request their participation to the study. The response fraction was very low. Out of 500 requests that were disseminated throughout the Adelaide region, 53 households replied to the researcher, either by mail or by telephone, and agreed to participate to the study. The response fraction represented 10.6% of households that were initially contacted.

Participants were asked a few questions about their water tanks and water usage, and whether maintenance works were carried on catchments areas and on tanks. This included bottom tank sludge drainage, gutters and downpipes to tank cleaning, tank age, whether they had first flush devices installed, whether they had filters installed and regularly maintained, whether the tanks were plumbed directly into the house and what the water was primarily used for.

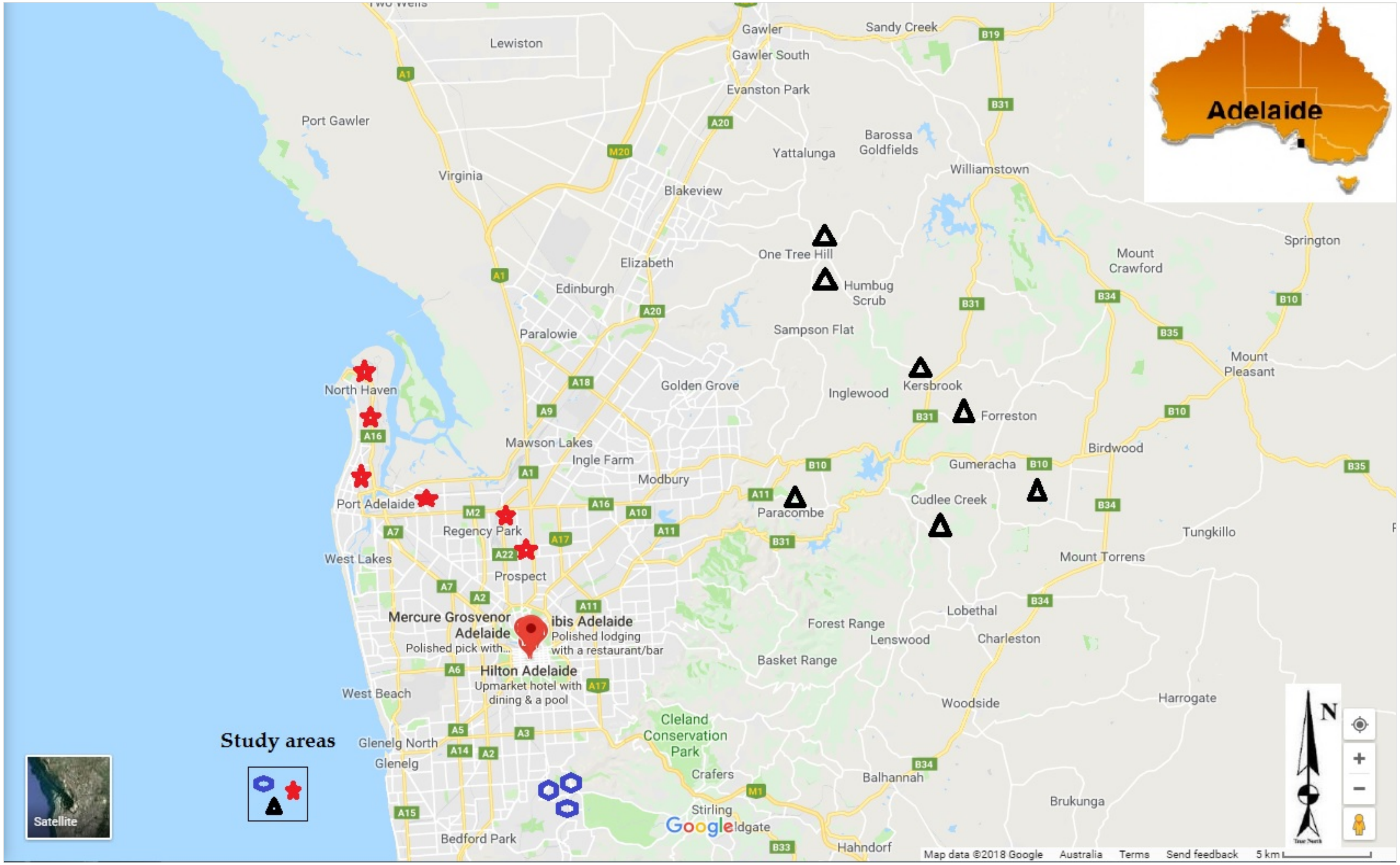

Figure 17. Study area showing the location of rainwater tanks sampled (2018, Google Maps).

Additional details on tanks and roofs structure materials were made via observation. The rainwater samples were collected in 1 L rinsed, acid-washed polyurethane bottles. During sample collection, the water was run for several seconds before collecting. For tanks that had water filtration systems fitted and were plumbed-in and the water used for drinking, homeowners were asked to provide a sample of water from an indoor tap for analysis. For those tanks, an unfiltered sample was also directly collected from the tank. Freshly collected samples were transported back to the laboratory in an esky on ice and processed immediately on arrival. Samples were tested for total coliforms, and for *E. coli* in a time not exceeding 24 hours after collection. Water parameters such as water pH and water temperature were taken in the field, at the time of sampling. A digital PH-618 Pen-Type Automatic Calibration IP65 Waterproof PH Meter was used for rainwater pH and temperature recording (Shenzhen Handsome Technology Co., Ltd. Guangdong, China, Walcom Int'l Industry Ltd., Hong Kong, China).

A total of 365 rainwater samples were collected in the Adelaide region from 53 different tanks, with 120 samples collected in the Adelaide plains from 18 tanks, 97 samples in the Adelaide foothills from 15 tanks, and 148 samples in the Adelaide Hills from 20 tanks[13]. Samples were collected every month or after storm

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[13] Note. The small number of tanks sampled (53 tanks) in the Adelaide region is a limiting factor in the study findings. Initially, 500 households were contacted to participate to the study. Of these, 53 households were willing to participate in the study (10.6%). It is possible that those households that were willing to participate might represent a skewed portion of the population (for example, might be from a higher or lower SES group), however, this limitation was unavoidable.

events that occurred between two scheduled sampling dates, for a period of one year. Many tanks did not have water for sampling in summer, following the drier conditions that prevailed in the region in summer months.

3.1.5.2. Samples Processing and Testing

Total coliforms and *E. coli* were enumerated with the Colilert™ IDEXX Quanti-Tray*/2000 water testing method using the standard procedure (IDEXX Laboratories, Inc., Westbrook 04092, ME, USA). Briefly, a Collilert*-18 reagent was added to undiluted and unfiltered rainwater samples in a 100 mL sterile polyurethane container. Then the sample was transferred in a Quanti-Tray*/2000, a semi-automated total coliform and *E. coli* enumeration method based on the Most Probable Number (MPN) model. The Quanti-Tray*/2000 was sealed in a Quanti-Tray*/2000 Sealer, Model 2X (IDEXX Laboratories, Inc., Westbrook, Maine 04092 USA). After sealing, the Quanti-Tray*/2000 was immediately incubated for 24 h at 37 °C. At the end of the incubation time, coliform positive reaction appeared in yellow wells, and *E. coli* positive fluoresces under 6-watt, 365 nm long-wave ultraviolet lamp. Organism numbers was estimated by means of the Most Probable Number (MPN).

3.1.5.3. Investigating Efficacy of Water Filter to Remove Microbial Contamination

The effectiveness of a commercially available filter to remove microbial contamination was assessed. The investigation was based on Puratap® Pty Ltd. filter performance claims. The Puratap® Ultrafiltration Filter advertising material states that the filter "protects rainwater consumers against faecal coliforms, bacteria and viruses (Puratap, 2010). Similarly, the Amway eSpring™ Water Filter states that it effectively destroys over 99% of bacteria (*E. coli, Aeromonas hydrophila, Campylobacter jujeni, Salmonella, Legionella pneumophila, Klebsiella terrigena, Vibrio cholera, Yesinia entertocolitica* and *Shigella dysenteriae),* viruses and protozoan parasites from rainwater (Amway, 2015). Fifty-three × 5 L rainwater samples were collected from January to June 2016 (from one tank known to have high levels of *E. coli* contamination) and run through the filter system. Each sample of 5 L of unfiltered rainwater was run through a Puratap® double cartridge filter mounted with MasterFlex tubing connectors, consisting of a pre-sediment cartridge (membrane cartridge) of 1 µm/pore size, and an activated carbon cartridge of 0.45 µm/pore size, using a powered Cole-Parmer MasterFlex Peristaltic® L/S pump, Model 7553-79 and a Cole-Parmer MasterFlex L/S Modular Controller 7553-78 (Cole-Parmer 625-Vernon Hills, IL 60061, United States). The filtered sample was collected from a Puratap® supplied outlet tap top-end, in a 100-mL sterile polyurethane container. Duplicate samples of both unfiltered and filtered were tested for *E. coli* and total coliforms using the Colilert™ IDEXX Quanti-Tray*/2000 water.

3.1.5.4. Statistical Analysis

Data in the study were graphed using Microsoft Excel (Microsoft Corporation, Washington, WC, USA), and analysed using IBM SPSS statistical software package (IBM SPSS Statistics for Windows, Version 23.0. IBM Corp, Armonk, NY, USA), and GraphPad Prism 7.02 (GraphPad Software, Inc., San Diego, CA, USA). The bivariate correlation by means of Test Between Subjects-Effects (3 Way-ANOVA) was used to measure the correlation and linear regression between variables. Data statistical significance was set to the statistical value of *p*-value < 0.05 against the null hypothesis[14]. A paired *t*-test was used to determine influence of filtration on the bacteria load (*p*-value <0.05)

3.1.6. Conclusion

This study demonstrates that rainwater harvested in the Adelaide region is of poor microbiological quality for drinking. Out of a total of fifty-three tanks surveyed, twenty-eight tanks (53%) were tested positive at least once for total coliforms and *E. coli* and 10 tanks contained *E. coli* at concentrations that exceeded the accepted threshold of 150 CFU/100 mL for recreational water. This is a significant public health concern as this water is being used by many Adelaide households as source of drinking water. In tanks with filters fitted, the concentration of *E. coli* was consistently reduced, but not completely removed. These results contradicted laboratory testing of a bench mounted filtration unit that successful reduce total coliforms and *E. coli* to 0/100 MPN. The study found little evidence linking rainwater microbiological quality and structure materials however; links were observed between rooftops mounted TV antennas and rainwater bacteriological quality. Most of the samples collected from tanks connected to rooftops with mounted TV antenna contained *E. coli*. Further research is needed to investigate the presence of other pathogenic microorganism and their potential to be removed by filters. A greater exploration of the effectiveness of filters and reasons for their failure is also needed.

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[14] Note. A table of null hypotheses is included in the appendix (appendix 15).

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Author Contributions: Chirhakarhula Emmanuel Chubaka collected the samples and co-designed the experiments with Kirstin Ross. Harriet Whiley and John Edwards. Then Chirhakarhula Emmanuel Chubaka run the experiments, analyzed the data and drafted the manuscript, and Kirstin Ross, Harriet Whiley and John Edwards provided the supervision and supplied the reagents and the materials for samples collection, samples processing and testing.

Conflicts of Interest:

The authors declare no conflict of interest.

3.1.7. Reference

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This remainder of this chapter presents the components of the thesis relating to the microbial quality of rainwater collected in the Adelaide region resulting from this work that were not presented in the above publication (3.1).

3.2. Rainwater and drinking water quality

This part of the thesis discusses the quality of drinking water, referring to the Australian drinking water guidelines, and compared the quality of rainwater (in terms of microbiological and metal contamination) that is being used by many households, in Adelaide, and elsewhere in Australia, as a source of drinking water.

3.2.1. Drinking water standards

At a global level, drinking water standards are specified by the World Health Organisation (2011b). In Australia, standards for drinking water quality are outlined in the Australian Drinking Water Guidelines (NHMRC, 2011). Essentially health-based, the standards are subdivided into primary standards that specify water contaminant safety levels, and secondary standards that are related to the physical quality of water (Munro and Travis, 1986). Drinking water standards were set to minimise and where possible, to ensure removal of pathogenic organisms and toxic substances from the water, to minimize risks of waterborne illness (World Health Organisation, 2011b).

3.2.2. Indicators of drinking water microbial contamination

In drinking water, total coliforms and *E. coli* are commonly used as indicator organisms in the assessment of water quality, as an indicator of the potential presence of pathogenic organisms (World Health Organisation, 2011b, NHMRC, 2011). *E. coli* is generally associated with total coliforms, and the bacteria occurs in the faeces of humans and blooded animals (NHMRC, 2011). Since total coliforms can grow in the environment (environmental coliforms) in the absence of faeces, total coliforms have lost the attribute of water faecal contamination indicators (World Health Organisation, 2011b). They have has been replaced by thermotolerant coliforms (faecal coliforms), *E. coli* and increasingly, enterococci (Odonkor and Ampofo, 2013). In humans, non-faecal coliforms (environmental coliforms) pose limited health risks (Stevens and Ashbolt, 2003), however total coliforms and faecal coliforms from different origins can occur in a water body (World Health Organisation, 2011b). Thus, the detection of total coliforms in any water intended for drinking should be investigated. In this project, a bacteria speciation analysis was not carried out since the detection of *E. coli* was sufficient evidence that faecal contamination has occurred and implicitly, other pathogenic bacteria members of the faecal coliforms group could exist in the water (Feachem et al., 1983; Edberg et al., 2000).

The family of coliforms (total coliforms, faecal coliforms, and pathogenic *E. coli*) belongs to the large Enterobacteriaceae family (World Health Organisation, 2011b). There are indications that nearly 70% of pathogenic organisms found in humans are coliforms (Fraimow and Reboli, 2008), primarily *E. coli,* and the remaining being *Klebsiella, Citrobacter* and *Enterobacter* species (Feachem et al., 1983). Of members of the Enterobacteriaceae family that occasionally occur with rainwater, *Yersinia, Shigella* and *Salmonella* are non-lactose fermenters and do not belong to the coliforms group (Feachem et al., 1983) (Figure 18).

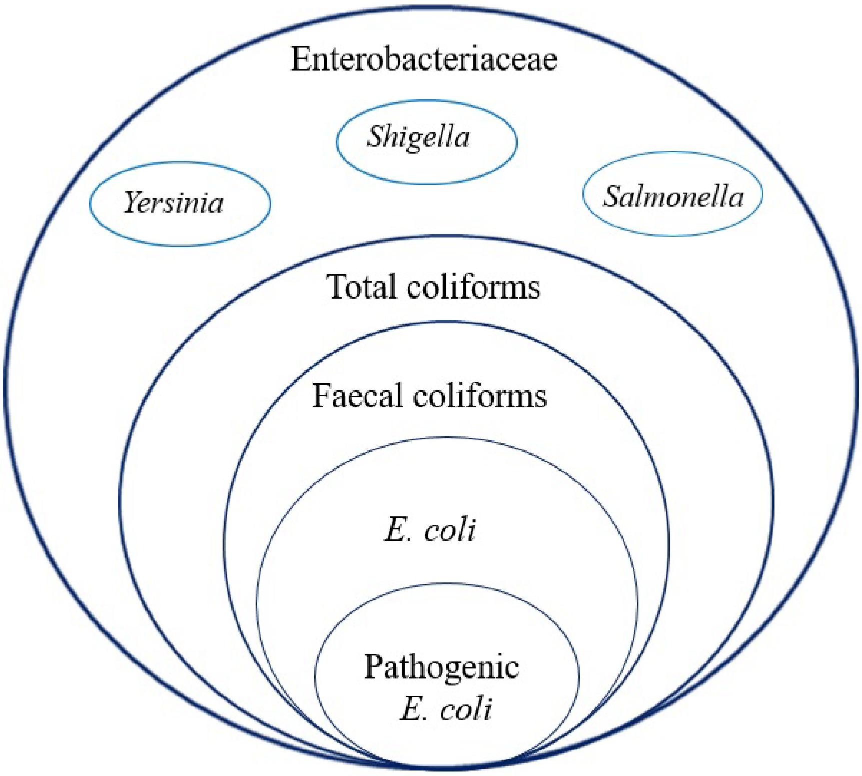

Figure 18. Members of the coliforms group in the Enterobacteriaceae family. Source: Leclerc et al. (2001) and Fung (2009).

3.3. Other studies on microbial quality of rainwater in Australia and Adelaide

Rainwater harvested in the Adelaide region can be of poor microbiological quality. An investigation carried out by Rodrigo et al. (2009b) on rainwater microbiological quality collected from 38 tanks in Adelaide metropolitan region and Mount Barker (Adelaide Hills) found that 82% of tanks contained total coliforms, with 72% of tanks containing enterococci, and 30% of tanks containing *E. coli.* Another investigation that involved the analysis of 974 samples collected from 100 tanks on three sampling events detected the prevalence of enterococci (71% of samples), and *E. coli* (33.5% of samples) (Rodrigo et al., 2009b). These results were consistent with another investigation carried out earlier on six Adelaide rainwater tanks, and with studies conducted on rainwater in other Australian cities and towns (Figure 19) (Chapman et al., 2008) .

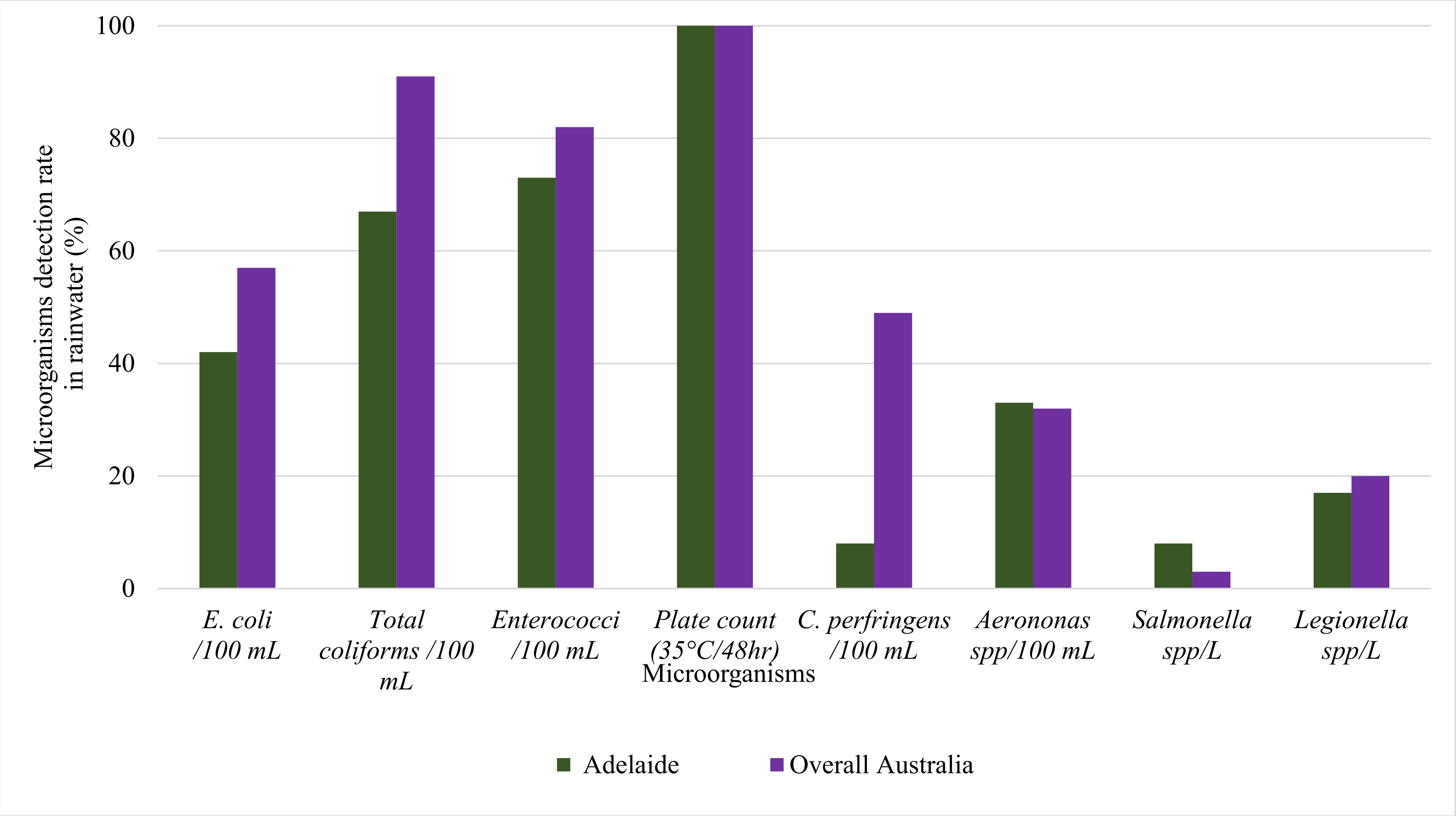

Figure 19. Reported microbial values of rainwater harvested in the Adelaide region

Source: adapted from Chapman et al. (2008) and Rodrigo et al. (2009a) enterococci and *E. coli* ubiquity in tank water collected in the Adelaide region is indicative of faecal contamination (Field and Samadpour, 2007). In addition to enterococci and *E. coli*, other pathogenic organisms have been isolated from samples of rainwater collected in many locations across Australia (Ahmed et al., 2014; Ahmed et al., 2017). In Queensland, pathogenic organisms such as *Salmonella, Giardia lamblia, Legionella pneumophila* and *Campylobacter jejuni* organisms were isolated from tank water (Ahmed et al., 2010b).

3.4. Rainwater consumption and associated health risks

Links exist between improper water supply to communities and waterborne diseases (World Health Organisation, 2003). High incidence in pathogenic *E. coli* and enterococci has been reported in rainwater harvested in many locations across Australia (Ahmed et al., 2010a). Not all *E. coli* strains are pathogenic (Rembacken et al., 1999). Strains of pathogenic *E. coli* include enterotoxigenic *E. coli* (ETEC), enteroaggregative *E. coli* (EAEC), enteropathogenic *E. coli* (EPEC), enteroinvasive *E. coli* (EIEC), diffusely adherent *E. coli* (DAEC) or verocytotoxigenic *E. coli* (VTEC), (NHMRC, 2011). The most virulent *E. coli* strain is the Shiga toxin-producing *E. coli* (STEC) O157:H7. The bacteria is responsible for bloody diarrhoea, haemorrhagic colitis and haemolytic uremic syndrome (Lupindu, 2018). *E. coli* infection symptoms occur after a 3-8 days incubation period and include abdominal cramps, fatigue, fever to bloody haemorrhagic colitis (World Health Organisation, 2018). In above ground tanks, *E. coli* is generally sourced from small animals and birds faecal matter (Ahmed et al., 2012). The people most vulnerable to *E. coli* infections are children, adults with compromised immune systems, and people with decreased stomach acidity (Thielman and Guerrant, 2004). A stringent *E. coli* guideline of zero colony forming units per 100 mL of water (0 CFU/100 mL) exists in Australia. This suggests that *E. coli* should not be detected in a minimum sample size of 100 mL of drinking water, in the water treatment and supply chain (NHMRC, 2011).

Notwithstanding , 11% of Adelaide families use rainwater as their primary source of drinking water (Australian Bureau of Statistics, 2011b), incidents of diseases and clinical cases linked with the consumption of untreated rainwater in the community are limited (Heyworth et al., 2006). In 2007, 19 cases of *Cryptosporidiosis* associated with drinking untreated rainwater were identified in a youth residential facility in the Adelaide hills (Cooke, 2015). The tank connecting pipes were found buried next to a sewer pipe system in a trench (Cooke, 2015). Elsewhere in Australia, other incidents of illness and disease outbreaks caused by drinking untreated rainwater have been reported. For example in 1999, a salmonellosis outbreak was identified in Rockhampton (Queensland) (Taylor et al., 2000), and a *Campylobacter enteritis* outbreak reported in an island resort in northern Queensland (Merritt et al., 1999). Both incidents were reported to have links with drinking untreated rainwater. In 2005, a *Giardia lamblia* outbreak suspected to originate from rainwater occurred in a health spa bath in a resort in New South Wales (Dale et al., 2010). It was suspected that the organisms linked to the outbreak originated from human faeces. In 2007, a *Salmonella Typhimurium* outbreak linked to drinking untreated rainwater affected 27 out of 55 students at a school camp site in Victoria (Franklin et al., 2009). The vector of the bacteria was not identified. Most incidents of illness and disease outbreaks occurred in aged care facilities (Kirk et al., 2011), in working camps (Dale et al., 2010), and in school camps (Franklin et al., 2009).

Few people who drink rainwater that contains pathogenic organisms develop gastroenteritis (Rodrigo et al., 2011). Susceptible people include immuno-compromised persons, the elderly, children and people with diabetes (Gould, 2015). A comparative study carried out in regional South Australia on a cohort of 1016 children (aged 4-6 years) found no difference in gastroenteritis incidence between children who drink centralised municipal water, and those who drink rainwater (Heyworth et al., 2006). In the cohort of children who drink rainwater, frequent exposure to pathogenic organisms might have enhanced their immune systems to control pathogenic organisms before they become a threat to health. In the event of frequent exposures, there are indications that the human body has the capacity to adapt and control pathogenic organisms (Price and Walker, 2015).

3.5. Steps undertaken to improve rainwater quality

Compared with centralised municipal water, rainwater is subjected to minimum treatment (Julius et al., 2013). In Australia, it has been suggested that rainwater should be chlorinated to control microorganisms (enHealth, 2010). In Adelaide, householders who use rainwater can consult the South Australia Department of Health and Wellbeing (SA Health), to enquire on methods to disinfect rainwater, where the harvest intends the use of rainwater for potable purposes. In South Australia, the public is advised to add 40 mL of liquid sodium hypochlorite (NaOCl) that contains 12.5% chlorine, or 7 grams of granular calcium hypochlorite [$Ca(ClO)_2$] that contains 75% chlorine in a 1000 L tank water (SA Health, 2017b). Notwithstanding the benefits, the introduction of chlorine into rainwater would affect the taste and is not likely to be acceptable to consumers. It was found that for many rainwater consumers, drinking water preference was essentially based on water taste rather than water quality, and chlorine was typically identified as primary cause of dissatisfaction with municipal water quality (Chubaka et al., 2017).

There are indications that chlorine is more effective in the control of indicator organisms (total coliforms and *E. coli*), but less effective on *Giardia* cysts, *Cryptosporidium* oocysts and *C. perfringens* spores as these organisms can survive in water for a number of hours after chlorination before they are inactivated (Cabral, 2010). Thus, boiling water is a more appropriate and effective method to control microorganisms in rainwater. Boiling water as a rainwater disinfection method is recommended by the Australian health authorities (enHealth, 2010), and the World Health Organisation (2011b). The method is effective in viral, human protozoa, *Giardia lambilia* and *Cryptosporidium* control. It is highly recommended that immunocompromised people, children, people with cancer or diabetes, organ transplants and people positive to human immunodeficiency virus (HIV positive) boil their rainwater prior to consumption (enHealth, 2010).

Alternatively, susceptible people are advised to install a UV light water purifier to disinfect the rainwater (SA Health, 2017c). In Adelaide and in South Australia, the main method used to improve rainwater is water filtration. A tendency to install water purifiers on tanks was observed in the Adelaide region (Chubaka et al., 2017).

Frequently used filters include Puratap® water purifiers, Aqua-Pure® water purifiers, Pure Water Systems® water purifiers, fridge embedded water purifiers and increasingly, eSpring™ Water Purifiers (Table 1). As noted above (3.1) however, filters were not found to be effective in removing *E. coli* in a residential setting

Table 10. Water purifiers frequently used on rainwater characteristics

Filter type	Pore size	Cartridge type	Capacity	Lifetime*	Reference
Puratap® water purifiers	1µm 0.45 µm	Pre-sediment and Activated carbon	2,330 L - 3,785 L	1 year	Puratap Pty Ltd, 2011
Aqua-Pure® Water Filters	0.2µm	Membrane pre-activated carbon	11,356 L	1 year	Aqua Pure Water®, 2018
Pure Water Systems	0.4µm	Activated carbon	1,500 L	1 year	Pure Water Systems Pty Ltd, 2018
eSpring® Water Purifier	0.2µm	Activated carbon and Ultraviolet light	5,000 L	1 year	Amway, 2016
Rainwater Harvesting™	15µm	Membrane pre-impregnated carbon	2,000 L	0.5-1 year	Rain Harvesting Pty Ltd, 2018
Puretec® Perfecting Water	1 µg	Ultraviolet light	7.5 L /minute	1 year	Puretec Pty Ltd, 2018
Aquadome Water Purifier	< 1µm	Activated carbon ceramic filter	3,180 L	1 year	Aquadome Water Purifiers, 2017
Tank Doctor	10 µg	Ultraviolet light Pre-sediment	-	1 year	Tank Doctor, 2017

* Time recommended for filter cartridge replacement

CHAPTER 4. METALS PRESENT IN RAINWATER

4.1. Publication: Lead, Zinc, Copper, and Cadmium Content of Water from South Australian Rainwater Tanks

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Lead, zinc, copper and cadmium content of water from South Australian rainwater tanks

4.1.1. Abstract

Rainwater is consumed for drinking water in many parts of Australia, either preferentially over municipal water or in regional or remote areas, because rainwater is the primary source of water. Previous rainwater studies in other areas in Australia have shown the levels of some metals to be above Australian Drinking Water Guidelines (ADWG). This study assessed the level of metals in rainwater harvested in the Adelaide region. Water samples were collected from 53 tanks from three different sampling corridors. A total of 365 water samples were analysed for lead, zinc, copper and cadmium using atomic absorption spectrophotometry. In 43 out of the 53 tanks, lead was above the ADWG of 0.01 ppm in at least one sample (with 180/365 samples above 0.01ppm). Zinc was above the ADWG (3.0 ppm) in 53/365 samples, copper above the ADWG (2.0 ppm) in 8 samples out of 365 samples and cadmium above the ADWG (0.002 ppm) in 19 samples out of 365 samples. These data are consistent with other studies of rainwater quality in Australia. Comparisons of levels of metals and volume of rainfall in the sampling and preceding month, roof material, and tank material, presence of a first flush device, sampling corridor and sample pH showed that the roof material was related to higher levels of metals. There was a significant relationship between sampling corridors and the levels of lead and zinc. Nine of the tanks surveyed had filters installed. There was a small but statistically significant decrease in the levels of metals that passed through a filter prior to collection but in those samples, filters did not remove metals to below

guideline concentrations. An estimate of exposure, and a brief discussion of health risks as a result of exposure to metals is presented.

4.1.2. Introduction

In Australia, rainwater is used as a potable and non-potable water source (Ahmed et al., 2010). In some cases, it is used for drinking water preferentially to the municipal water supply, in other cases it is the only available domestic water source (Simmons et al., 2001). There is a general consensus in the community that drinking rainwater is safe for human consumption (Heyworth et al., 2006). However, research indicates that roof harvested rainwater can contain bacteria and metals above the Australian Drinking Water Guideline (ADWG) limits (enHealth, 2010). The presence of elevated levels of metals, such as lead, cadmium and copper, can present an issue of concern for human health (Järup, 2003, Geiger and Cooper, 2010, Tchounwou et al., 2012). Lead is a cumulative toxin that affects the central nervous system and can trigger the dysfunction of renal and cardiovascular systems (Naja and Volesky, 2009, Flora et al., 2012, Oregon Health Authority, 2016). Lead can also affect brain development and impact on human intellectual quotient (IQ) (Jakubowski, 2011). Cadmium is classified as a Group 1 carcinogen (International Agency for Research on Cancer (IARC), 2018) and long-term exposure has the potential to affect reproductive organs, cause low birth weights, kidney damage and cardiovascular or nervous system impairment (Godt et al., 2006, Bernhoft, 2013, Rahimzadeh et al., 2017). In low concentrations, copper is an essential trace element that play a role in many enzymes involved in vital biological processes. However, chronic exposure or high concentrations causes oxidative stress resulting in kidney, gastrointestinal tract or liver damage, which can be fatal (Gaetke and Chow, 2003, Jomova and Valko, 2011). In drinking water, copper gives the water an unpleasant taste at 3 mg/L and in susceptible people, illness incidents can occur from a concentration of 2 mg/L (National Health and Medical Research Council (NHMRC), 2011). Comparatively, zinc is less hazardous to human health and zinc deficiency has the potential to impact human growth, neuronal development and the immune system (Plum et al., 2010). In drinking water, copper and zinc can cause a metallic taste to water at concentration above 3.0 mg/L (Chubaka et al., 2017).

Unlike municipal water which is subject to treatment to ensure it is safe for human consumption, rainwater is harvested and consumed untreated by many households (Chubaka et al., 2017). Previous studies have found that rainwater collected in Australia contained trace metals but generally within health guidelines (Kus et al., 2011). However, in urban Australia and in former industrial and mining precincts, metals such as lead, chromium, silver, nickel, copper, arsenic and manganese have been detected in rainwater above health limits (Sinclair et al., 2005, Rodrigo et al., 2009, Heyworth and Mullan, 2009). This study investigated the concentrations of lead, zinc, copper and cadmium in samples sampled from three sampling corridors around Adelaide; an urban area, a peri-urban area and a rural area outside of Adelaide. The effect of volume of rainfall in the sampling and preceding month, roof material, tank material, and the presence of a first flush device, sampling corridor and sample pH was examined. The effect of filtration was also examined in those homes that had a filter fitted to their rainwater tank.

4.1.3. Material and methods

4.1.3.1. Study site

Rainwater samples were collected in the Adelaide region nine times over a fourteen-month period that covered more than one year from July 2015 to August 2016. The study was approved by Flinders University Social and Behavioural Research Ethics Committee (SBREC No 6782) in accordance with the National Statement on Ethical Conduct in Human Research (NSECHR). The selection of sampling corridors was based on land use, and on vegetation cover. Three sampling corridors were selected in the Adelaide region, based on vegetation cover, and on human activities. One sampling corridor, predominantly residential with light manufacturing industries was selected in the Adelaide plains (urban corridor). The second corridor, essentially residential with high vegetation cover was selected in the Adelaide foothills (peri-urban corridor). The third corridor was selected in semi-rural suburbs in the Adelaide hills that spreads from One Tree Hill to Paracombe, Kersbrook, Gumeracha and Cuddle Creek (rural corridor) (Figure 20).

Households approached to participate in the study were randomly[15] chosen based on the criteria that they were located within a sampling corridor and had a rainwater tank. The initial contact with tank owners was through direct contact (knocking on doors). The decision to participate to the study was voluntary. A briefing on the study objectives was given to tank owners before they made their decision to participate. A letter of introduction, a consent form and a questionnaire for the study were given to every household. Questions were about their water tank, whether they had first

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[15] Note. The word randomly has been replaced by the word ‘conveniently’

flush devices, and questions about what the water was used for, whether their tanks had filters fitted and whether the tanks were plumbed directly into the houses. Additional details on tank and roof structure materials were taken by looking at the tank and roof structure. Metals roofs were grouped together (colorbond® steel, zincalume®, galvanised iron, etc).

4.1.3.2. Sampling techniques

The water was collected in 1 L acid washed polyurethane bottles. During transport from the field to the laboratory, all samples containers were tightly closed and properly labelled, to avoid incidents of samples cross-contamination. There were zero detections in many samples indicating that there was no leaching from the equipment used to collect and transport the samples. During sample collection, the water was run for several seconds before collecting. Then, the samples were transported back to the laboratory in an esky on ice and processed immediately on arrival. The samples were stored refrigerated and acidified with 2.5 mL nitric acid in a 2.5 mL polyurethane container. The acidified samples were stored at 4°C prior to testing. Water parameters such as water pH and water temperature were taken in the field. A total of 365 rainwater samples were collected across these three corridors from 53 tanks, with 120 samples collected in the Adelaide plains from 18 tanks, 97 samples in the Adelaide foothills from 15 tanks, and 148 samples in the Adelaide Hills from 20 tanks. Samples were collected every month or after a significant storm that occurred between two scheduled sampling dates. Many tanks did not have water for sampling in summer, after drier conditions that prevail in the Adelaide region in summer months and so were not sampled. Nine (16.9%) of the tanks surveyed had filters installed. These tanks were sampled before the filter using the method described above, and a second sample taken post-filtration at the tap inside the house. These pre-filtration samples were included in all the analyses (365 samples), but the post-filtration sample not.

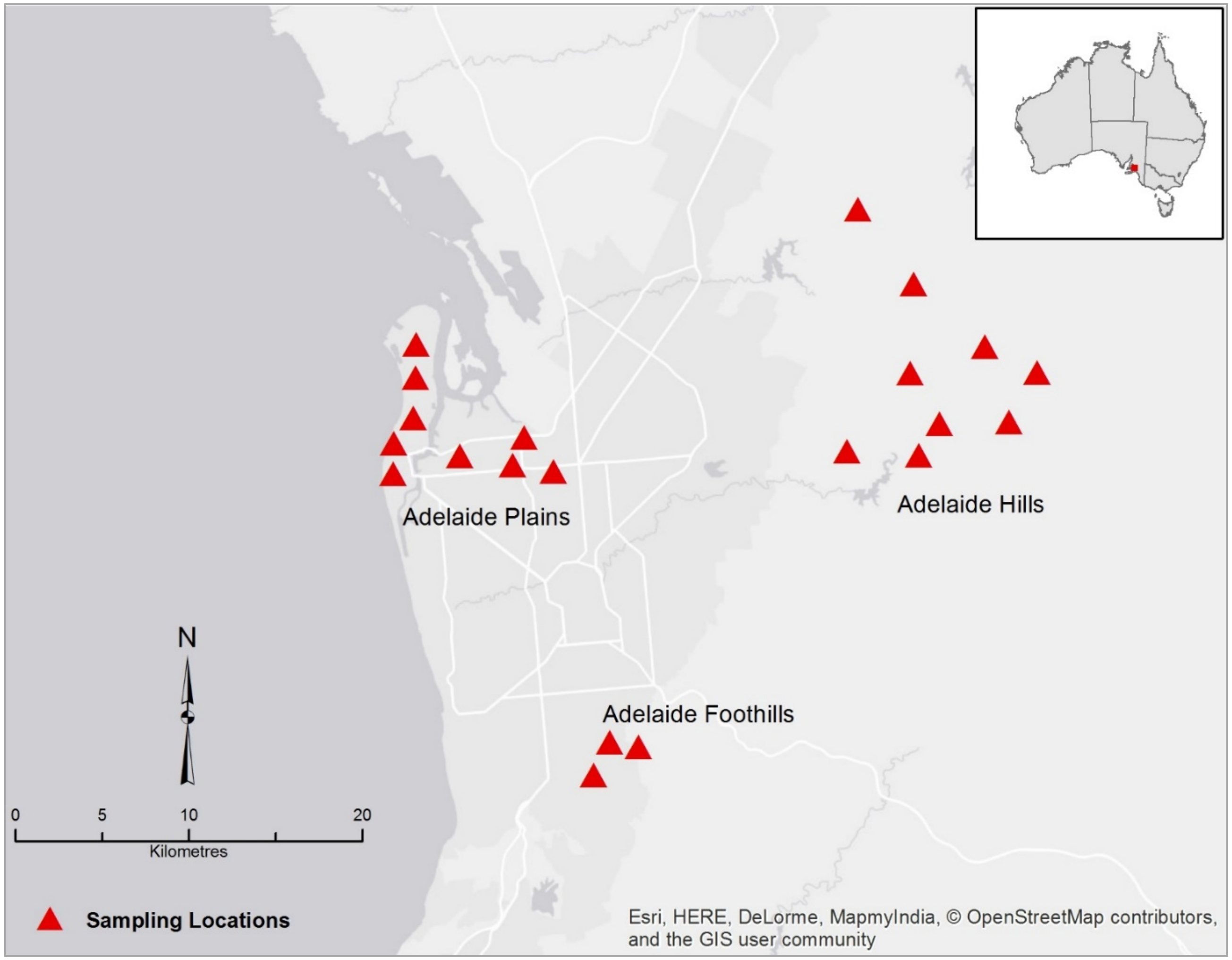

Figure 20, Study area, Adelaide region. The geographical spread of a study corridor is illustrated by the number Δ, this does not correlate to number of samples. Esri Map Data, Delorme maps 2018

4.1.3.3. Samples preparation, testing and analysis

All samples were filtered prior to analysis through 22 µm pore size filters (Whatman® ashless filters Grade 541, Whatman, London) to reduce the volume of suspended solids associated with rainwater, to minimise risks of obstruction on the instrument capillary tubing. Paper filters can contain metals that can be leached out in aqueous matrices during water filtration (Hedberg et al., 2011, Matoug, 2013). Therefore, blanks using filters were created. Sample analysis was carried on a Grey-Bartlett-Charlton 933 atomic absorption spectrometer unit (GBC 933 AAS) (GBC Scientific Equipment Australia, Dandenong, Melbourne). Cableless Photron Coded Hollow Cathode Lamps for common elements were used to source radiation to excite the free atoms into the atomic flame (Photron Ptd Ltd, Narre Warren, Victoria, Australia 3805) (Liberatore, 2017)

The GBC 933 AAS uses air and acetylene as fuel to ignite the atomic flame (GBC, 2002). Avanta Software for Windows®95 was used for the GBC 933 AAS calibration and data processing. Lead, zinc, cadmium, and copper stock solutions were created using 2% nitric acid (HNO_3). A volume of 1.12 mL nitric acid (HNO_3) at 1% concentration was added to 100 mL deionised water to create calibration blanks which were run in between every sample. All samples were analysed in triplicate. Metals were determined as total metals. The GBC 933 AAS elemental detection limits were 0.009 mg/L for cadmium, 0.025 mg/L for copper, 0.06 mg/L for lead and 0.008 mg/L for zinc.

4.1.3.4. Data analysis

All data were entered and graphed using Microsoft Excel (Microsoft Corporation, Washington, USA) and GraphPad Prism software (GraphPad Software, Inc. San Diego USA). Data were tested for normality and an analysis of variance of metal concentrations and different roof and tank material, presence of a first flush device, sampling corridor and pH was conducted. Before and after filtration metal concentration was compared using a paired t-test.

4.1.4. Results

4.1.4.1. Metal levels detected above the ADWG

Metals of health concerns and/or unacceptable for water drinking water taste were detected in tanks at least once over the ADWG values. Lead was the metal detected most often above the ADWG (180/365 samples). In total, 43 tanks (88.1%) were positive to lead above the ADWG guideline of 0.01 ppm at least once and the highest concentration detected was 3.24 ppm. Higher lead levels were detected most often in the Adelaide foothills. In that area, 51% of samples contained lead above the ADWG, compared with 41% in the Adelaide hills, and 27% in the Adelaide plains (Table 11). In total, 29 samples (7.9%) that exceeded the guidelines of 0.01 mg/L were taken from tanks that used the water for drinking.

Table 11. Metal levels found in 365 rainwater samples and the number of tanks those samples came from.

Lead				
Level of contamination	Number of samples (out of 365)	Percentage (%)	Number of tanks (out of 53)	Percentage (%)
< 0.01 ppm	185	50.6	10	18.8
0.01 - 0.10 ppm	83	22.7	15	28.3
0.11 - 1.0 ppm	84	22.9	19	35.8
> 1.0 ppm	13	3.5	9	16.9
Zinc				
Level of contamination	Number of samples (out of 365)	Percentage (%)	Number of tanks (out of 53)	Percentage (%)
< 3.0 ppm	312	85.4	24	45.2
3.1 – 4.0 ppm	24	6.3	15	28.3
4.1 – 5.0 ppm	16	4.3	8	15.0
> 5.0 ppm	13	3.5	6	11.3
Cadmium				
Level of contamination	Number of samples	Percentage (%)	Number of tanks	Percentage (%)

	(out of 365)		(out of 53)	
< 0.002 ppm	346	94.7	40	75.4
> 0.002 – 0.003 ppm	9	2.4	7	13.2
> 0.003 – 0.004 ppm	4	1.0	2	3.7
> 0.004 ppm	6	1.6	4	7.5

In addition to lead, the study detected zinc, cadmium and copper in a few samples that exceeded the ADWG limits. Zinc was above the ADWG of 3.0 ppm in 53 (14.5%) samples. As with lead, the number of samples that exceeded the zinc ADWG limits was highest in the Adelaide foothills, and lowest in the Adelaide plains (Figure 21). It should be noted that the zinc and copper guidelines are guidelines for aesthetic reasons and not health based guidelines (National Health and Medical Research Council (NHMRC), 2011). Cadmium and copper were also detected in few samples. Cadmium was detected in 19 samples (5.2%) above the guideline of 0.002 ppm. The metal was mainly detected in samples that were collected in the Adelaide hills. The detection of copper above the ADWG of 2.0 ppm was limited to 8 samples (2.1%). The samples were collected from one tank in the Adelaide Hills. The tank was plumbed-in and a filter installed, and the water used as drinking water.

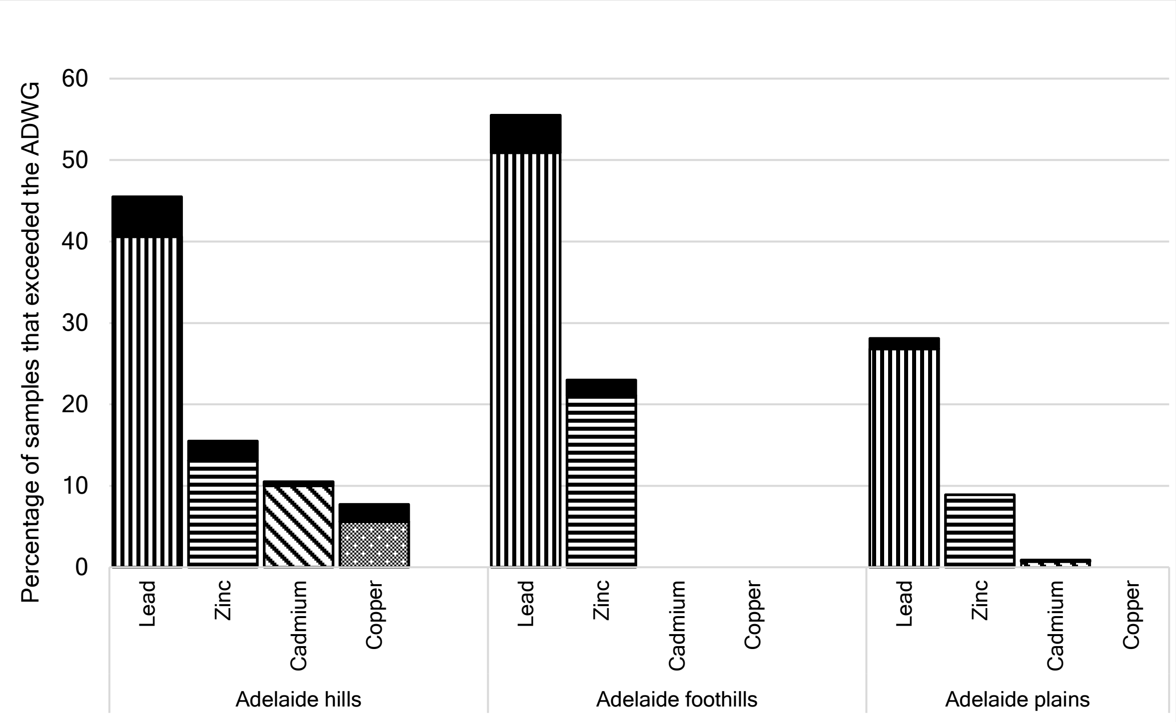

Figure 21. The percentage of total samples and samples used for drinking above the ADWG for each sampling location

4.1.4.2. Influence of tank and roof material and other parameters on metal levels

Metal concentrations were compared with characteristics including tank and roof material, whether the tanks had first flush devices, the sampling corridor and the pH of the sample. The roof material was related to the levels of lead, zinc, copper and cadmium (Table 12). An analysis of variance was used to show when the association was significant ($P<0.05$). There was a relationship between lead and zinc and the sampling corridor, although this might be a result of the fact that the roof type in the Adelaide the hills foothills were predominately galvanised, whereas on the Adelaide plains, the roof types was predominately covered by tiles. The presence of a first flush device had an influence on the level of cadmium and rainwater pH was related to the concentration of copper detected in water samples.

Table 12. Relationships between metal concentrations and various parameters (bold = $p < 0.05$ * = $p < 0.1$)

	Lead	Zinc	Copper	Cadmium
Tank material (galvanised steel and polyethylene)	0.696	0.335	0.228	0.846
Roof material (galvanised steel and tiles)	**0.001**	**0.015**	**0.001**	**0.004**
First flush installed	0.173	0.421	0.963	0.086*
Corridor (Adelaide Hills, foothills and plains)	**1.04×10^{-5}**	**0.001**	0.825	0.608
Rainwater pH (ranged from pH 4.5 to pH 8.4)	0.681	0.823	0.074*	0.950

4.1.4.3. Seasonal variability of metals load in rainwater

There was no detectable trend between metal levels and the mean monthly rainfall in either the sampling month or the preceding month. Adelaide's wettest season extends from May to August, and early September (Australian Bureau of Meteorology, 2018a). In December 2015, and in February and April 2016, many tanks did not have water for sampling and so sampling across the three regions did not take place. For instance, 32 tanks (60.3%) in December 2015, 35 tanks (66%) in February 2016 and 28 tanks (52.8%) in April 2016 did not have enough water for sampling. Although the water was available in tanks for sampling, no sampling event occurred in July 2016 (Table 13).

Table 13. Sampling rounds and lead and zinc levels in rainwater samples

Sampling year	Sampling month	Metals in tanks above the National Health and Medical Research Council (NHMRC) guideline		
		Number of tanks out of 53 with lead above NHMRC guidelines (%)	Number of tanks out of 53 with zinc above NHMRC guidelines (%)	Rainfall (mm)*
2015	August	31 (58.4)	3 (5.6)	67.8
	September	18 (33.9)	5 (9.4)	59.6
	October	16 (30.1)	7 (13.2)	41.9
	November	19 (35.8)	6 (11.3)	29.5
	December	N/A	N/A	29.1
2016	January	16 (30.1)	5 (9.4)	29.1
	February	N/A	N/A	15.6
	March	14 (26.4)	6 (11.3)	26.8
	April	N/A	N/A	39.0
	May	12 (22.6)	8 (15.0)	60.8

June	17 (32.0)	7 (13.2)	77.0
July	N/A	N/A	76.5
August	22 (41.5)	6 (11.3)	77.7

* Mean monthly rainfall, Kent Town, Adelaide: 34.92° S°, 138.62° E, Station number: 23090

(Australian Bureau of Meteorology, 2018b)

N/A = No samples collected

4.1.4.5. Filters' capacity to remove metals from rainwater

Nine tanks had filters fitted. As there were 9 sampling events, a total of 72 paired samples (before and after filtration) were taken. Lead, copper and zinc were above the NHMRC guidelines in 29, 10 and 8 tanks respectively. All (100%) of these samples remained above the NHMRC guidelines after filtration. A minor reduction in cadmium was observed with 8 samples above the guidelines before filtration and 6 samples after filtration. There was a statistically significant ($p < 0.1$) reduction in the concentration of all four metals (lead: $p = 0.074$, zinc: $p < 0.05$, copper $p < 0.05$, cadmium $p < 0.05$). However, this decrease was very small, and did not reduce any of the samples to less than the ADWG concentrations, except for two samples of cadmium.

4.1.5. Discussion

Lead was the metal of greatest concern detected in rainwater in the Adelaide region above the ADWG. The presence of lead in rainwater at concentrations above NHMRC guidelines is supported by previous studies. In 2010, a survey across South Australia found 62.8% of rainwater tanks to contain lead above NHMRC guideline levels. The highest concentration of lead record was 22.4 ppm (Rodrigo et al., 2010). Another study conducted across Australia found 79% of tanks to contain lead at levels exceeding guideline levels (Chapman et al., 2006).

This study found that concentration of lead in Adelaide rainwater ranged from <0.01 ppm (limit of detection) to 3.24 ppm, which is consistent with studies of other urban areas in Australia. In Brisbane (Queensland), a study detected lead in 15% of harvested rainwater samples at concentrations ranging from 0.01 ppm to 10.0 ppm (with one sample having a concentration of 85.0 ppm) (Sinclair et al., 2005). In Sydney, Newcastle (New South Wales) and Esperance (Western Australia), the situation was similar. Water sampled from rainwater tanks in Sydney contained lead up to 0.35 ppm (Sinclair et al., 2005), up to 0.16 ppm in Esperance (Rodrigo et al., 2009), and up to 5.77 ppm in Newcastle (Heyworth and Mullan, 2009). A tank in the town of Karumba in the Shire of Carpentaria, northern Queensland contained up to 100 ppm lead (Godt et al., 2006). These results demonstrate a need for future epidemiological studies to determine whether there is a public health risk from these detected levels.

In Adelaide, it is not clear where the lead found in rainwater samples comes from, although the relationship detected between lead and both roof material and geographic region might provide some clues. It is possible that the lead comes from the roof material, although lead as a component of galvanized or coated metal rooves is not regularly reported. The lead might be environmental. Vehicles were switched to unleaded petrol in 1985 (O'Brien, 2011), although it may take many decades for the metal to be removed from the environment. The National Health and Medical Research Council (NHMRC) (2016) indicates that in areas with history of higher road traffic, lead spread by vehicles before the introduction of unleaded petrol can still exist in roadside soils and from there, the metal can spread to other areas in the environment (O'Brien, 2011). Domestic paints in South Australia were reduced to less than 0.1% in 1997 (Australian Government, 2016), although it is possible this could still be a source of lead. Studies indicate that lead naturally occurs in the environment (Boggess and Wixson, 1979, Pattee and Pain, 2003). A study by Lovering (1976) indicated that industrial precincts in large cities can have an average atmospheric lead up to 2.5 µg/m^3 or 0.0025 ppm, and that lead trace particles can spread in the environment miles away from the initial point of emission. Alternatively, lead could have been sourced by plumbing fixtures of plumbed-in tanks in older houses built before 1990 with galvanised pipes, chrome plated brass or piping joints sealed by adhesive that contained lead (Northern Territory Government, 2012). This could have been the case in the Adelaide Hills and foothills where tanks are essentially installed on older houses, and in the Adelaide plains where samples were mainly collected in semi-industrial areas. This is supported by a study in Brisbane that found lead above NHMRC guideline levels in 15% of rainwater samples and attributed lead paints and flashing to 79% of this contamination (Huston et al., 2012) .

Fewer samples of zinc were over the ADWG. As with lead, there was a relationship between zinc and both roof material and geographic regions. This is more likely to come from galvanized roofing (enHealth, 2010). Zinc was higher in sample collected in the Adelaide hills and foothills, which are also those areas that have higher numbers of galvanized roofing. It is possible that lead and zinc found in rainwater could be linked to a combined corrosive action by solar radiation, wind, weathering and pollution on rooftop structure materials. Studies indicate that an exposure to solar ultraviolet radiations can rapidly fade coatings on structure materials, scale off tiny metallic micro-particles and paints on coated surfaces and trigger a corrosion

(England, 2011, Kogler, 2015). With rainfall, scaled off metallic particles can easily be removed from faded surfaces and get washed in the tank.

Cadmium and copper detection above the ADWG were limited to few samples collected in the Adelaide Hills. Copper was detected in samples collected from plumbed-in tanks, and the water used as source of drinking water. Copper was the only metal that was influenced by the water pH and copper was only detected in those samples that had a pH ≤ 6.5 and is likely to be a result of corrosion of pipes. Acidic rainwater can result in increased corrosion and dissolve metals on tanks and roof materials structures, and on pipes, structure materials and tank fittings (National Health and Medical Research Council (NHMRC), 2011, U.S. Environmental Protection Agency, 2007). Such water would be corrosive on copper and lead (World Health Organisation, 2004). Another possible source of copper might be copper-chromium-arsenate (CCA) treated timber. It should be noted that the Adelaide hills region was affected by extensive bushfires in January 2015 that caused damages to building structures, livestock and to vineyard farms (Jasper and Waldhuter, 2015, SA Country Fire Service, 2017). Few tanks had elevated levels of cadmium, and only samples from the Adelaide hills. It is not clear where this cadmium might come from, although studies have reported that cadmium as a zinc impurity occurs in substantial amounts in galvanised structures (de Miguel et al., 1997).

4.1.5.1. Filters to improve rainwater quality

A number of household filters are commercially available and most claim to remove a wide range of impurities, including metals and bacteria (Puratap Pty Ltd, 2011) (Amway, 2003); however, it was clear from this study that there was very little reduction in metals by the filters, even though there was a statistically significant reduction, the filters did not reduce contamination below the ADWG, except in two cases.

4.1.5.2. Exposure assessment to metals from rainwater harvested in the Adelaide region

The exposure assessment is based on the proportion of samples that exceeded the ADWG thresholds, and the estimated proportion of households in Adelaide and regional South Australia that use rainwater as their primary source of drinking water. There are several studies which have previously examined the number of households in South Australia that are using rainwater for drinking. A survey conducted in 2015 and 2016 found that 36.4 % (167/459) of household's used rainwater as a main source of drinking water. The participants of this survey were from a range of areas across South Australia, including Adelaide (Chubaka et al., 2017). This supports a previous study conducted in 2010 that found nearly 22% of South Australia households used rainwater as source of drinking water, compared with the national average of 10.1% (enHealth, 2010). Adelaide has the highest proportion of households (10.6%) that use rainwater as a primary source of drinking water compared to other capital cities (Australian Bureau of Statistics (ABS), 2007). In regional South Australia (outside of Adelaide), nearly 66% of households used rainwater as source of drinking water (Australian Bureau of Statistics, 2010).

Exposure was estimated using the median tank value for lead and cadmium compared with the ADWG (Figures 3 and 4). Also included in these figures is the tank with the highest concentrations of lead and cadmium detected in the study (the worst case). In the worst-case scenario, lead was found above the ADWG in one tank 8 times in 9 samplings rounds, and in the median scenario 5 times in 9 sampling rounds for the median case scenario. Cadmium was found in one tank 3 times in 9 sampling rounds in the worst case, and 1 time in 9 sampling rounds in the median case scenario. Only one tank contained copper, at above the ADWG (8 times/9 sampling rounds), and this water used as primary source of drinking water (Figures 22, 23 and 24). If we assume that the median tank represents tanks across Adelaide, then at any one time approximately 6% of households are drinking water that exceeds the ADWG for lead. If the median tank represents tanks across South Australia, then in rural areas the estimate is much higher. This is consistent with an earlier study on rainwater across Australia, which found that 30/38 tanks surveyed (79% of tanks) contained lead above the ADWG (Chapman et al., 2006).

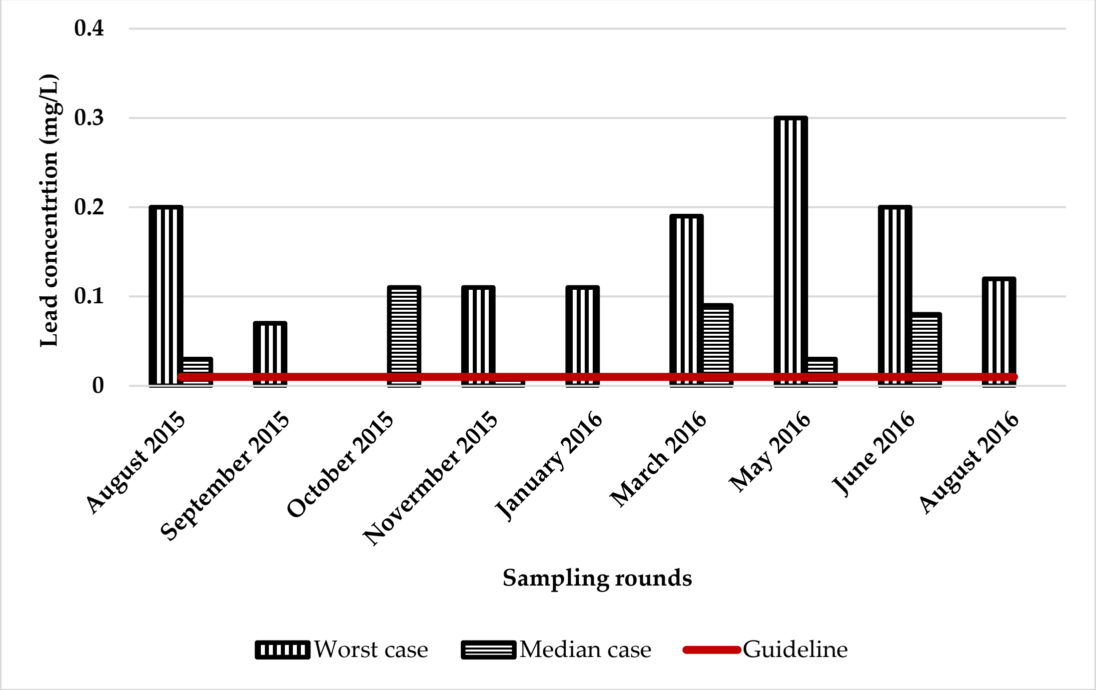

Figure 22. Levels of lead in the worst and median tanks

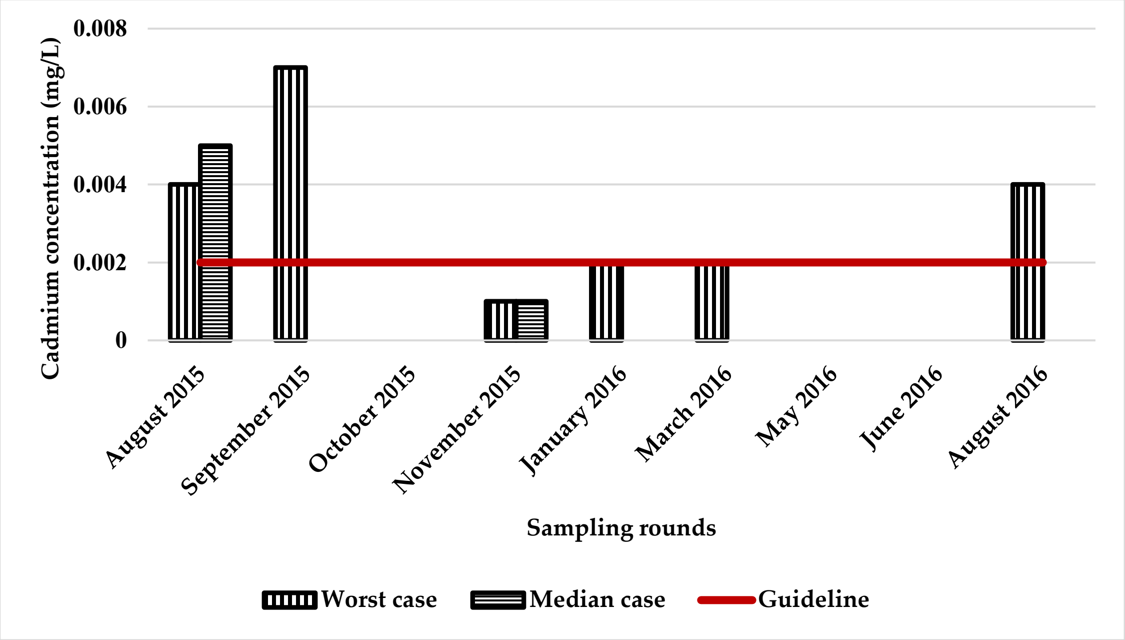

Figure 23. Levels of cadmium in the worst and median tanks

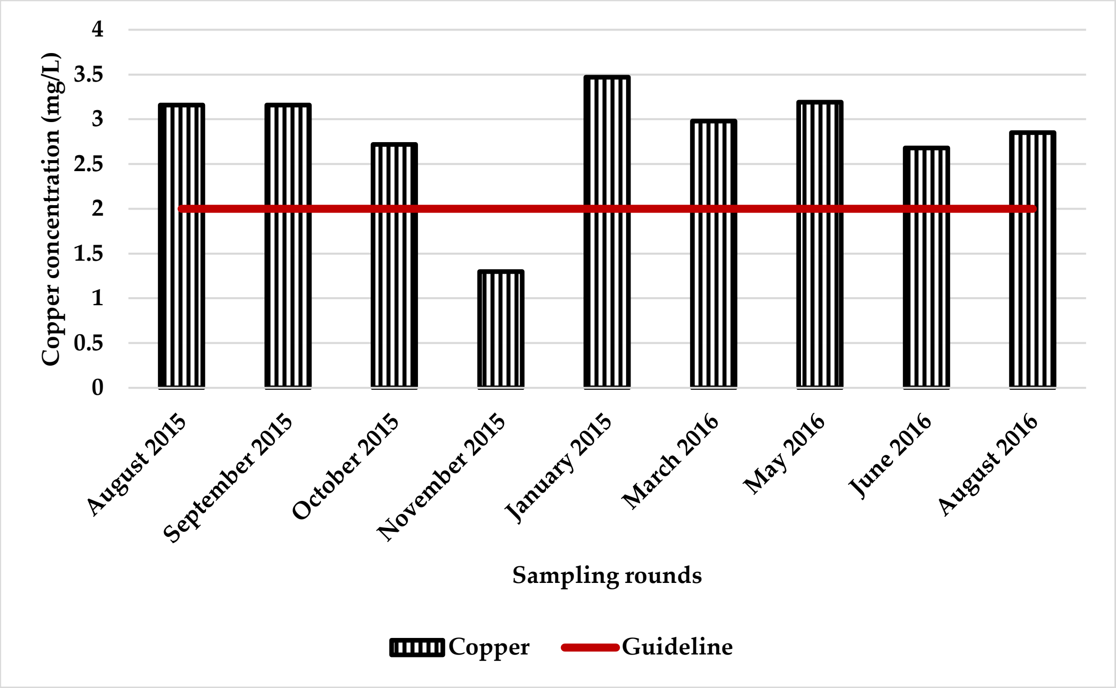

Figure 24. Levels of copper in the one tank found to have cooper above the ADWG

The Australian public is advised not to use water with a lead concentration of 2.0 ppm or greater for garden watering as the metal can be taken up by the plants (ANZZEC, 2000). In total, 7 samples (2% of samples) exceeded this limit. The FAO (Ayers and Westcot, 1985), and EPA South Australia (1999) set 0.10 ppm (0.1 mg lead/L) as upper limit lead concentration in livestock drinking water. Of 365 samples tested for lead, 100 samples (27.3% of samples) exceeded this limit. In the United States, a lower concentration is recommended for livestock feeding as it is argued that lead affects may occur from 0.05 ppm (Pfost et al., 2001). Epidemiologists argue that there is no safe threshold for lead in humans (Spivey, 2007).

Cadmium detection above the ADGW in this study was limited to few tanks in the Adelaide Hills. In the median case scenario, 1.2% of Adelaide households are likely to be exposed to elevated blood cadmium levels. As for copper, the metal was detected above the ADWG in only one tank and, thus, no exposure assessment was conducted. However, it is important to note that this one tank was being used for drinking purposes and the concentration of copper detected (2.69 ppm to 3.47 ppm) was not only above the guideline for drinking water, but also above guidelines for watering of plants and for poultry or sheep feeding (EPA South Australia, 1999).

4.1.6. Conclusion

This study indicates that lead was the metal detected in samples above the ADWG most often. Of 53 tanks surveyed, lead was detected in 47 tanks above the ADWG, in at least one sampling event. Zinc, cadmium and copper were detected in fewer samples, predominantly in the Adelaide hills and foothills. Lead and zinc in rainwater content was consistent with roof materials and geographic area, although it was not possible to determine which of these effects was the primary contributor, as roof material in the Adelaide hills and Adelaide foothills are primarily, or solely galvanised metal. In the absence of effective rainwater filtration systems, it is suggested that rainwater use be limited to non-potable purpose in areas where municipal water is supplied. However, there is a need for future studies investigating the potential human health impact of metal contamination to determine whether there is a public health risk from these levels.

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Conflict of interest: The authors declare no conflict of interest

4.1.7. Reference

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This remainder of this chapter presents the components of the thesis relating to metals found in rainwater collected in the Adelaide region resulting from this work that were not presented in the above publication (4.1).

4.2. Review of detection of metals in rainwater harvested in the Adelaide region

Unlike centralised municipal water which is treated and supplied to communities by SA Water, rainwater harvested on private properties and consumed by families is mostly untreated (Chubaka et al., 2017). Metals of health concern such as arsenic, cadmium, chromium, cobalt, copper, lead, and mercury, have been detected in rainwater samples collected in many Australian locations of Australia above the Australian drinking water guideline (ADWG) (Chapman et al., 2006). Studies indicate that wind-blown sediments found in tanks can contain high concentrations of metals (Lye, 2009). Alternatively, metals can be directly sourced from catchment areas, storage facilities and pipe fittings (Morrow et al., 2010, enHealth, 2010). A few studies exist on rainwater contamination by metals in the Adelaide region. In a study that involved the investigation of six tanks in Adelaide, lead and zinc were detected above the ADWG in rainwater samples (Chapman et al., 2008). Copper, aluminium and iron were also detected, but generally below guidelines. Another study involving more than 300 households who drank rainwater, measured copper, lead and zinc in Adelaide rainwater samples (Rodrigo et al., 2010). The median detection level was 8.4 µg/L for copper, 0.8 µg/L for lead, and 700 µg/L for zinc, with the highest detection being 789 µg/L for copper, three orders of magnitude above the ADWG of 2.0 µg/L for water aesthetic, and 30.1 µg/L for lead, four orders of magnitude higher than the

ADWG of 0.01 µg/L. The highest detection of zinc was 16,100 µg/L, also four orders of magnitude above the ADWG (3.0 µg/L for water aesthetic).

Studies have indicated that rainwater with a pH of 6.5 and below can dissolve metals on structures and leach them in stored rainwater (World Health Organisation, 2011a). In plumbed-in tanks, metals can be sourced in rainwater by plumbing fixtures (enHealth, 2010). Ageing building rooftops and tanks (such as that presented in Figure 25), may have a greater propensity to leach metals into the tank and affect the quality of stored rainwater, particularly when the pH of harvested rainwater is 6.5 or below (Mendez et al., 2011, Abbasi and Abbasi, 2011). For instance, zinc concentration in water collected from the tank in Figure 4.1 ranged from 4.5 ppm to 8.05 ppm, and 5/9 samples collected from the tank contained zinc above the aesthetic threshold of 3.0 ppm for drinking water. This is consistent with a study by Wicke et al. (2014) that investigated two experimental roof sheets of 0.5 m^2 made of corrugated galvanised steel roofs aged 55 and 15 years, and two other experimental roof sheets of 0.5 m^2 made of copper roof sheets aged 53 and 45 years. It was found that at all pH levels (pH 4, pH 6, pH 8), metal detection in rainwater samples was higher on older roofs (Wicke et al., 2014).

Figure 25. Corrosion on galvanised steel rainwater tank, photo Adelaide Hills, 2016.

4.3. Removing metals from rainwater

In Australia, health authorities advise the public not to drink untreated rainwater in areas where centralised municipal water is supplied (enHealth, 2010). However, enHealth notes:

> *“The decision about how to use rainwater is a matter of personal choice”*
>
> (enHealth, 2004).

In areas where rainwater is the only available option, the public are advised to disinfect, boil or filter rainwater before use (enHealth, 2010). However, metals are inorganic compounds that cannot be removed from water through water disinfection. Water disinfection methods are only effective in microorganisms control (World Health Organisation, 2011b). Instead, water treatment such as filtration is required to remove inorganic compounds from rainwater, including trace metals (Dvorak and Skipton, 2013).

Water distillation is effective in removing metals from water, although it does not remove water impurities that have a lower or same boiling point as water (Dvorak and Skipton, 2013). For instance, volatile organic compounds, such as benzene and toluene, can turn to vapour, rise with the steam as the water boils and later, get detected in distilled water (Dvorak and Skipton, 2013). Water distillation has the advantage of leaving minerals of health benefit behind (nutrients), turning the water into soft water, and improving the taste of water (Alexander, 2007). However, it is unlikely that rainwater consumers would be willing to distil their rainwater. Like municipal water, water filtration would be the most suitable option for metals removal from rainwater (Helmreich and Horn, 2009, enHealth, 2010, Brown et al., 2017).

4.4. Filter effectiveness in removing metals

An experimental study by Ross et al. (2018) showed that a jug filter and an under-bench filter, fitted with new cartridges, failed to reduce a number of metals in water to below acceptable drinking water standards. The full paper is presented in Appendix 8. This is counter to claims by Puratap (2010) and Amway (2015) water purifier suppliers' notices of product performance, and enHealth (2010). Filters' poor performance in metals removal from rainwater is supported by this study, which found that the samples collected from nine tanks that had water filtration systems installed at the tap were slightly lower than the unfiltered samples, although filters did not remove metals to below the ADWG in instances when it was exceeded (Figures 26 to 29).

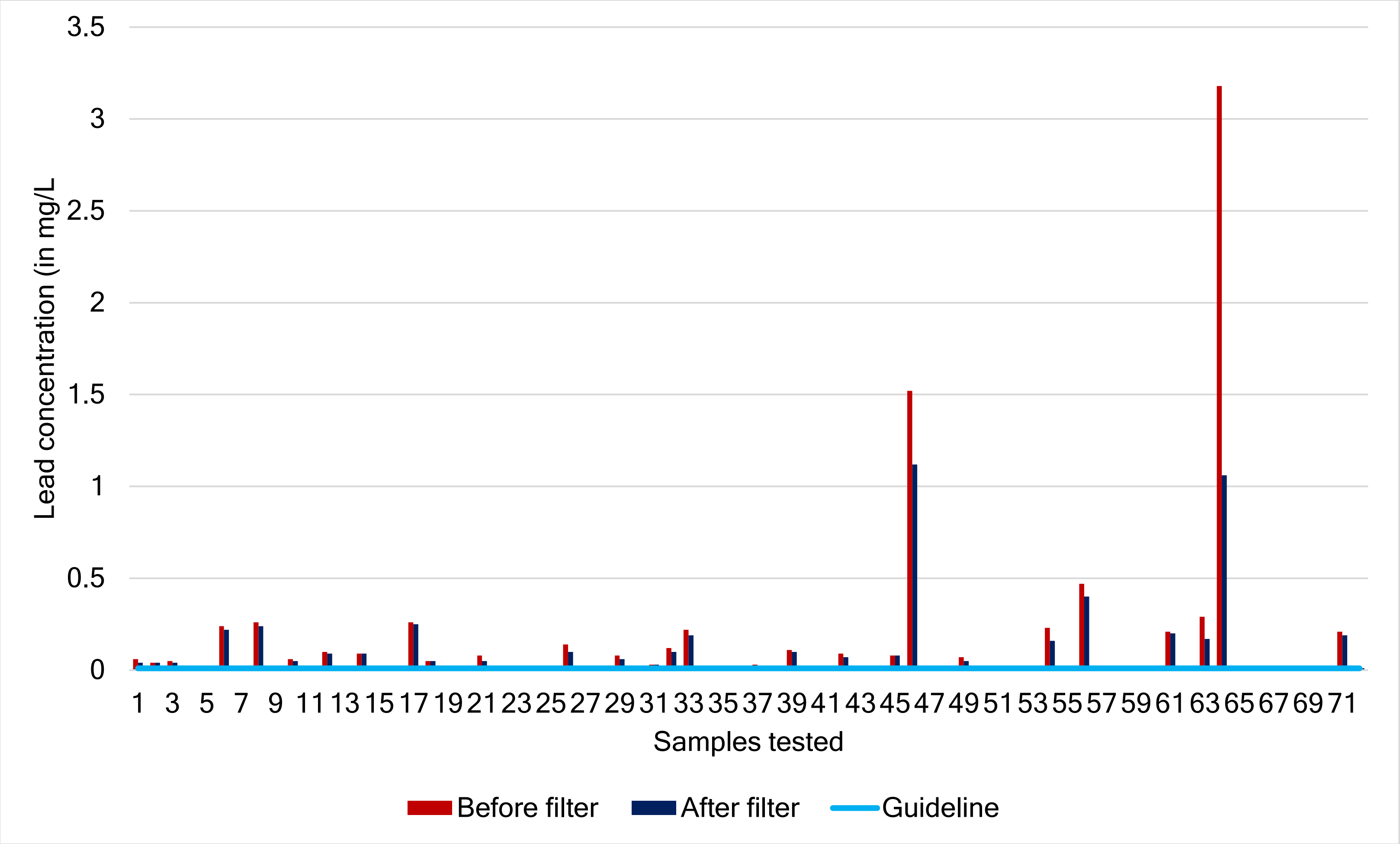

Figure 26. Lead in filtered and non-filtered rainwater samples

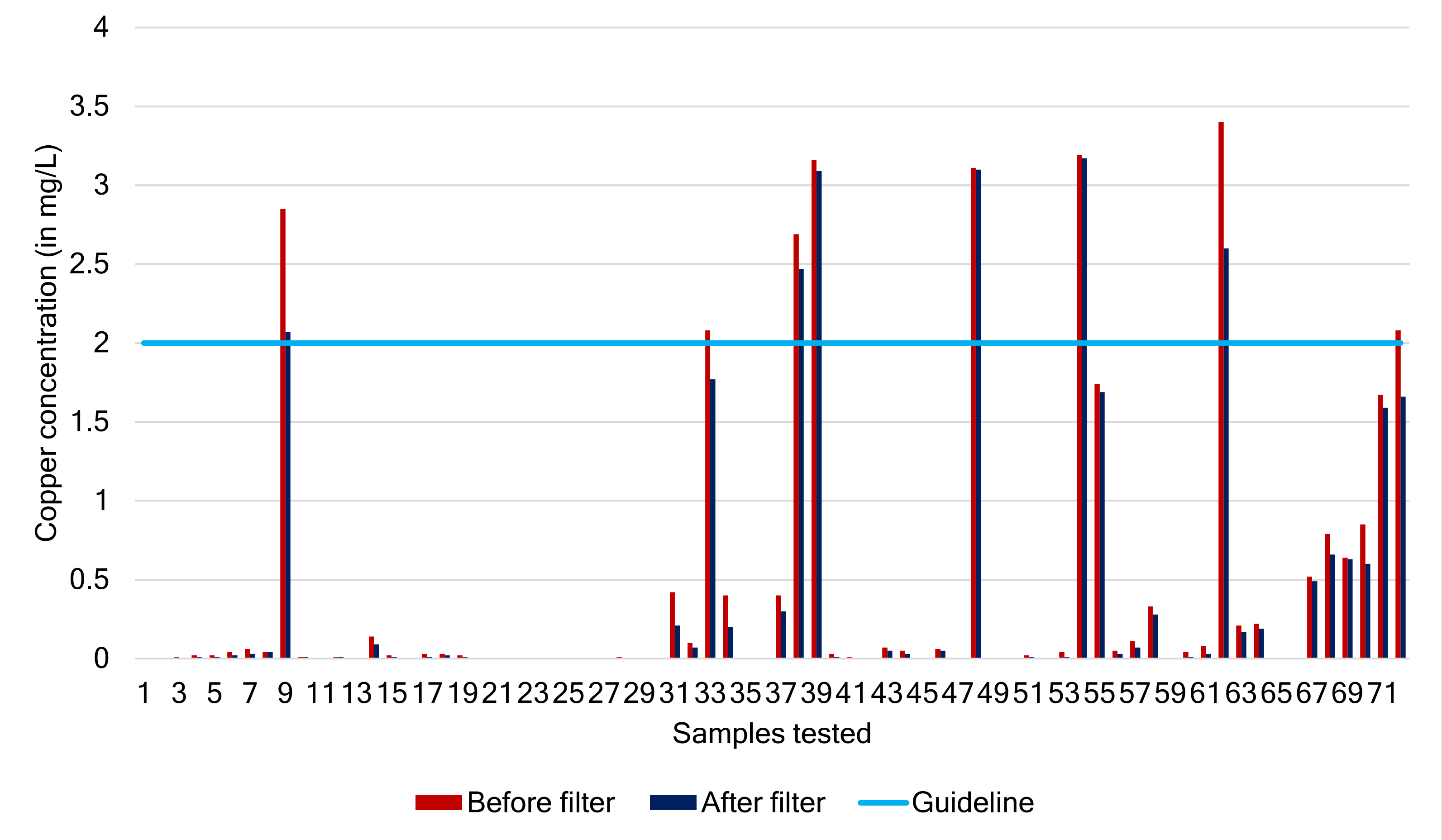

Figure 27. Copper in filtered and non-filtered rainwater samples

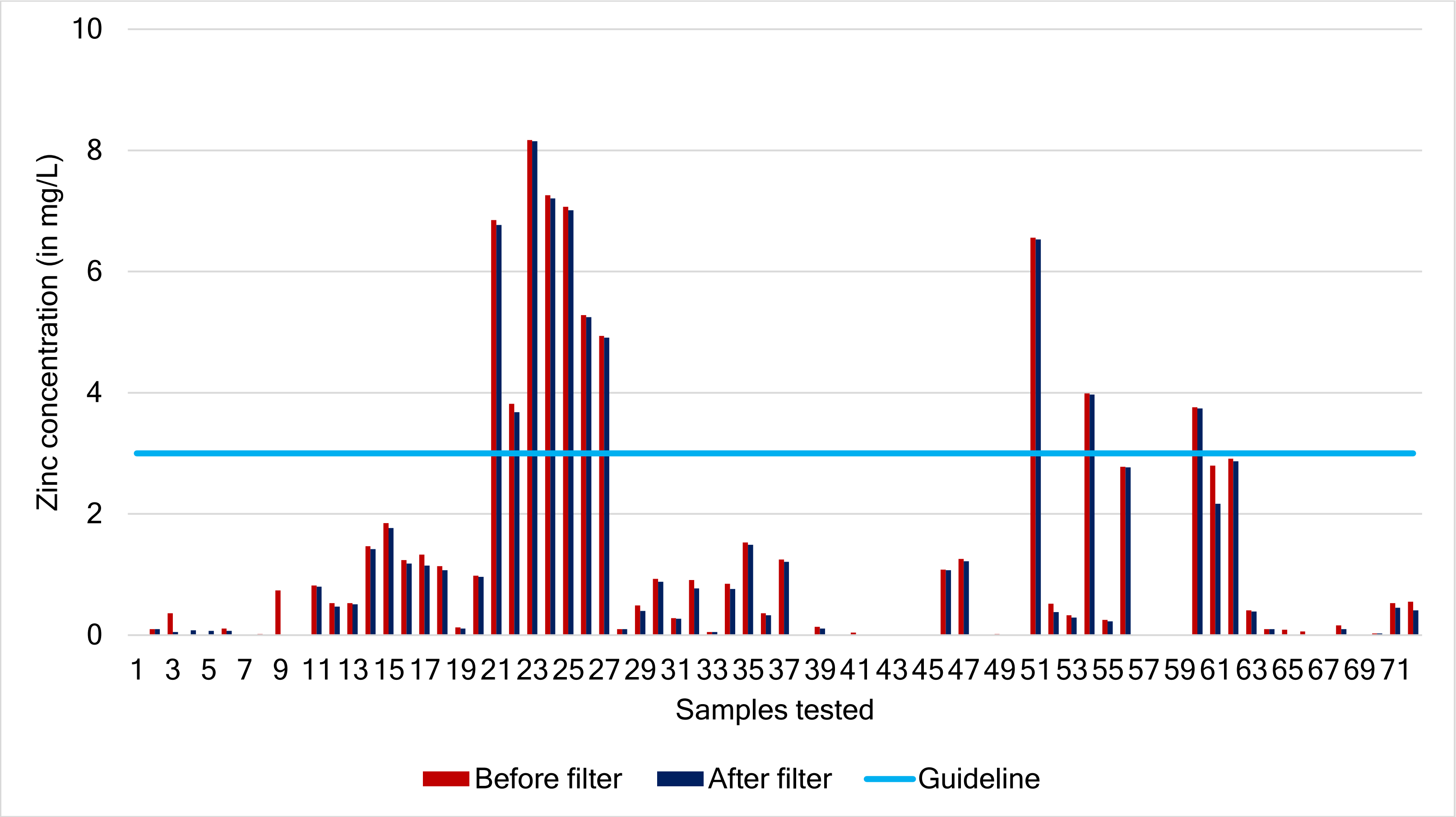

Figure 28. Zinc in filtered and non-filtered rainwater samples

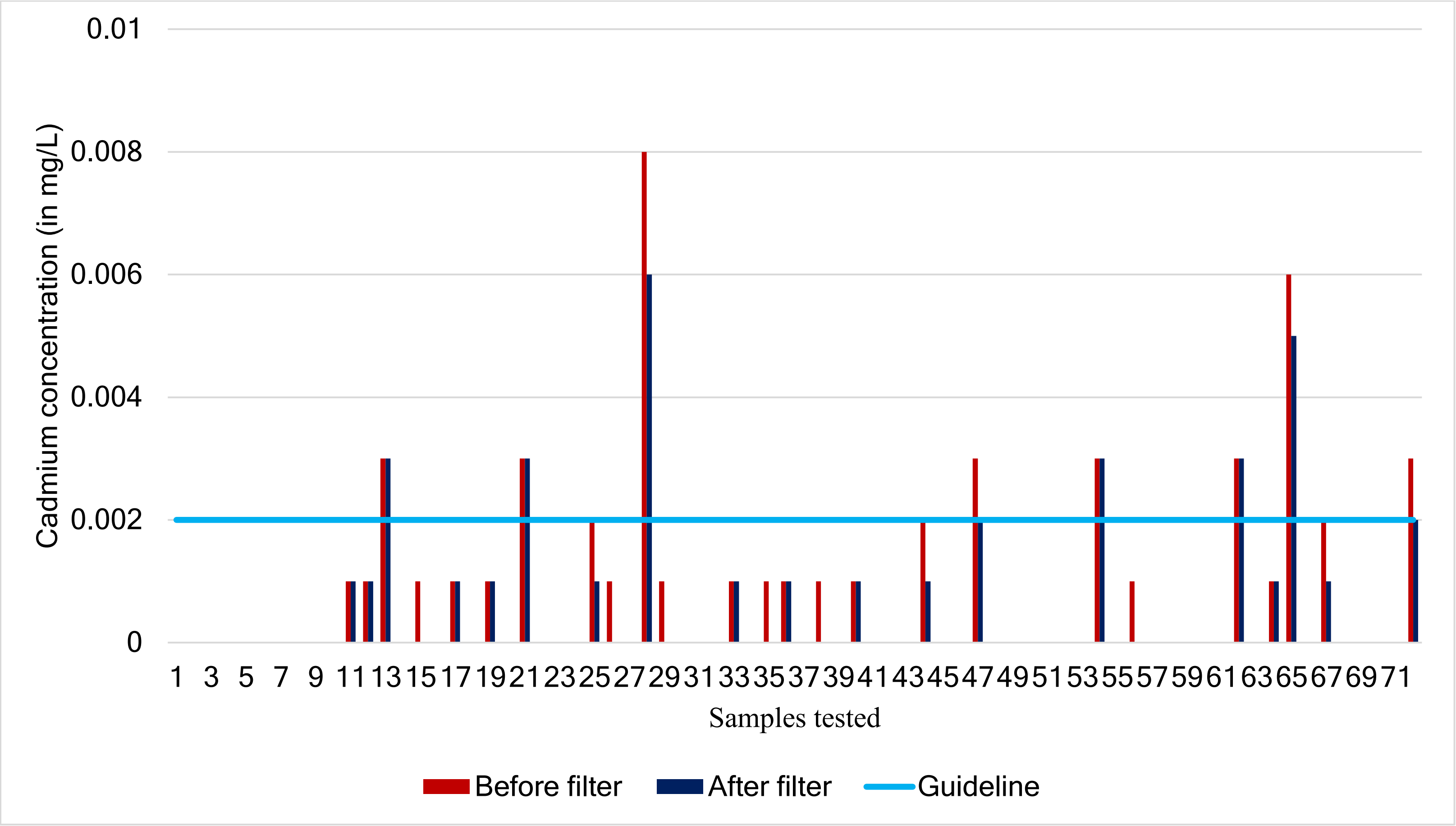

Figure 29. Cadmium in filtered and non-filtered rainwater samples

For municipal water, the manufacturers' suggested filter lifetime for commonly used filter cartridges is generally 12 months (Amway, 2015, Puratap, 2010). This lifetime could be significantly less for rainwater as sediments associated with rainwater could block the cartridges earlier (Chubaka et al., 2017). Notably many households that had filters installed in their homes to filter their rainwater used the filter cartridges after they reached the end of the manufacturer's proposed lifetime, and a number had never replaced or undertaken maintenance on their filters (Chubaka et al., 2017).

Trace metals vary in size from 1 to 2.5 µm for fine particles, and 0.1 µm to 1.0 µm for ultrafine particles (Geiger and Cooper, 2010a). The diameter of many of the trace metals of health concern, such as arsenic, cadmium, copper, chromium, lead and mercury are in the category of ultrafine particles (Chester. R, 2001). Thus, their removal from rainwater could be achieved by ultra-filtration membranes (0.0-0.05 µm) or reverse osmosis membrane filtration (ROM) (0.0001 µm) (Safe Drinking Water Foundation, 2017). It has been reported by Dvorak and Skipton (2014) that a ROM water filtration system successfully removed arsenic, barium, cadmium, copper, chromium, lead, manganese, mercury, chromium, radium, silver, thallium, uranium and zinc from municipal water. NSW Health (2017) indicates that ROM filters are effective in removing microorganisms and chemicals from rainwater, and advise the public to have pre-sediment cartridges, and first flush diverter installed where ROM filters are in use. Due to the small pore size, ROM filters can be clogged by sediments before end of the predicted lifetime of the filter. A triple console filter with 0.5 µm cartridge for coarse particles, and a 0.3 µm cartridge for fine particles can be used as buffer to extend the lifetime of ROM filters. A leaf catcher, and first flush diverter may also be required as pre-buffer to filter cartridges to maximise ROM filter performance. However, the technology may not be suitable or affordable to small scale domestic water filtration.

4.5. Consumption of untreated rainwater and potential health impacts

In Australia, incidence of illness as a result of drinking untreated rainwater is low (enHealth, 2010). It is generally thought that rainwater harvested from a well-designed and maintained catchment, and stored in clean tanks can provide safe drinking water (World Health Organisation, 2011b). Health authorities in South Australia advise the public not to use rainwater harvested in areas of high manufacturing industry and heavy traffic for potable purposes (SA Health, 2017c). However, there are few, if any, epidemiological studies of rainwater consumers assessing the extent of health effects associated with metals from using rainwater as drinking water in South Australia. Unlike bacterial infections that emerge after a short period time (Griffin and Tauxe, 1991), metal effects on health are cumulative, and symptoms develop over time, posing problems for epidemiologists and affected persons to identify cases of metal poisoning (Oregon Health Authority, 2016). In children, lead has adverse effects on cognitive function (Jakubowski, 2011). Lead compounds (inorganic lead) are classified as carcinogen Group B (IARC, 2018). Cognitive problems have been reported in children with blood lead levels of 5 µg/dL (World Health Organisation, 2010b). In addition, impulsivity and hyperactivity were observed in children at a lower blood lead of 1-3 µg/dL, and a decrease of 6 points in children's IQ at a blood lead from 1 µg/dL has been reported (World Health organisation, 2010a). This is consistent with other studies that were carried out by Baghurst et al. (1992), Canfield et al. (2003) and Kosnett (2009). Other studies have found a blood lead of 5-10 µg/dL linked with a reduction in IQ of 1-2 points (Koike, 1997).

Reduction in academic performance and an increased rate in loss of focus has been observed in children with a blood lead level below 5 µg/dL (Hauptman et al., 2017). In adults, studies have found a link between a blood lead below 5 µg/dL and heart diseases, stroke and peripheral arterial damage (World Health organisation, 2010a), and an increased systolic blood pressure from a blood lead of 5µg/dL to 10 µg/dL (Kosnett, 2009). The National Health and Medical Research Council (NHMRC) suggests that a blood lead level of 10 µg/dL can result in organ malfunction and suggests that a level of 5 µg/dL in children and pregnant women should be subject to investigation (SA Health, 2015). It is thought that in pregnant women, a level of 1 µg/dL could result in the reduction of the foetus weight (Taylor et al., 2016), while in adults, a combined long-term exposure to lead and cadmium has been reported to have the potential to increase kidney disease risk in individuals aged 20 years and older (Navas-Acien et al., 2009). Currently it is thought that there is no known safe threshold for lead in humans (Spivey, 200; Wani et al., 2015; Vorvolakos et al., 2016).

This current study confirms the results of other studies that have found elevated levels of metals in rainwater tanks and demonstrates a link between elevated metals concentrations to roof type and/or catchment area. It was not determined in this research whether there are health effects resulting from the consumption of rainwater that has elevated levels of metals, particularly lead. The efficacy of removal of these metals by filtration was low. The efficacy of other small scale, affordable filtration units and other devices such as first flush diverters that affect rainwater quality requires further investigation so that appropriate evidence-based advice can be given to rainwater consumers.

Chapters 3 and 4 in this thesis provide evidence that the quality of rainwater collected in the Adelaide area may be compromised, both in terms of contamination by microorganisms and metals. The discussion in Chapter 5 presents perceptions of what good drinking water means, from the perspective of experts in the water treatment industry, which, as will be discussed, often differ from that of the wider public. Given the results presented in Chapters 3 and 4, the aim was to identify the reasons that a proportion of the public preferentially drink untreated rainwater when clean municipal water is made available.

CHAPTER 5. DRINKING WATER: PUBLIC PERCEPTIONS

5.1. Publication: Rainwater for Drinking Water: A Study of Household Attitudes

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Rainwater for Drinking Water: A Study of Household Attitudes

5.1.1. Abstract

Many people in Australia choose to drink rainwater even in areas where clean municipal water is available. Domestic rainwater is defined here as any water collected from building rooftops subsequent to rainfall events and stored by households for later use. Rainwater has been found in some cases to contain bacteria, or trace metals, or both. As a result, in Australia, the Department of Health and Ageing advises the public to limit rainwater use to outdoor purposes, and to laundry and toilet flushing. In this study, over 12 months, rainwater samples were collected around Adelaide and tested for *E. coli* and total coliforms. Of 365 samples tested, more than 50% contained *E. coli.* In Australia, the health guideline for *E. coli* is 0MPN/100 mL for drinking water. A survey on household drinking water choice was undertaken across the metropolitan area of Adelaide. The aim was to determine drinking water choices and to understand the driving forces behind drinking potentially contaminated rainwater in a city where clean municipal water is supplied. The investigation concluded that a higher proportion of households use rainwater as their primary source of drinking water in the Adelaide Hills and foothills compared with other areas in metropolitan Adelaide (the Adelaide plains). It was found that a higher proportion of households are using domestic filtration systems to improve municipal water quality in the Adelaide plains. Opposition to municipal water chlorination and fluoridation was reported and this was central to peoples' drinking water preferences. Notably, this opposition to municipal water chlorination and fluoridation is not supported by epidemiological evidence suggesting that these chemicals are harmful.

5.1.2. Introduction

The supply of safe and adequate drinking water to communities remains a global challenge (United Nations Childrens' Fund (UNICEF), 2015), and water security is an important issue for many communities (United Nations University Institute for Water Environment & Health (UNU-INWEH), 2013). Water security is not only the absence of water, but also water quality, particularly with respect to water-borne diseases (United Nations University Institute for Water Environment & Health (UNU-INWEH), 2013). In Australian cities, water utilities supply high quality, safe reticulated municipal water, but many Australians are preferentially drinking roof harvested rainwater. This observed behaviour and the underlying factors giving rise to this choice is the focal point of this investigation.

In many areas of Australia, concerns over water security arise from water quality rather than quantity of water supplies, and many small towns in regional and remote Australia still have limited access to clean water. Notwithstanding, in Australia, threats to water security include drought conditions and population growth. Projections indicate a doubling demand in water resources for Australia by 2050 (Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2015). Following drought conditions, water storage was severely reduced in Victoria, with Melbourne water storage declining by 152 GL in 2015 (Victoria State Government, 2016). In South Australia, the raw water prior to treatment is often of poor quality. This means that the level of treatment necessary can be extensive (SA Water, 2016). Additionally, water quality and quantity are impacted by population growth and extreme weather conditions. In New South Wales and Tasmania, notices of water boiling are periodically issued to the public and in 2016, 18 Tasmanian water utilities were targeted by notices of water boiling. In that same year, 23 drinking water alerts were issued by NSW Health (Australian Water Association (AWA), 2016). In many areas of NSW, water hardness is the primary contributor to poor municipal water quality (Jaravania et al., 2016). For example, in the regional towns of Quirindi, Walhallow and Caroona, it’s common to hear local people claiming that there is no water to drink despite municipal water being supplied, if rainwater is unavailable (Alan, 2016). Further west, since 2000, concerns over municipal water quality emerged in 26 towns in the mid-west and goldfields regions of Western Australia (Neuweiler, 2016).

Incentives to address these challenges are underway in Australia and include increased funding, regulatory frameworks, quality control and community engagement (Gleick, 2000), and water recycling, seawater desalination and RHRW are emerging as options with the potential to mitigate water stress.

RHRW can be associated with bacteria and metals that may be harmful to humans’ health (Gwenzi et al., 2015). Many Australians use RHRW as their primary source of drinking water (Australian Bureau of Statistics, 2010). The EPA Victoria (2006), echoing the Department of Health and Ageing (DHA) messages (Department of Health and Ageing, 2004), advises the public to abstain from drinking RHRW in areas where municipal water is accessible. South Australia and its capital city Adelaide have higher proportion of households drinking RHRW compared with the rest of Australia (Commonwealth of Australia, 2010). Enteric *E. coli,* total coliforms and trace metals have been detected in RHRW in Adelaide (National Health and Medical Research Council (NHMRC), 2011). The health guideline for *E. coli* is 0 CFU/100 mL in drinking water (National Health and Medical Research Council (NHMRC), 2011).

A study by found that taste, smell and physical appearance are central to community perception of municipal water quality. If smell, taste or colour can be perceived, the water is considered to be of poorer quality. This is despite the fact that, with the exception of manganese (concentration ≥ 0.5 ppm/L[16]) and sulfate (concentration ≥ 500 ppm/L), bacteria and dissolved metals are unlikely to affect drinking water taste(Australian Government, 2002). Detection of poor water quality requires expertise and appropriate laboratory tests. The bacteria and metals that can affect water quality are not visible and contaminated water can feature all the qualities of clean water (Thomas, 1998).

Concerns over municipal water quality, consumers' lifestyle factors, and the absence of municipal water supplies are the primary factors contributing to drinking RHRW (Hurlimann and Dolnicar, 2010). In Australia, water supplied to communities is disinfected as precautionary measure to reduce risks and as the final barrier to prevent water borne pathogenic bacteria from entering the distribution network (Calabrese, 1989). Chlorine (NaCl), potassium chloride (KCl), citric acid ($C_6H_8O_7$) and chlorine dioxide (ClO_2) are largely used in drinking water disinfection (National Health and Medical Research Council (NHMRC), 2011). Whilst not directly part to the treatment process, fluoride (F) is introduced in municipal water to prevent dental caries in children. In Australia, commonly used fluoride components include sodium fluoride (NaF), sodium fluorosilicate (Na_2SiF_6) and aqueous fluorosilicic acid (H_2SiF_2) (Victorian Government, 2009). Drinking water fluoridation is accepted practice by the Australian health authorities (National Health and Medical Research Council (NHMRC), 2011), and a drinking water fluoridation policy controlled and implemented by States and Territories is enforced in Australia (National Health and

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[16] Note. Read ppm and not ppm/L

Medical Research Council (NHMRC), 2011), The National Health and Medical Research Council (NHMRC) (2011) sets the guideline for fluoride in drinking water at 1.5 ppm. In Adelaide, the average guideline for fluoride in drinking water is 0.88 ppm (SA Water, 2014). Despite the significant achievement of dental caries prevention in children resulting from fluoride and improved water sanitation resulting from chlorine, debate still exists around the introduction of chlorine and fluoride in drinking water. Studies by Cantor (1997), Hassinger and Watson (1998), and Plewa et al. (2004) indicate that chlorine in drinking water has the potential to bladder cancer, stomach, pancreas, and kidney malfunction, and rectum cancer, and Hodgkin's and non-Hodgkin's lymphoma. However, it is not clear whether the concentrations of chlorine currently added to drinking water could trigger an incident of illness. Studies have shown that fluoride in drinking water could result in bone fractures in children at 3 ppm and in hip fractures in elderly from 1.5 ppm to 4.3 ppm (Aragón et al., 2006, Carton, 2006), in lowering children IQ from 2.47 ppm to 4.5 ppm (Plewa et al., 2004), in lowering fertility at 3.0 ppm and in thyroid dysfunction at 2.3 ppm (Balog, 1996, Aragón et al., 2006). Notwithstanding, this is countered by a review of 33 studies, which concluded that fluoridated water at 1 ppm does not have an adverse effect on bone strength, bone mineral density and fracture incidence, and at higher concentrations may even have a favourable effect on these parameters [17](Demos et al., 2001).

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[17] Note. This section of thesis aimed to investigate the drivers behind a fraction of Adelaide households to preferentially drink untreated rainwater when they have access to municipal water and to assess drinking water quality perceptions, risk factors associated with drinking rainwater and the future of rainwater use.

5.1.3. Methods

5.1.3.1. Study area and design

A survey of households' drinking water choice was conducted from March to May 2016 in five locations around the metropolitan area of Adelaide. Of five survey locations, two were in the Adelaide plains, one in the Adelaide foothills and two in the Adelaide Hills (Figure 30). Interviews were run in car parks adjacent to shopping malls during the busiest times, from 9:00 am to 3:00 pm. At times, interviews were conducted on Saturdays and Sundays to maximise the chance of including working people in the survey. An application to allow the access to survey sites and a certificate of public liability (Certificate N°: UL FLI 16) were sent to the management of shopping malls to comply with the provision of SA Trespass Act 1953 which regulates entries on private properties (Government of South Australia, 2016). In Adelaide, most shopping malls are owned privately. On approval, a reply mail to allow the access to the study area was sent by electronic mail. In event of late response or response not received, officers in shopping malls were directly contacted to obtain the approval. A few shopping malls refused to allow access on their properties for undisclosed reasons.

Figure 30. Study area map, Adelaide, South Australia

The study was approved by Flinders University Social and Behavioural Research Ethics Committee (SBREC N° 6782) in compliance with the National Statement on Ethical Conduct in Human Research (NSECHR) (National Health and Medical Research Council (NHMRC), 2015). The survey used the National Statistical Service (NSS) sample calculator to determine the sample size, using 95% as confidence level (CL), 0.5 as proportion, 0.05 as confidence interval (CI) and 5.11 as relative standard error (RSE) (Australian Bureau of Statistics, 2016).

The survey involved 459 respondents. The sample was representative of an estimate 504.400 households identified in Adelaide in 2011 (Australian Bureau of Statistics, 2015). Participants were chosen among people entering or leaving shopping malls and answering questions was voluntary. The survey was anonymous. The chi-square (X^2) statistic model was used in testing parameters goodness-of-fit. This is expressed in the test statistic equation (eqn 1):

Equation 1. Chi-square statistics formula

$$\boldsymbol{X^2} = \sum \frac{(\boldsymbol{O} - \boldsymbol{E})^2}{\boldsymbol{E}} \quad \text{(eqn 1)}$$

Where: X^2 = Chi-square, E = expected frequency, O = observed frequency

5.1.3.2. Questionnaire construction and design

Five questions were put to persons aged 18 and over, and questions included suggested responses as prompts and allowed free responses where desired.

- Which water do you most drink? Answers included town water or municipal water, bottle water and RHRW.
- Why do you prefer drinking municipal water, bottle water or RHRW? Proposed answers included: it's more convenient, it's clean water and it tastes better.
- Do you have any other reasons for choosing municipal water, bottle water or RHRW? The question was purposely unprompted to allow respondents to expand on reasons in prolong to their drinking water choices. An additional question of 'How do you use your RHRW' was asked to respondents having RHRW harvesting systems but not using RHRW for drinking.
- Do you have a RHRW tank? Answers consisted in 'Yes' or 'No' without further option.
- What is your postcode? The question was used to identify participants' area to later establish their relative socio-economic status. In Australia, suburban postcodes align with the Australian socio-economic indexes for areas (SEIFA). In the survey, SEIFA indexes were based on data collected during 2011 census of population and housing (Australian Bureau of Statistics, 2013). The maximum time to answer the questionnaire was set to three minutes however; some respondents devoted more time to expand their views on drinking water quality.

5.1.3. Results and discussion

People’s drinking water choices, in many ways, are based on municipal water community perception (Crampton and Ragusa, 2016). While studies exist on municipal water, groundwater and recycled water, limited resources were found on RHRW community perception, given recent government incentives to RHRW harvesting and use in Australia (Ward et al., 2008). Studies by de França Doria et al. (2009) have concluded low health risks associated with drinking municipal water. A gap exists between perceived benefits and risks to encounter in making drinking water options (Ward et al., 2008), and the public is more inclined to understand the level of risks severity when they are directly perceptible and with immediate effects (Marks et al., 2006).

In two respects, the investigation provided insight into trends in RHRW harvesting and use in Adelaide. Firstly, the investigation showed the magnitude of RHRW consumption and related driving factors to consumption. Secondly, the investigation found relationships between RHRW consumers, their geographical distribution and associated relative socio-economic indexes. Survey responses were grouped into themes and tallied for examples.

5.1.3.1. Source of drinking water

Results of household drinking water sources are presented in Figure 31. The investigation found that a higher proportion of households were using RHRW as their primary source of drinking water in the Adelaide Hills. The tendency was observed from the Adelaide foothills and gradually, reached higher proportions in the Adelaide Hills. The limited or absence of municipal water supplied to communities in many small towns of the Adelaide Hills makes RHRW the most convenient source of drinking water in the area. As a result, RHRW consumption was more popular than any other water in the Adelaide Hills. In contrast, RHRW was less popular in the Adelaide plains. In this area, drinking municipal water and bottled water dominated, with higher proportion of households drinking municipal water in western suburbs, and increasingly in the Adelaide foothills.

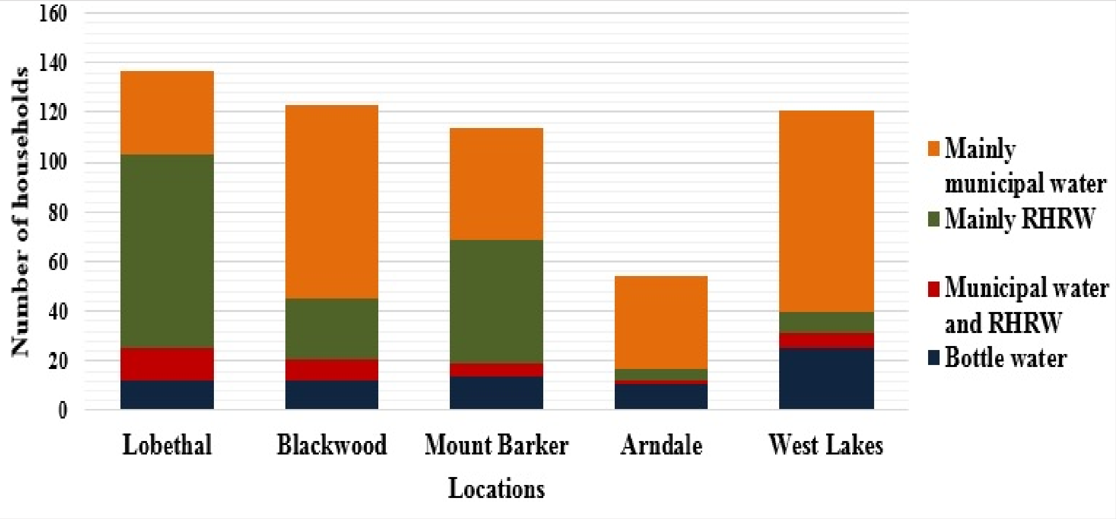

Figure 31. Sources of drinking water[18]

P-values of parameters tested in the model (P<0.0001) were lower than the critical statistic value of 0.05. This suggested a correlation that could exist between households and the source of their drinking water. In the model, the proportion of respondents who indicated drinking municipal water, along with those who drink RHRW, was central to the chi-square formation. Locations such as Lobethal and West Lakes had larger chi-square statistic values; indicating greater likelihood of linking households' choices and the sources of their drinking water (Table 14).

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[18] Note. Appendix 16, Source of drinking water with Figure 31 revised

Table 14. Sources of drinking water and X^2 statistic

Locations	X^2	P-value	Main contributor to X^2	Proportions (%)
Lobethal area (Adelaide Hills)	140.37	< 0.0001	Mainly rainwater	63.1
Mount Barker area (Adelaide Hills)	23.14	< 0.0001	Mainly rainwater	45.1
Blackwood area (Adelaide foothills)	22.01	< 0.0001	Mainly rainwater	14.7
West Lakes area (Adelaide plains)	280.63	< 0.0001	Mainly rainwater	2.9
Arndale area (Adelaide plains)	28.56	< 0.0001	Municipal water and RHRW	8.0

5.1.3.2. Drinking water preference

Generally, respondents' choices aligned with municipal water community perception. Apart from areas where municipal water supplies are limited, many respondents' drinking water choices were driven by municipal water taste rather than its quality[19]. In answering the question 'Why do you prefer RHRW?' the 'yucky factor' associated with municipal water emerged from respondents, who indicated that chlorine and fluoride in drinking water was a source of dissatisfaction regarding drinking water choice. However, there were no respondents identified during the investigation who directly stated that they thought that municipal water chlorination and fluoridation affected their health.

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[19] Note. Appendix 17. Drinking water patterns and trigger to preference by location

During the investigation, it was common to hear people saying: “although RHRW may contain bugs, it is still better than municipal water”. This sentiment was reported all over the metropolitan area, with the sentiment increasing among respondents from the Adelaide foothills towards the Adelaide Hills (Figure 32). Of 459 participants, 2 households (the equivalent of 0.4% respondents) stated that they drank municipal water for health reasons (specifically, that municipal water contains fluoride which is efficient in children dental caries prevention), and 123 (45%) respondents (out of those 275 respondents who mainly drink municipal water) stated the major reasons as convenience.

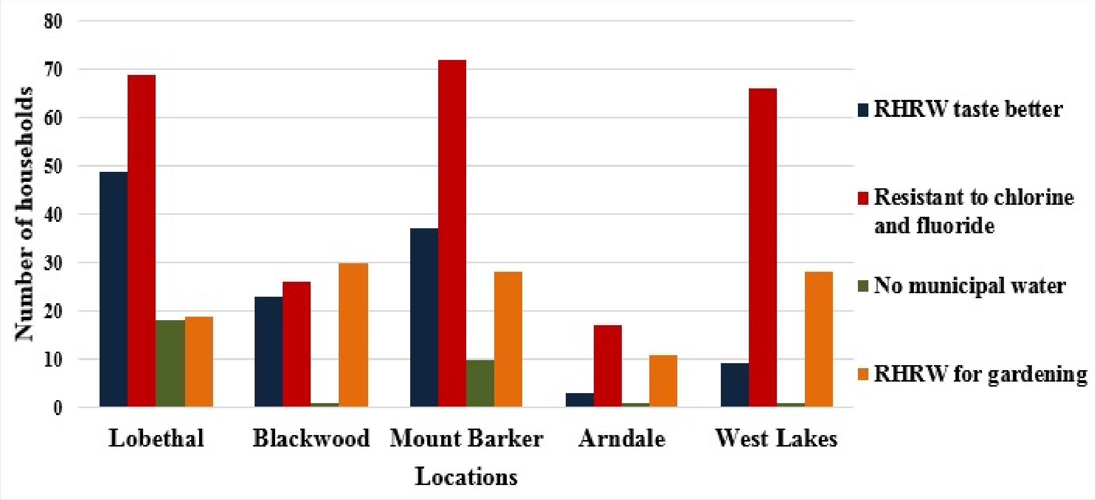

Figure 32. Factors affecting choice of drinking water[20]

Advertising campaigns by water filtration systems suppliers and water purifiers are likely to play a role in consumers thinking that municipal water quality is inferior. In Adelaide, statements such as: “We remove 99.9% of chemicals and bacteria in your water” are frequently heard in advertising on local radio. This is despite the fact that reticulated municipal water in Adelaide is of very high quality. It should be noted that

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[20] Note. Appendix 17. Factors affecting choice of drinking water with Figure 32 revised

not all Adelaide households have private RHRW harvesting systems or use RHRW for drinking and cooking. In the model, the probability associated with chi-square values ($P<0.0001$) shown in Table 15 was lower than the significance level of 0.05. Thus, the null hypothesis could be rejected for tested parameters. This suggests a plausible relationship between observed drinking water choice, and the place where respondents live in the metropolitan area. In the Adelaide foothills and the Adelaide plains, RHRW for gardening was a major contributor to the chi-square formation whereas 'Have no municipal water' contributed to the chi-square formation only in the Lobethal area, with all parameters equally contributing to the chi-square formation in the Mount Barker area.

Table 15. Drinking water choices and X^2 statistic

Locations	X^2	P-value	Main contributor to X^2	Proportions (%)
Lobethal area	25.76	< 0.0001	Have no municipal water	17.5
Mount Barker are	1.68	< 0.0001	No difference between parameters	-
Blackwood area	19.80	< 0.0001	Rainwater for gardening	32.5
West Lakes area	7.34	< 0.0001	Rainwater for gardening	31.5
Arndale area	21.27	< 0.0001	Rainwater for gardening	22.0

5.1.3.3. The propensity to filter drinking water

The investigation observed a higher tendency to use private filtration systems to filter drinking water in the metropolitan area (Figure 33). Puratap, an Adelaide domestic water filtration systems supplier established in 1996 (Puratap Ltd Pty, 2016), sold 280,445 domestic water filtration units to Adelaide households between 1996 and 2016 (Jana, 2016); the equivalent of approximately half of households in Adelaide (Australian Bureau of Statistics, 2015). As one household could have more than one water filtration unit and remain recorded as just one unit, it is difficult to estimate the correct number of households using water filtration units. Moreover, the number is not inclusive of water filtration units purchased by households from suppliers other than Puratap, and filters that are imbedded into refrigerators and used to improve drinking water quality.

This study found that private filtration units were applied to both RHRW and municipal water. Unlike municipal water, RHRW is not integrated into SA Water reticulated supply and therefore treatment. So, while installation of private filtration systems could be done in households using RHRW for microbiological and toxicological reasons, this cannot be the case for municipal water. In Adelaide, SA Water supplies high quality, safe, reticulated municipal water to communities. Thus, the primary reason for installing filters may be directly linked with water filtration systems suppliers' and water purifiers' campaigns, along with the perception of municipal water. As a result, the study found that the use of private filtration systems on municipal water targeted chlorine and fluorine removal to improve water taste.

The role of chlorine in water sanitation may have been achieved prior to its removal at the point of consumption. For fluoride however, the chemical is being removed from municipal water before consumption. This practice is counter to Australia drinking water fluoridation policy outlined in the Australian Drinking Water Guidelines (ADWG) [(National Health and Medical Research Council (NHMRC), 2011). South Australia has no formal legislation on drinking water fluoridation (National Health and Medical Research Council (NHMRC), 2011). This study found that the use of private water filtration units on municipal water was higher in the Adelaide foothills and the Adelaide plains. In contrast, the use of private filtration systems was mainly in conjunction with RHRW in the Adelaide Hills and the Adelaide foothills.

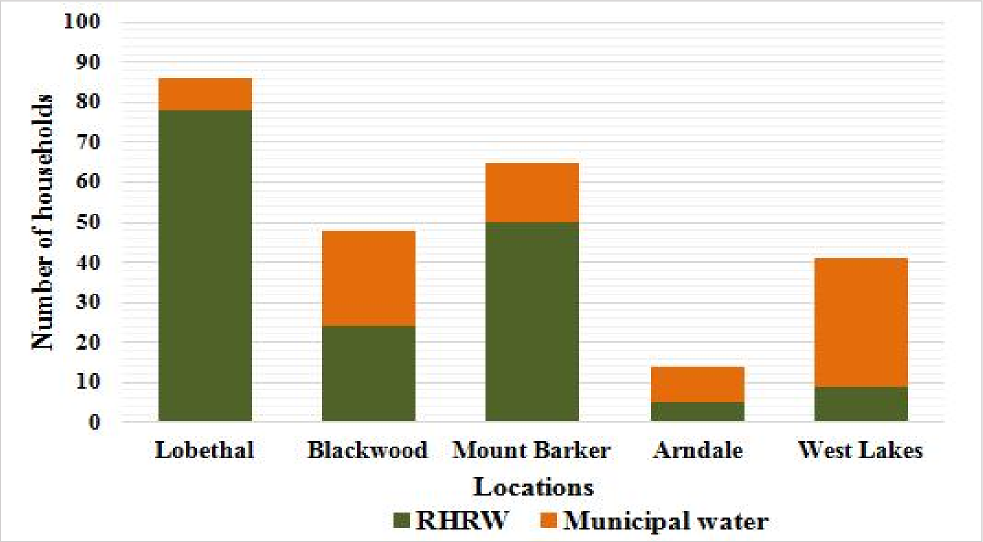

Figure 33. Use of private filtration systems [21]

In considering chi-square P-values (<0.0001) as expressed in the model, the null hypothesis cannot be accepted. For tested parameters, chi-square values ranged from 34.12 in the West Lakes area and 3.83 in Mount Barker area, to 5:00 in the Blackwood area and 5.42 in the Arndale area. This is indicative of householders' wish to improve their drinking water quality on either municipal water or RHRW. Across locations, the main contributor to the chi-square formation was essentially municipal water.

5.1.3.4. Rainwater harvesting and use

Figure 34 shows that RHRW used for drinking was highest in the Adelaide Hills, with moderate consumption in the Adelaide foothills. Two factors could explain the

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[21] Note. Appendix 17. Use of private filtration systems with Figure 33 revised

results. These are: the observed limited municipal water supply in many small towns and the presence of higher proportion of households having private RHRW harvesting systems in the area and observed resistance to municipal water fluoridation and chlorination. In the Adelaide plains however, the investigation noted that the small number of households having private RHRW harvesting systems used the water primarily for gardening.

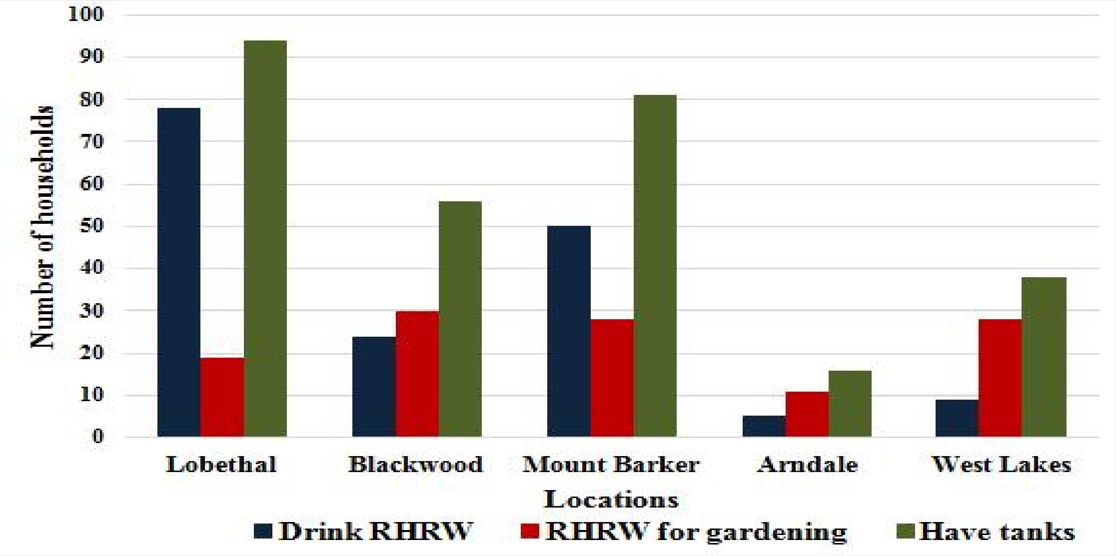

Figure 34. Have tanks and drink rainwater[22]

In the model, results of chi-square test indicated a relationship between having a private RHRW harvesting system and using RHRW as primary source of drinking water, particularly in the Adelaide Hills and foothills. P-values (< 0.0001) for tested parameters were lower than the accepted significance level of 0.05 to confirm the rejection of the null hypothesis. Across locations, the study found that RHRW used for gardening was main contributor to chi-square results.

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[22] Note. Appendix 17 with Figure 33 revised

5.1.3.5. Drinking water choice and socio-economic indexes

In order to understand underlying factors and trends in RHRW consumption within the community, the investigation used suburban postcodes provided by respondents and related socio-economic indexes for areas (SEIFA) to determine households part to the study relative socio-economic indexes. In reference to South Australia SEIFA, respondents were grouped in three categories with the least disadvantaged having a SEIFA greater than 150; with the middle disadvantaged having a SEIFA comprised between 75 and 150 and the most disadvantaged having a SEIFA lower than 75. In the SEIFA indexes scale, the larger the SEIFA, the greater likelihood the area is wealthier.

The study observed a higher proportion of households using both municipal water and RHRW as their primary source of drinking water in the least disadvantaged group. In that category, many respondents indicated that they used private water filtration systems with municipal water to improve water quality. The removal of chlorine and fluoride was main issue of concern. The study found that people in the least disadvantaged group lived in most affluent suburbs of the Adelaide foothills and the Adelaide Hills. Using the same identifiers, the investigation observed a significant proportion of households using bottled water as their primary source of drinking water in the middle and most disadvantaged categories, and majority of respondents were from the Adelaide plains and a few from the Adelaide foothills. In that category, a large fraction of respondents used filtered municipal water for drinking. The proportion of households who used both RHRW and municipal water as their source of drinking water was constant across all sub-groups.

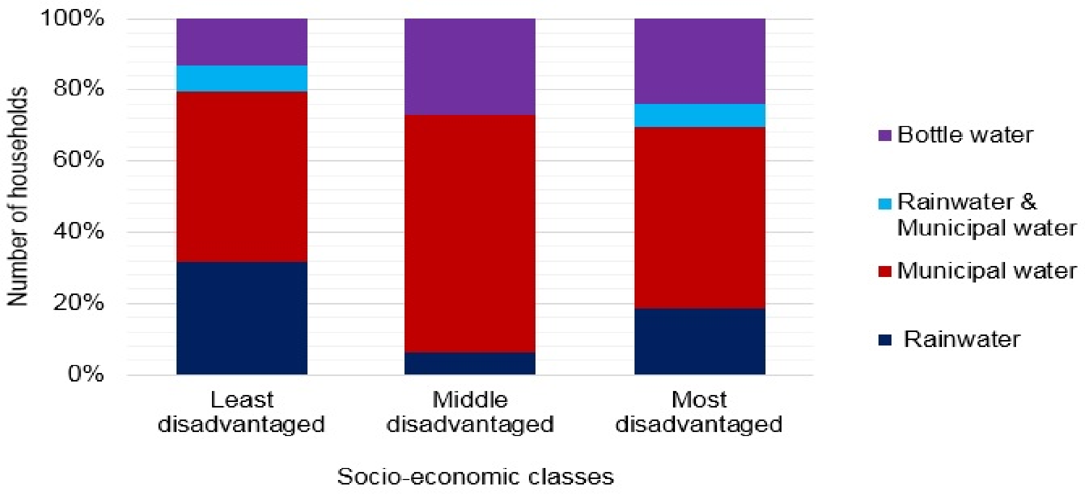

Figure 35. Relative socio-economic indexes and drinking water choice

The investigation observed higher opposition to drinking water chlorination and fluoridation in the community. Figure 35 presents the parameters tested in the model. Chi-square values associated with P-values ($P<0.0001$) were lower than the critical value of 0.05 confirming the rejection of the null hypothesis. In the model, the middle disadvantaged group was the major contributor to the chi-square formation.

The investigation was unable to efficiently untangle the RHRW drinking water factors observed in most affluent Adelaide suburbs. It should be noted that in the least disadvantaged group, people have a range of choices available and given the wealth of people living in the area, households have greater choice in drinking water. Based on respondents SEIFA indexes, people in that group are more likely to be able to afford the equipment required for water filtration, whether it is RHRW or municipal water. This was supported by the study findings that observed a higher proportion of households having private RHRW harvesting systems and using private water filtration systems to improve the quality of their drinking water in the least disadvantaged group.

5.1.4. Conclusion

The investigation found that in Adelaide, households' drinking water preference was based on the community's perception of municipal water, and the choices of many households were driven by water taste rather than water quality. Opposition to drinking water that has been chlorinated and had fluoride added was high across the community. Municipal water consumption was popular across the metropolitan area, but more popular in the Adelaide plains than in the Adelaide foothills and Adelaide Hills. In contrast, RHRW used as source of drinking water prevailed in the more affluent suburbs of the Adelaide Hills and foothills. Similarly, the consumption of filtered municipal water and bottled water was predominant in the middle and most disadvantaged sub-groups. The investigation observed a higher reliance on RHRW as primary source of drinking water in small towns of the Adelaide Hills. This was a result of both limited supply of municipal water and observed opposition to drinking fluoridated and chlorinated municipal water in areas where the product was available. Apart from taste discomfort expressed by most respondents; the investigation recorded no claim of illness as a result of drinking chlorinated and fluoridated municipal water.

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The remainder of this chapter presents the components of the thesis relating to drinking water quality perception not presented in the publication (5.1) resulting from this work. This chapter further explores the motives that result in members of the public favouring untreated rainwater as their source of drinking water, particularly when they have clean municipal water available.

5.2. Drinking water quality perception, risk assessment and rainwater future direction

This section of the thesis explores what is understood by “good drinking water” by experts in the water treatment industry, and the perception of good drinking water by water consumers from the wider public. It also considers whether people are aware of, or take seriously, the health risks associated with the consumption of untreated rainwater water, in areas where treated municipal water is made available by water utilities. Good drinking water, from a health perspective, entails any water that does not contain pathogenic microorganisms, and toxic substances (metals, hydrocarbons, and diverse toxic chemicals) that can make the consumers develop waterborne diseases (NHMRC, 2011; World Health Organisation, 2011b). Good drinking water is generally referred to as potable water that is clear, has no odour, and a pleasant taste (SA Water, 2017b). Non-treated raw waters can falsely have the physical appearance of potable water, while being contaminated, making of the waters unsafe for human consumption (Francis et al., 2015). Clear water, for example, can be deceptive as most microorganisms (Weeks, 2012), and toxic metallic elements and chemical substances (Chester. R, 2001, Geiger and Cooper, 2010b) that can occur in drinking water cannot be seen with the naked eye.

5.2.1. Safe drinking water

Water and drinking water quality is a central issue in public health (SA Water, 2016b). Physical, chemical and microbial components of water quality are important and the determination of its quality is usually measured against standards and guidelines (Australian Bureau of Meteorology, 2015b). Ideally, safe drinking water should be colourless, tasteless, and odourless (Syahyogi, 2015). In addition to microbial contamination, chemicals such as organic and inorganic constituents, radiological materials and pesticides can contaminate water (NHMRC, 2011). In many areas, inorganic substances naturally occur within the environment (Barrett, 2014), or are discharged into potable water sources through industrial, mining and agricultural effluents (World Health Organisation, 2004). Inorganic constituents include metallic elements, which can be at concentrations that may cause harm. For example, arsenic, cadmium, chromium, and lead can be toxic, even at low concentrations (Tchounwou et al., 2012).

Globally, only 40% of the world population have access to safe drinking water (2015 data) (World Health Organisation, 2017). Gaps in access to clean drinking water exist between the least and most disadvantaged countries, and also within countries, between urban and rural communities (World Health Organisation, 2017). In Australia, gaps exist between urban and rural communities. A Royal Flying Doctor Service (RFDS) report indicates that many communities in rural Australia do not have access to clean water (Laverty and Bishop, 2016). Nearly 99% of families that live in urban Australia have access to clean municipal water, compared with 84% of those living outside major towns and cities (Australian Bureau of Statistics, 2013).

In outback South Australia, many small towns still have a problem with access to safe drinking water that fully complies with the Australian Drinking Water Guidelines (ADWG) (Willis et al., 2015). Factors that contribute to limited municipal water supply in outback Australia include a smaller and dispersed population, along with very low (200 mm) annual rainfall in many areas of Australia (SA Water, 2018d). Thus, households in outback South Australia mainly rely on rainwater for drinking (Willis et al., 2015). As a result, 66% of families outside Adelaide rely on rainwater as their primary source of drinking water (Australian Bureau of Statistics, 2010).

5.2.2. Drinking water and perception of risk

Risk perception and attitudes to drinking water quality greatly vary with individuals, and most people consume their drinking water with little consideration of any health risks associated with their decision. This aligns with Hillson and Murray-Webster (2017) who note that in the course of human life, people often make decisions with little attention on uncertain outcomes that may result from their decisions. Even though no data exist in support to this, a fraction of rainwater drinkers may have awareness of the health risks and still decide to preferentially drink untreated rainwater when clean municipal water is readily available.

In Australia, municipal water is generally safe (Marks et al., 2008), with microorganisms inactivated and other contaminants removed by water utilities prior to distribution (de França Doria, 2010; Shannon et al., 2010). This contrasts with rainwater, where the water is generally being consumed untreated. Rainwater can appear cleaner than most occurring raw waters (Thomas, 1998), and associated microorganisms and trace metals are not visible (Weeks, 2012; Geiger and Cooper, 2010b). Use of rainwater for drinking water is generally either a result of dissatisfaction with municipal water quality, or the absence of municipal water (Kumara and Wickramasinghe, 2003; Xiang et al., 2003; Levy et al., 2006; Hurlimann and Dolnicar, 2010; Seidl et al., 2010). This section of this thesis is primarily focussed on the first point – the consumers who have access to municipal water but choose to drink rainwater.

5.2.3. Water related knowledge and perception of water quality

It has been shown that the public is more inclined to accept risks when they are perceptible, and with immediate effect (Marks et al., 2006). Perception of quality can be subjective, particularly when the assessment uses sensorial methods using sensory organs, rather than measurable standards. Subjectivity has been described as:

> *"A view that is based on emotive, anecdotal, and/or personal experience. It is the opposite of objectivity, which purports to be bias- or -judgement-free and data-driven"*
> Daniels (2015).

This subjective perception of quality is observed in many rainwater consumers, who consider rainwater as pure natural water from the sky. Many rainwater consumers indicate that they consider that rainwater tastes better than any other water. Water taste, smell and colour are central in the perception of drinking water quality (Kelly and Pomfret, 1997; Dupont, 2005; Ross, 2005; de França Doria, 2010), although studies report that using sensorial means to determine water quality are subjective, unreliable and not standards based (Rogers, 2002).

Water treatment technologies such as activated carbon water filtration, water aeration and water ozonation have been found to be effective in the removal of chemicals and organic matter that cause taste and odour (World Health Organisation, 2008). However even at concentrations below health concerns, chlorine can impact on the taste and smell of water and cause dissatisfaction, even when the dissatisfaction is not health related (World Health Organisation, 2011b). In areas where municipal water taste and smell are compromised, there is a tendency to harvest and use alternative raw water sources for potable use, which while good in appearance, and better in taste, might be less safe for human consumption (World Health Organisation, 2011b). This is likely to be the case with rainwater which is being used as a substitute to municipal water by many Australian households.

While the South Australia Water Corporation (SA Water) supplies high quality municipal water to Adelaide communities, it has been reported that higher rainwater consumption in the community has links with municipal water having poor physical qualities (Dolnicar et al., 2014). This is consistent with the result of a survey that was part of this study carried out between March and May 2016 on Adelaide household drinking water attitude that involved 459 respondents, and which found that 431 out of 459 respondent (93.8%) had municipal water supplied, but 36% of them preferentially drank rainwater. In the survey, it was found that 30% of respondents stated having their preference to rainwater guided by the water natural taste, and 6% indicated having only rainwater a sole alternative. All respondents indicated being aware rainwater may contain unwanted microorganisms.

Similar attitudes were observed in the township of Walhallow in the Hunter region, New England (New South Wales), when residents were asked questions about drinking water availability. The answer was '*we do not have enough drinking water here'*, when municipal water was present, as they had not sufficient rainwater in their tanks (Alan, 2016). In the town, it was reported that residents were aware about safety issues around their tank water. A resident stated that they suffered with urinary tract infections caused by *Escherichia coli* (*E. coli*) associated with rainwater but regardless, the resident refused to drink municipal water (Jaravani et al., 2017). In this town, municipal water is very hard water, with a very high calcium content (Durant, 2005; Jaravani et al., 2017). In the Koonibba Aboriginal community (Eyre Peninsula, South Australia), attitudes towards municipal water and rainwater are like those observed in the township of Walhallow in New South Wales. In Koonibba, when asked a question about drinking water, residents in the community indicated that they have no water, if rainwater is unavailable, irrespective of the fact municipal water is available (Pearce-Churchill et al., 2005). Thus, water quality perception and perception of risk were found to be central to water acceptance, as noted by Mankad and Tapsuwan (2011). The perception of water quality, and the perception of risks, to some extent, are influenced by people's reluctance to accept advice from experts and institutions in their perception of risk, particularly when people have fixed ideas of what they believe is correct and acceptable (Ross, 2005).

Despite SA Water's high quality drinking water, it was found that 10.5% of Adelaide households gave preference to drinking untreated rainwater despite having municipal water supplied (Australian Bureau of Statistics, 2007). In Australia, health authorities advise the public not drink untreated rainwater in areas where municipal water is accessible (enHealth, 2010). The decision to drink rainwater despite widely available information about the safety of municipal drinking water and published data about the potential risks associated with rainwater aligns with the work of Fazio (2018). It is easier for people to ignore trustworthy information and facts on issues of relevance, if the information is unclear to them (Nebel et al, 1997). Cook and Linden van der (2017) emphasise that people reject facts when their feelings or held cultural opinions can be subject to challenge.

5.2.4. Quality of drinking water supplied to communities in Adelaide

In the perception of water utilities, drinking water as any water which is suitable for human consumption, food cooking, dish washing, and oral sanitation (SA Water, 2006). Water quality is based on two parameters; microbial and chemical parameters below levels causing illness, based on available scientific evidence, and secondly, on water physical qualities (NHMRC, 2011). According to Rojas and Megerle (2013), water quality in terms of health driven water values may differ from water quality as determined by members of the public. The difference in the perception of water quality between water experts and the consumer perspectives can prevent water experts from understanding what the public consider good, and therefore, may influence the design and plan of policies for municipal water.

SA Water reports indicate that municipal water supplied to Adelaide communities complies with health-related guidelines for microorganisms, and for chemical parameters as outlined in the Australian drinking water guidelines (ADWG) (SA

Health, 2017d). It was reported that in the metropolitan area, 99.97% of samples tested for *E. coli* complied with the guideline of 0 CFU/100 mL, compared with 99.95% of samples in regional South Australia. Compliance with health guidelines for chemicals was also high. The level of compliance with guideline values was 99.84% in the metropolitan area, and 99.66% for regional areas (SA Water, 2017b). From November 2016 to January 2017, poor quality of water from the River Murray, along with a drop in rainfall combined with warmer weather, were believed to trigger higher incidence of enteric protozoa, cyanobacteria, and incidents of trihalomethanes in treated water, compared with previous years (SA Water, 2017b). An earlier report (financial year 2015-2016) on municipal water quality by SA Health (2016) indicated higher *E. coli* compliance level (99.97% in metropolitan Adelaide and 99.95% in regional areas), and a related-health compliance of 99.96% for chemicals in the metropolitan area, and 99.79% in regional areas. In the Adelaide region, the health requirement of municipal water as outlined in the ADWG was met at 100% in 2014-2015 (SA Water, 2015)

Table 16. SA Water level of compliance with the ADWG over time

(*NDA: Data not available)

Years	Parameters / Level of compliance with guideline (%)								
	E. coli	Chlorine (free)	Fluoride	Total dissolved solids	Water hardness	Water colour	Water pH	Total THMs	Reference
2016-17	99.99	100	100	100	100	100	100	97.8	SA Water, 2017b
2015-16	100	100	100	100	100	100	100	99.5	SA Water, 2016b
2014-15	100	100	100	100	100	100	100	97.4	SA Water, 2015
2013-14	99.9	86.1	100	100	100	100	100	97.0	SA Water, 2014
2012-13	99.9	86.1	100	100	100	100	100	99.8	SA Water, 2013
2011-12	100	100	100	100	100	100	100	95.6	SA Water, 2012
2010-11	100	100	100	100	100	100	100	99.4	SA Water, 2011
2009-10	100	NDA	NDA	NDA	NDA	NDA	NDA	NDA	SA Water, 2014
2008-09	100	NDA	NDA	NDA	NDA	NDA	NDA	NDA	SA Water, 2014
2007-08	100	NDA	NDA	NDA	NDA	NDA	NDA	NDA	SA Water, 2014

5.2.4.1. Municipal water reported incidents of non-compliance

Reported incidents concerning municipal water quality are generally small scale *E. coli* detections, improper chlorination and fluoridation, dissolved solids, water hardness, and water colour (NHMRC, 2016). At the end of the 2017 financial year, incidents of *Cryptosporidium parvum* infections, and inadequate chlorination were reported by SA Water to health authorities (SA Health, 2017a). Nineteen notices of *E. coli* incidents were reported, with 14 incidents being rainwater related, reported to health authorities by water suppliers other than SA Water (SA Health, 2017a).

In the same period, isolated incidents of non-compliance with *E. coli* and free chlorine, and a non-compliance recurring problem for trihalomethanes (THMs) were reported (SA Health, 2017a). All incidents were investigated by SA Water and corrective measures undertaken (SA Water, 2017a). THMs refers to four chemicals that form in chlorinated water when organic matter (algae or rotting leaves) reacts with chlorine; chloroform ($CHCl_3$), bromodichloromethane ($CHCl_2Br$), bromoform ($CHBr_3$) and chlorodibromomethane (NHMRC, 2011). Such water can still appear colourless and tasteless (Madabhushi, 1999). THMs compounds are classified carcinogens, based on animals studies (IARC, 2018). Not enough data and evidence exist on THMs as human carcinogens (NHMRC, 2011, World Health Organisation, 2011b).

5.2.4.2. Debate concerning Adelaide's municipal water quality

Concerns over the presence of THMs in many water treatment plants exist in the community and calls for compliance are made to SA Water to address incidents of THMs detection in municipal water (Littlely, 2011; Schriever, 2012; Parnell, 2016). In 2011, a complaint was made to SA Water by Amis (2012) on behalf the Friends of the Earth about the breach in THMs guideline. A formal request was made that the public in Adelaide be informed on the quality of water as a matter of public safety and that a guideline be enforced for each of the four THMs compounds. Given the link between THMs and chlorine in municipal water, reducing THMs could require that the required dose of chlorine used to achieve optimal water disinfection be lowered, compromising water disinfection. Instead, additional water filtration can help remove THMs from disinfected water (NHMRC, 2011). THMs-related health risks are lower in comparison to those associated with drinking poorly disinfected water (Hrudey, 2008).

The THMs health guideline is set at 0.3 mg/L for chloroform, 0.1 mg/L for bromoform, 0.1 mg/L for dibromochloromethane (DBCM), and at 0.06 mg/L for bromodichloromethane (BDCM) µg/L by the World Health Organisation (2011b), and should not exceed 0.25 mg/L for all chemicals in the group of THMs at the point of water collection by consumers in Australia, based on health aspects (NHMRC, 2011). Complaints made about Adelaide municipal water are mainly taste and smell related, and chlorine is usually blamed for the water taste and smell (SA Water, 2016a). In the community, it is frequent to hear people saying (with respect to Adelaide municipal water):

> *"It's a national joke and gives bottled water suppliers a high rate of profit"*
>
> (Beechey, 1998).

> *" It smells a bit ... musty or like mud", "I would recommend a Puratap"*
>
> Debbie (2013).

In a post made in a discussion platform about the quality of municipal water in supplied to communities in Adelaide, a question was put to the public:

> *"Have just read in a hotel review that 'it's well known that Adelaide tap water is undrinkable". Is this true? Sounds odd to me but would be grateful for locals' comments".*
>
> TripAdvisor Forum (2007)

In response to the question, a participant to the forum has this to say:

> *"What absolute rubbish. Never was true - the water has always been very safe but until a few years ago it was often a bit murky looking and tasted strongly of chlorine. We now have filtration plants which give us lovely clean clear water which most people drink happily, it can have a bit of a chlorine smell - but if you put it in a jug for little while that goes away too. Also, lots of homes apartments etc. have filters for drinking water on the sinks too which does get rid of the chemical smell".*

The comment, less pessimistic than that of the two other commentators, indicates that municipal water physical qualities supplied to communities in the Adelaide region have improved. In addition, the commentator indicated that the water was safe for consumption and gave to water consumers' a direction on ways to get chlorine out of the water before the consumption.

5.2.4.3. Drinking water fluoridation

A passionate debate exists over municipal water fluoridation at a global level, and this is reflected in Australia and in Adelaide. Hostilities over water fluoridation first emerged from the USA in 1975 (Cantor, 1997). While not directly part of the municipal water treatment process, fluoride is introduced in the water prior to disinfection, to prevent dental caries in children and adults (World Health Organisation, 2011b; NHMRC, 2011; Gooch, 2015; Public Health England, 2018). It is agreed that improper fluoridation can result in adverse health effects, when fluoride is ingested beyond permissible levels in drinking water (Fawell et al., 2006). A correlation has been found between improper fluoridation and skeletal fluorosis, bones fracture at all ages, potential cancers, intellectual impairment and thyroid dysfunction. This is supported by studies carried on fluoride toxicity by Plewa et al. (2004), Levy et al. (2006), and by Carton (2006), the World Health Organisation (2010c), and by the Australian and Health and Medical Council (NHMRC, 2017b).

The hard line anti-fluoridation activists link fluoride to nerve and brain damage, to cancer, and even to Nazism (Bryson, 2004). In the anti-fluoridation movement, the addition of fluoride in drinking water has been criticised as dental caries is not a transmissible disease, compared with mandatory immunisation to eradicate infectious diseases (Balog, 1996). Anti-fluoridation groups claim that water fluoridation should be able to be refused (Perlin et al., 2008) and argue that it is a breach of public and individual liberties (Balog, 1996; McLellan, 1999), a violation of ethical and legal code of conduct, and unwanted mass-medication (Barnett-Rose, 2014). Connett (2012) argues that fluoride is not a needed nutrient in humans and argues that there is no disease proved to be found as a result of fluoride deficiency in humans. Thus, he argues, members of the public can harvest and consume untreated rainwater to avoid fluoride. He contends that water fluoridation is a result of forged deductions without factual support (Armfield, 2007) from individuals who are recruited from a scientifically cultured elite. On these grounds, countries like the Czech Republic, Sweden, Netherlands and Switzerland dropped their fluoridation schemes from 1993 onwards (Awofeso, 2012).

In the USA, the Health Department lowered the level of fluoridation from 4.0 mg/L to 0.7 mg/L, to maintain fluoride benefits in dental caries prevention, and to minimise risks of dental fluorosis (Gooch, 2015). The US Environment Protection Agency (EPA) was unable to set fluoride safe thresholds in drinking water and instead, suggested that more studies be conducted at 1.0 ppm/L to update water fluoridation risk assessment (Carton, 2006). Fluoridation proponents consider that studies on fluoride toxicity (fluoridation levels $\geq$ 1.5 mg/L) are goal oriented, carried out on limited subjects, and the conclusions are drawn on individuals that live in areas where fluoride naturally occurs in raw water above permissible levels (Sutton et al., 2015).

In parts of Pakistan, Sri Lanka, India, China, Thailand and Argentina, fluoride can occur in raw waters at concentrations $\geq$ 2.0 mg/L (Ali et al., 2016). In countries in the African Rift Valley that extends from Eritrea, Ethiopia, South Sudan, Kenya, Uganda, Eastern Democratic Republic of Congo, Tanzania, Zambia and Malawi, fluoride can be found in raw water at concentrations that range from 0.7 mg/L to 2,800 mg/L (Ayoob and Gupta, 2006; Malago et al., 2017). In Colorado (USA), fluoride can occur in raw water from 2.0 mg/L to 13.7 mg/L (State of Nevada, 2016). In addition, and while making a correlation between water fluoridation and bones fractures, these studies did not take into account factors such as the use of oestrogen, smoking and low body weight that are contributors to high rates of bones fractures in humans (Gass and Dawson-Hughes, 2006)

Table 17. Studies of fluorinated drinking water (note: WHO Guidelines for fluoride in drinking water is 1.5 mg/L)

Country	Potential health risks	Level of evidence	Reference
United States	Lower IQ, bone fractures, fertility and thyroid impairment	Bones fractures in children at 3 mg/L, hip fractures in elderly at 1.5 mg/L to 4.3 mg/L, lowering of IQ at 1.8 mg/L, lowering fertility at 3 mg/L and lowering of thyroid function at 2.3 mg/L	Levy et al., 2006
United States	Bone fracture, IQ and thyroid dysfunction	Bones fracture at 1 mg/L with long term exposure, hip fracture at 1.5 mg/L and IQ deficiency in children at 2.5 mg/L to 4.0 mg/L and thyroid dysfunction at 4:0 mg/L or less	Carton, 2006
China and India	Skeletal fluorosis	Increased prevalence in skeletal fluorosis form 1.4 mg/L	Ayoob and Gupta, 2006
China	Decrease in children IQ and behavioural disorders	222 children drinking water at 2.47 mg/L - 4.5 mg/L had lower IQ and 290 children drinking water at 0.15 mg/L - 0.76 mg/L had higher IQ	Xiang et al., 2003
India	Skeletal fluorosis	In the range of 3.5 mg/L - 4.9 mg/L, patients with skeletal fluorosis symptoms have 4.6 times chance to develop kidney stones	Annadurai et al., 2014
United States	Risk of bone fracture	Risk of bone fracture at 1.5 mg/L in drinking water	Carton, 2006
United States	Lowering fertility	3 mg/L exposure can trigger young female infertility	Levy et al., 2006

United States	Skeletal fluorosis	The level of fluoride concentration is not specified however, the author consider that fluoridated water increases risks of cancer in young males, bones fractures in adults, and infertility in young females	Balog, 1996
Canada	Effects on bones mineral density and potential to axial skeleton	Likely in young females (aged 18-25 years) from areas of fluoridation at 1.0 mg/L, compared to those from areas of concentration less than 0.5 mg/L	Arnold et al., 1997
Italy	Skeletal fluorosis	Higher occurrence in females, at ≥4 mg/L fluoride concentration	Petrone et al., 2011
China	Decrease in children IQ	Lower mean IQ in the children living in the area with a high-fluoride level in drinking water (2.57 mg/L and greater)	Zhao et al., 1996
India	Decrease in children IQ	Lower IQ in subjects that live in high fluoride areas (3.54 mg/L)	Trivedi et al., 2007
China	Dental fluorosis and decrease in children IQ	Dental fluorosis at a fluoridation of 0.24 mg/L to 2.84 mg/L, and decrease in children IQ from a fluoridation of 3.0 mg/L	Ding et al., 2011
India	Decrease in children IQ	Lower IQ at fluoridation of < 1.5 mg/L, high decrease from a fluoridation of 4 mg/L and greater	Saxena et al., 2012
East Africa	Endemic fluorosis	From a concentration of 1.5 mg/L and greater	Malago et al., 2017
China	Endemic fluorosis	Potential to fluorosis at 1.0 mg/L and greater in endemic fluorosis areas	Huang et al., 2017
China	Decrease in children IQ	Lowering IQ from aa a fluoridation of 1.0–8.6 mg/L, and greater	Choi et al., 2012

5.2.5. Debate over municipal water fluoridation in Australia

The debate exists in Australia over municipal water fluoridation. For example, concerns over the danger to drink fluoridated water was publicly raised by an independent member of South Australia's State Parliament who expressed concerns over the intentional addition of fluoride in Mount Gambier's Blue Lake water (Channel Seven Adelaide, 2010). This Member of Parliament stated that sodium fluoride (NaF) added to municipal water was a toxic chemical which differs from the naturally occurring calcium fluoride (CaF_2) (Channel Seven Adelaide, 2010).

Presently, more than 17 towns and communities in Queensland have terminated adding fluoride in their water, and 72 towns in Victoria have never adopted the schemes (Hansen, 2015). In Queensland, the move to abandon water fluoridation schemes was subsequent to a Queensland Health Minister's decision to rule out mandatory municipal water fluoridation (Wordsworth, 2015). Some medium sized cities in Queensland, such as Cairns, Rockhampton, Bundaberg, Hervey Bay, Maryborough, Mackay, Warwick and Stanthorpe dropped their fluoridation schemes between 2013 and 2015 (Wordsworth, 2015).

SA Water fluoridation levels range from <0.1 gm/L to 1.0 mg/L for Adelaide (SA Water, 2017c), well below the NHMRC guideline of ≤ 1.5.mg/L (NHMRC, 2011). In an open letter to the Australian community about water fluoridation, the NHMRC indicated that no consistent evidence has been found that links drinking fluoridated water at a fluoridation level ≤ 0.7 mg/L, and potential health problems (NHMRC, 2018). The letter outlined that in contrast with lead, which accumulates in human tissues, fluoride is steadily removed by the kidneys at a safe rate

(NHMRC, 2017a). This is consistent with an earlier NHMRC public statement in which Australian states and territories were advised to fluoridate municipal water at a fluoridation level of 0.6 mg/L to 1.1 mg/L, to help reduce dental caries (NHMRC, 2017b).

An assessment on prevalence of dental caries in children in the town of Bathurst (fluoridated) and Oberon (non-fluoridated), two towns 48 km apart in New South Wales, found that Oberon had twice the number of incidents of tooth decay in children than Bathurst (Power, 2018). In the town of Oberon, fluoride has been depicted as a poison that when added, increases metal concentrations such as arsenic, lead, and mercury (Power, 2018). The claims may have genesis in a publication stating that fluoride additives are extracted from phosphate rocks that contain arsenic, cadmium, chromium, lead and mercury that must be removed before fluoridation, for the water to meet drinking water standards (Mullenix, 2014). There are no reports of the presence of these metals in municipal water across Australia as a result of water fluoridation.

5.2.6. Municipal water community satisfaction in Adelaide

Community satisfaction with municipal water is lower in South Australia (57% of households) than anywhere else in Australia (Australian Bureau of Statistics, 2013). In mid-2018, based on health and research perception, SA Water reported an overall 60% community satisfaction in supplied municipal water (SA Water, 2018c). In the Adelaide region, complaints over municipal water were related to the water taste, the smell, and milky appearance (SA Water, 2018b). In the survey undertaken for the current research, the quality of municipal water was a common reason given by participants in their decision to drink rainwater (Chubaka et al., 2017). An Adelaide resident who was approached during the survey on 13 April 2016 in West Lakes (Adelaide plains), while talking about the quality of municipal water supplied by SA water to communities stated:

> *"Mains water (municipal water) contains quantities of chemicals that many people from overseas dislike, mentioning chlorine and fluoride. Even international crew ship members who come here do not drink Adelaide water, as it is for those who dock in Suez (Egypt). The water is pumped in the River Murray. We are at the bottom end of the River Murray which sees its water extensively used for irrigation in upper lying States of Queensland, New South Wales and Victoria. All pesticides and wide range of chemicals used in agriculture are collected by drains and tributaries streams and discharged in the Murray. This is an additional reason why international ship crew members and many people in the community dislike water pumped from the Murray".*

This statement reflects similar comments given by other survey participants. Many dislikes municipal water either because they think rainwater tastes better, or because they do not like the chlorine and fluoride that is added to municipal water. Notably, the quote above does not refer to any notice of non-compliance submitted to health authorities or reports of incidents of municipal water contamination by pesticides or related chemicals. All studies carried out on rainwater suitability for use in households have suggested non-potable use, if water is not subjected to treatment to remove potential contaminants (enHealth, 2010; Ahmed et al., 2010b; Ahmed et al., 2011; World Health Organisation, 2011b). Despite this, households in urban and rural Australia are using untreated rainwater for potable purposes. In a society, problems that have links to the past can determine people's behaviour and have an enduring influence (Doria, 2006). This was observed in Adelaide where a propensity to favour rainwater exists. Municipal water in these areas was of poor physical quality before the installation of filters in 1977, which meant that many Adelaide households only drank rainwater (Heyworth et al., 1998). There is anecdotal evidence that suggests that the trust in municipal water has still not recovered (Heyworth et al., 1998).

5.2.7. Public discussions on drinking water quality

Internet discussion fora platform provide insight into people's perceptions of drinking water. It is acknowledged that posts are put up by a self-selecting group of people and may not be representative of the population as a whole, and that the posts can suffer from bias, correctness, and credibility (Savolainen, 2011). The analysis of these posts is an interesting insight about people beliefs, and how biased opinions can undermine facts and evidence-based standards. As is found in the literature, perceptions of drinking water quality are based primarily on its physical quality, and the taste of water is the primary determinate of quality (de França Doria, 2010; Rahmanian et al., 2015). A discussion forum was launched in Australia in October 2013 (Whirlpool Forums) asking people in the community to express their views on the quality of their drinking water. The forum received posts from all over Australia. A starting statement – the initial post starting the thread – was:

> *"Just little worried about tap water, I never boil it and hardly buy battled water, how many of you use tap water to drink? Do you always boil it first?"*
>
> Whirlpool (2018).

A summary of responses illustrating people's opinions, and reason to drink or not drink rainwater is presented in Table 2. For anonymity, names in the forum are nicknames, and numbered in the table as WD (water drinker). Individuals that live Melbourne and Sydney described their water as fantastic in taste. Of a total of 439 posts made, 88 posts (20%) discussed reasons for their satisfaction/dissatisfaction in supplied municipal water. Out of these 88 posts, a total of 62 (15% of all posts) indicated that the respondents dislike chemicals present in drinking water. This compares with 26% of respondents from Adelaide who expressed dissatisfaction with municipal water based on taste.

The 'funny', 'yucky' and bad taste posts come from Adelaide, Brisbane and Perth. Respondents' opinions greatly varied between individuals, and reasons for dissatisfaction were driven by subjective assessment of quality. In the forum, 14 postings (3% of postings) were made by anti-fluoridation advocates. A number referred to the fluoride deception theory of Bryson (2004), to support their dissatisfaction in municipal water. One of the anti-fluoridation advocates said:

> *" Sorry I believe a scientific study conducted by Harvard University over your comments".*

The study being referred to noted: "*extremely high levels of fluoride are known to cause neurotoxicity in adults*" (Marge, 2012). The conclusion of that study was based on animal studies, and carried out in China in areas where fluoride naturally occurs in raw waters above fluoridation permissible levels in drinking water (Choi et al., 2012). A counter remark came from fluoridation proponents:

> *" That's the best thing about scientific studies, you can always find one that will back up your point of view", and "In some places where they have removed fluoride from tap water (municipal water), the incidence of tooth decay has risen, IQ levels not changed neither has the number of cancer patients".*

The forum reflects the debate in the community over adding fluoride to drinking water. An anti-fluoridation advocate stated they had difficulties in taking scientific advice. It has been shown by in the social science literature that when faced with facts that counter held beliefs, people are inclined to hear what they want, and exclude those facts that do not support their existing beliefs (Griffin, 2017). One of the more difficult tasks scientists face is to communicate evidence-based science. This involves giving people that capacity to understand what risk is, and the associated level of severity (Lamberts, 2017).

Table 18. Public forum over municipal water quality in Australia (Whirlpool, 2018). (X) - Chemical of discomfort and/or action taken not stated

		Municipal water		Action taken	
Name	Drink	Chemical	Reason for discomfort	Boils	Reason for discomfort (if any)
WD1	Yes	Chlorine	It’s safe	No	Taste bad
WD2	Yes	X	Straight from tap because it’s safe	No	X
WD3	Yes	X	Good or better than bottle water	No	X
WD4	Yes	Chlorine	It’s safe	No	Dislike chlorine
WD5	Yes	Chlorine	It’s safe after chlorine removal	No	Dislike chlorine
WD6	Yes	X	It contains fluoride	No	X
WD7	No	Chlorine	I would prefer not to drink	Yes	My mum at her place boils it
WD8	Yes	Chlorine	Its fine	No	I only filter it to remove chlorine
WD9	Yes	X	Taste fine to me	No	X
WD10	Yes	Chlorine	Its fine	No	Taste ruined by chlorine
WD11	Yes	Chlorine	Its fine	No	Boiled water tastes flat

WD12	No	Chlorine	Taste horrible	No	Drink rainwater
WD13	No	Chlorine	Tastes foul	No	Drink rainwater
WD14	Yes	Chlorine	Have no concern	No	Undrinkable at my friend’s place
WD15	Yes	X	Have no concern	No	Water is water
WD16	Yes	Chlorine	But does not taste nice as rainwater	No	Instead, use filter
WD17	Yes	Chlorine	…bit heavy and taste funny	No	Feel like to drink something else
WD18	No	Chlorine	It tastes super bad like main land China	No	X
WD19	Yes	X	Mouth to tap, no glass required	No	X
WD20	Yes	Chlorine	Matter of taste	No	X
WD21	Yes	Chlorine	Chlorine smell/taste	No	Instead, use filter to cut down chlorine
WD22	No	Chlorine	Taste metallic	No	Buy bottle water from supermarkets
WD23	No	Chlorine	It has heavy metallic taste	No	Buy bottle water
WD24	No	Fluoride	Fluoride in water kills you	No	X
WD25	No	Fluoride	Worried about the fluoride	No	I’ve started drinking bottle water
WD26	No	Chlorine	My kids refuse to drink it	Yes	I use a solar distiller and we are happy
WD27	Yes	Chlorine	Taste	Yes	Boiled and filtered

WD28	Yes	Chlorine	Worried by chlorine taste	No	My charcoal cartridge still works
WD29	Yes	Chlorine	Dislike taste	No	I use filter instead
WD30	Yes	Chlorine	I have anywhere to save for good rainwater	No	X
WD31	Yes	Chlorine	The problem is the nasty taste	No	Carbon filter here
WD32	Yes	Chlorine	Not for any health or scientific reason	No	X
WD33	No	Chlorine	Taste cloudiness*	No	X
WD34	No	Fluoride	Worried about fluoride	X	X
WD35	Yes	Chlorine	Taste	Yes	Water need to be boiled and filtered
WD36	No	Chlorine	Don’t like the taste	No	I filter/but prefer bottle water
WD37	Yes	Chlorine	Used to taste bad	No	Do not trust filters efficacy in water
WD38	Yes	Chlorine	It tastes different	No	Use filters
WD39	No	Chlorine	Got sick 10 years back from drinking tap water	No	X
WD40	No	Chlorine	Dislike chlorine and don’t like the taste	No	I drink raw water (rainwater)
WD41	Yes	Chlorine	X	No	Use filter or drink coke

WD42	Yes	X	Well fluoridated and meets drinking water standards	Yes	Just old habit
WD39	Yes	X	Chlorinated and free of germs and microorganisms	No	Chlorinated and fluoridated
WD40	No	Chlorine	Taste concern	No	Drink bottle water
WD41	Yes	X	It’s safe for consumption	No	X
WD42	Yes	X	It’s safe for direct consumption	No	Fluoridated and chlorinated
WD43	Yes	Chlorine	Contains chemicals but let is settle for 4 days	No	Have no problem with our water
WD44	Yes	X	Fluoridated and good for your teeth	No	Its unnecessary waste of energy
WD45	No	Fluoride	Don’t want to poison myself with fluoride	No	Boiling does not remove fluoride
WD46	No	Fluoride	Have concerns with fluoride	X	X
WD47	No	Fluoride	I dislike associated chemicals (fluoride)	No	I only drink bottle water
WD48	Yes	Chlorine	It’s clean water	No	I use filters to improve the taste
WD49	Yes	X	Risk of older pipes leaking poisoning chemicals	Yes	X
WD50	Yes	Chlorine	Hate the taste	No	Use jug filter to change the flavour

WD51	Yes	X	Fine to me	No	X
WD52	Yes	Salt	Bad taste	Yes	X
WD53	Yes	Microbes	Fine after water was retreated	Yes	X
WD54	No	Fluoride	The chemical is a poison	No	Drink alternative water
WD55	No	Fluoride	Fluoride is poisonous	No	Drink rainwater
WD56	Yes	X	Fine to me (if you don't drink, you are worse than Hitler	X	X
WD57	Yes	Chlorine	It has no good taste	X	I drink bottle water at 75%
WD58	Yes	X	X	Yes	
WD59	Yes	X	Its fine and I fill no difference with filtered water	No	My wife insisted we get a Puratap
WD60	Yes	Chlorine	Smell in the water	Yes	I have bought a water distiller
WD61	Yes	Fluoride	I am not worried	No	Looking into buying a distiller
WD62	No	X	X	No	I only drink rainwater
WD63	No	X	X	X	I drink bottle water when thirsty
WD64	No	Chlorine	It makes tea taste like garbage	No	I will go with a filter

WD65	Yes	X	No real reason 9my grandmother was boiling her water	Yes	X
WD66	No	Chlorine	Taste better (take my water straight from the tank)	No	X
WD67	Yes	X	It’s safe for us	No	X
WD68	Yes	Chlorine	…don’t like the taste	Yes	X
WD69	No	Chlorine	Chlorinated water is taste rubbish	Yes	I also filter my water
WD70	No	Fluoride	Studies have shown its potential in IQ lowering	No	X
WD71	No	X	Water in our town is horrible	No	We filtered drink tank water
WD72	Yes	X	Fluoridation hasn’t decreased my life expectancy	No	X
WD73	Yes	X	Its tastes better when boiled	Yes	I also use a Brita filter
WD74	No	Chlorine	It’s safe but taste flat	X	X
WD75	No	X	X	X	Drink filtered rainwater
WD76	Yes	Chemicals	It’s safe after boiling	Yes	To kill microbes and improve taste
WD77	Yes	Chlorine	I can’t stand chlorinated water taste	No	I use reverse osmosis filter

WD78	Yes	Chlorine	I hate chlorine taste in tap water	No	I use filter
WD79	No	Chlorine	Fade the water taste	No	I drink bottle water
WD80	No	X	X	No	I drink filtered water since childhood
WD81	Yes	X	Taste fine	No	X
WD82	Yes	Chlorine	My water tastes weird	No	Look getting into a filter
WD83	No	Chlorine	Don’t like the taste	No	I filter my water and it tastes better
WD84	No	X	Tastes flat	No	I grow up in farm, drinking rainwater
WD85	No	Chlorine	Any city filtered water-based muck tastes horrible	No	I filter the water
WD86	Yes	X	Funny taste	No	I am saving to for good rainwater
WD87	Yes	X	Tastes flat	No	Tap water is fine, but like rainwater
WD88	No	X	Bad taste	No	Only tank water

In the United States, a discussion platform (Quora Inc. Forum) about rainwater fitness for drinking received 35 respondents. In the forum, people can use nicknames: what is essential is their opinions. In the initial post, an open question was brought to the public in these words:

> *"Is rainwater safe to drink?"*
>
> Quora Inc (2018)

Out of the 35 answers received, 23 respondents (66%) endorsed rainwater as a safe drinking water source. The problem of rainwater readiness all year round was raised, and many respondents suggested that rainwater should be filtered or boiled to inactivate the microbial component. Other respondents advised not drinking rainwater if it was harvested in highly polluted cities or near a chemical plant. The study undertaken for this thesis found no similar forum in Australia, but it seems likely that the US responses would be comparable to that which would be found in Australia, based on the survey responses collected during this research (Chubaka et al., 2017).

Consistently, studies on untreated rainwater in Australia and worldwide, indicate it may contain pathogenic organisms, and inorganic dissolved substances that can be hazardous in humans (World Health Organisation, 2008; enHealth, 2010; Stewart et al., 2016). Notwithstanding this, an epidemiological study found no difference in gastroenteritis incidence in children who drank municipal water compared with those who drank rainwater (Heyworth et al., 2006). As a result, the national broadcaster noted:

> *"In one of the first studies of its kind, researchers have found that rainwater from tanks is safe to drink"* (ABC News, 2009).

Rainwater is believed to be safe for consumption with low risk of causing an incident of illness if harvested from a well maintained catchment system, and collected from clean storage facilities (enHealth, 2010; NHMRC, 2011). This is accepted by the New South Wales Government (2015) and the State of Victoria (2013). The regulatory framework, more flexible in approach, seems to consider the social context under which rainwater is being harvested and consumed in regional areas. In regional South Australia, municipal water is not made readily to communities in many small towns and in remote communities (Heyworth et al., 2006; Gardiner, 2010; Laverty and Bishop, 2016). There are indications that in areas where treated municipal water is accessible, rainwater use should be limited to non-potable purpose (enHealth, 2010). In this context, the Australian Building Codes Board (2016) interprets the drinking rainwater regulatory framework as follows:

> *"It is implied that rainwater is unsafe when a water supply from a water monopoly or water utility is available but safe if [it is not].*

Further to this comment, suggestion was made by the Australian Building Codes Board to formally have in place two clear guides and two directions, one for rainwater harvested for non-potable use, and another for drinking water supply (Australian Building Codes Board, 2016). It should be noted that the concept of a well-maintained catchment areas does not refer to the tank location. It was found that pollution in urban areas and in industrialised precincts can significantly deteriorate rainwater quality (Huston, 2010).

Other advice, with a softer approach, indicates that the decision to drink rainwater is every tank owner's responsibility (Government of South Australia, 2006). This implies that in rural areas and in isolated communities, the consumption of rainwater does not pose any problem, unless the water is stored in unclean containers (Government of Western Australia, 2018). This advice is likely to result in people overlooking the 'do not drink' advice from health authorities.

5.2.8. Historical influences

In the Adelaide Hills, it was frequent to come across people stating that they have never drank municipal water, and that their parents and grandparents only drank rainwater, not only because municipal water was unavailable. Such statements were heard during interviews on households drinking water attitude conducted from March to May 2016 in the town of Mount Barker and Lobethal (Chubaka et al., 2017). Similar attitudes were observed in the communities in the Hunter New England region (New South Wales) where residents stated only drink rainwater for generations because they were told not drink municipal water by their parents and grandparents (Jaravani et al., 2017).

5.2.9. Water purifier suppliers' marketing

Another aspect that may be having an influence on water consumers' preferences is related to aggressive campaigns led by small-scale domestic water filter suppliers (Chubaka et al., 2017). Exposed to these advertising materials, and to claimed performance of products, the public could be led to think that water supplied by municipal water supply companies is not safe. The aim of the suppliers is to sell the filters and the advertising suggests that they are effective in removing all substances from drinking water, whether these substances are likely to be found in drinking water or not. For instance, the title of a leaflet handed to the public at a local supermarket in Adelaide (West Lakes Shopping Centre, January 2017) was:

> *"What can be found in tap water?"*
> Puratap Pty Ltd (2017)

At the bottom of the page, the list of substances included: rust, dirt, sludge, smelly organic matter, chloramine and trihalomethanes, chlorine, living organisms such as bacteria, viruses, parasites, *Giardia lambilia*, and inorganic invisible products like lead, nickel, cadmium mercury arsenic and barium (Puratap Pty Ltd, 2017). The advertising material was displayed near a newspaper article telling the public how to cut the risk of cancer by half, with an image of a happy person drinking bottle water. Filters being advertised were displayed on a table, with a notice on the performance of cartridges stating "we remove herbicides, pesticides, asbestos, lead, ash, faecal coliforms, bacteria and viruses from your water" (Puratap, 2010).

In that context, reference was directly made to municipal water and not to rainwater. Another company, in a different shopping centre (Marion Shopping Centre, May 2018), was displaying a leaflet that was advertising an under-sink water filter that claimed "100% performance in bacteria, chlorine, arsenic, copper particulate, nickel, yttrium, cadmium, and cobalt removal from both municipal water and rainwater". The pamphlet also claimed a performance of 96% removal of lead, and 98% of zinc and iron, and the capacity to reduce fluoride up to 85% from municipal water (Aquadome Water Purifiers, 2017).

While at times the target for trihalomethanes was not met, all SA Water reports to SA Health indicate compliance with guidelines for metals (SA Water, 2017b). In the financial year ending June 2017 and during previous years, reports (SA Water, 2011; SA Water, 2012; SA Water, 2013; SA Water, 2014; SA Water, 2015; SA Water, 2016b; SA Water, 2017b) indicated a compliance level of 99.96% for chemicals of health concern in reticulated water in the Adelaide metropolitan area and 99.79% in regional areas, and no notice of non-compliance indicating the presence of the listed metals in municipal water was submitted to health authorities. Fears of health risks associated with substances that could be found in municipal water indicated by domestic filtration companies, in addition to people's unwillingness to drink fluoridated water, and the aversion to chlorine in municipal water, combine to contribute to a suspicion about municipal water, which in turns contributes to the decision by householders to drink rainwater.

It has been suggested to not collect rainwater near busy roads, heavy industrial areas, metal processing factories and rubbish incinerators sites where contaminants can escape and spread in the environment, if rainwater harvesting is intended for drinking and food preparation (SA Health, 2017c). Irrespective of the areas where rainwater is being harvested (private properties or commercial premises), regulators in Australia recommend that rainwater, when used for food preparation and for drinking, should comply with drinking water standards as specified in the Australian Drinking Water Guidelines (NHMRC, 2011). In community-based community (schools, nursing homes and hospitals), it has been suggested that rainwater be disinfected for bacteria control before use for potable purposes (enHealth, 2004)

5.2.10. Direction to rainwater harvesting schemes

The data from all components of this study (microbial and metal content of rainwater together with the surveys of drinking water preference and information collected about rainwater tank maintenance) sheds light on rainwater quality and use. While a fraction of the public may be unaware that metals of health concern can be found in rainwater, most people in the community were aware that it may contain pathogenic microorganisms. It was found that for many rainwater consumers, the presence of microorganisms in rainwater does not deter them preferentially drinking rainwater, even when they have potable water supplied. The fact that a significant proportion of the public accepts these risks (10.6% of Adelaide households) and ignores the ‘not drink advice’ from health authorities is an interesting outcome. It was found that in Adelaide rainwater is being consumed untreated more in wealthier suburbs where people may better understand the health risks associated with drinking untreated raw water (Chubaka et al., 2017).

CHAPTER 6. GENERAL CONCLUSION

This study aimed to identify the attitudes of households in the Adelaide region towards rainwater and the drivers that influence these attitudes, particularly in areas where clean municipal water is made available to the public and investigated the level of microbiological and metal contamination of roof harvested rainwater in the Adelaide region, and risk factors influencing their presence. The study has found that both *E. coli* and lead levels were often above Australian Drinking Water Quality Guidelines (ADWG) (NHMRC, 2011), which suggests potential health risks associated with drinking rainwater. It also identified that a significant fraction of Adelaide households preferentially drinks potentially contaminated rainwater, when they have access to clean municipal water supplied by water utilities.

Of the 53 tanks that were investigated, 28 contained *E. coli* in at least one of the sampling events (ADWG = 0 MPN/100 mL). These results are comparable to other studies across Australia (Chapman et al., 2008, Rodrigo et al., 2009a). *E. coli* in tanks ranged from 1 MPN/100 mL to ≥ 2419.6 MPN/100 mL. The water from nine of these 28 tanks (20.7% of tanks) was collected from tanks that had filters installed, and the water was used by households as their primary source of drinking water.

Water filtration units installed in homes to remove contaminants were not successful in removing *E. coli*. Samples that were collected from tanks with filters installed were all found to contain *E. coli* in at least one sampling event. Three of the nine tanks that had filters installed exceeded the upper limit of 2419.6

MPN/100 mL in the MPN table. This contrasts with the test in the laboratory of a Puratap® filter unit, which removed *E. coli* completely until it became clogged after 265 L had been passed though it (contrary to a 2,330 L- 3,785 L filtration capacity claimed by the manufacturer). While few conclusions can be drawn based on one laboratory test, this suggests that the maintenance of filtration units and regular replacement of cartridges probably play an important role in their capacity to remove bacteria.

Lead was the primary metal of health concern detected in rainwater samples. It was found that 47 out of 53 tanks (86.6%) that were assessed, contained lead above the ADWG in at least one sampling event. It was found that 180 of the 365 samples (49%) that were tested for lead exceeded the ADWG threshold of 0.01 ppm. In total, 29 of 465 samples (7.9% of samples) that exceeded the guideline were collected from tanks that were plumbed into houses where the water was used as a source of drinking water. Zinc was also detected above ADWG, although the health considerations from zinc contamination are not as concerning as those from elevated lead levels, as the ADWG is for aesthetic consideration only. Rainwater contamination levels with lead found in this study were consistent or slightly higher compared with the results of previous studies undertaken in other locations across Australia (Sinclair et al., 2005, Magyar et al., 2008, Martin et al., 2010, Huston et al., 2012, Gulson et al., 2016). The investigation also detected copper in 8/365 samples above the ADWG, and cadmium in 19/365 samples above the ADWG.

Tank and roof materials, water pH and the presence of first flush devices installed on tanks, were not found to have significant relationships with rainwater microbiological values (P-value >0.05). In contrast, relationships were found between *E. coli* and the catchment area having overhanging trees canopies, and *E. coli* and roof mounted TV antennas. This suggests that removing structures or trees overhanging the roof might improve rainwater quality. No seasonality trends in rainwater contamination by microorganisms was detected, although samples that were collected during or immediately after rainfall events had higher *E. coli* levels. It is therefore surprising that first flush devices installed on tanks did not have a significant effect on *E. coli*, although this might be due to too few tanks having them installed to detect a statistically significant result. In addition, there was no difference between *E. coli* detection in rainwater samples in different sampling corridors.

With metals, a relationship was found to exist between the detection of lead in rainwater and the roof material factor (P-value <0.05). As with *E. coli*, the tank material, the presence or absence of first flush diverters, and the water pH were not found to have a significant relationship with any of the metals (P-value >0.05). In addition, there were no seasonality trends observed in metals abundance in stored rainwater. On a few occasions, increased detection of lead and zinc occurred in samples that were collected after a prolonged dry period, following a rainfall event. In contrast with the testing for *E. coli*, sampling corridors were significantly different, with lead being predominantly detected above the ADWG in samples from particular geographic areas, notably areas that have higher rainwater consumption, the Adelaide Hills and foothills.

As with microbial removal, success of the in-home filter performance in removing metals was limited. In samples that were taken from tanks that had filters installed, lead, zinc, and cadmium were detected in both unfiltered and filtered rainwater samples. Metal concentrations in the filtered samples were slightly lower in all samples, although the filters did not remove the metals to below the ADWG in instances when this was exceeded. In a laboratory experiment (Appendix 9) a filtration unit with a new cartridge installed was not successful in removing chromium and arsenic from a spiked solution, but initially removed copper and zinc. Combined, these results suggest that the manufacturers' claims of removal of metals from water are overstated, although the field results might also be the result of limited or no maintenance being carried out on filters and cartridges, as indicated by the householders.

Data from this study, which is supported by data from previous studies, suggests that rainwater collected in the Adelaide region is often of poor quality and potentially a risk to human health. It should be concluded that the *E. coli* and lead levels found in rainwater mean that rainwater should not be consumed untreated and that if municipal mains water is available this should be used preferentially over rainwater for drinking.

However, a conflicting definition of water quality, and the perception of drinking water quality was found to exist between experts in drinking water treatment, and the public. While the official definition of water quality is health related and based on measurable and quantifiable standards by experts in the water treatment industry, a subjective and non-standardised assessment of water quality was found to exist in the community. In the community, it was found that members of the public's assessment of drinking water quality was based on water taste rather than water related health values. Based on people's views on municipal and rainwater found in the survey, and the opinions expressed on drinking water quality in internet discussion forums, it was found that many Adelaide households have their minds deeply fixed on the alleged better taste of rainwater, and the undesirable or ‘yucky’ taste of municipal water. Given the observed dichotomy in the definition of the quality of drinking water quality by up-stream experts in water treatment, and by downstream water consumers, water utilities should undertake steps to reverse the public perception of municipal water that is being supplied to communities in the Adelaide region. This could be achieved through an awareness campaign that aims to achieve greater acceptability of municipal water by members of the public.

However, for areas that rely on rainwater for drinking water, further research needs to be undertaken to provide evidence-based advice to consumers about approaches to ensuring their rainwater is safe to drink. This includes research into first flush diverter devices. First flush devices have been shown to be of limited value, particularly in removing lead (Martinson and Thomas, 2009, Kus et al., 2010, Gikas and Tsihrintzis, 2012). First flush devices were not found to impact on the level of contamination in this study, although as noted above, that might have been the result of a small sample size, as few tank owners had first flush devices installed. Additionally, there is little evidence about the value of maintenance through tank desludging, although this is recommended by health authorities. Preliminary evidence from this study suggests that roof material plays a significant role in lead contamination, although this could not be clearly separated from geographical area, as the roof material in the hills was all of one type, while roof material from the plains another type. The contribution to lead contamination from roofing structure material requires further investigation.

In contrast with microbial contamination, for which there is evidence that drinking rainwater above the ADWG is not likely to cause health effects (Heyworth et al., 2006), there have been no epidemiological studies assessing the effect of drinking rainwater that contains elevated levels of lead. This is important, especially as it is now agreed there is no known safe threshold below which lead does not cause a health problem in humans (Spivey, 2007). The safe provisional guideline of 25µg/kg/body-weight/week has been withdrawn by the World Health Organisation (World Health Organisation, 2011c), and by health authorities in Australia (FSANZ, 2011). It is suggested that blood lead levels of rainwater consumers that have been identified as having high levels of lead in their rainwater tanks be measured, although it is noted that there are ethical issues associated with using the existing householders for further study.

Furthermore, studies should further assess commercially available filters' capacity to remove microorganisms and metals from rainwater. The claims made by the water filter companies seem exaggerated considering the outcomes of this study. Filters that maintain rainwater taste but remove metals, particularly lead, should be identified. If they do not exist, this is an avenue of research that requires further investigation. In conclusion, this study sought to investigate potential microbiological and metal contaminants present in rainwater collected from South Australian rainwater tanks and found levels of *E. coli* and lead in concentrations that might be harmful to human health. The primary risk factors associated with elevated concentrations were overhanging structures for *E. coli* and geographical area and/or roof type for lead.

The study also sought to identify households' attitudes towards rainwater and the drivers that influence these attitudes. It was found that many people drink rainwater in preference to municipal water, and that taste was a primary determinant, although a number of factors including fluoride addition played a role in their decision. Even when people were aware that rainwater might contain contaminants, they still drank rainwater in preference to municipal water. There is a need for better understanding of the things that might mitigate risk associated with drinking rainwater so that consumers can be provided with evidence-based advice.

CHAPTER 7: REFERENCES

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CHAPTER 8. APPENDIX

Appendix 1: Research Ethic Approval Statement

6782 Final ethics approval notice (21 April 2015)

Human Research Ethics

To:

Chirhakarhula Chubaka;

Kirstin Ross;

John Edwards;

Dear Emmanuel Chirhakarhula,

The Chair of the Social and Behavioural Research Ethics Committee (SBREC) at Flinders University considered your response to conditional approval out of session and your project has now been granted final ethics approval. This means that you now have approval to commence your research. Your ethics final approval notice can be found below.

FINAL APPROVAL NOTICE

Project No.: **6782**

Project Title: Toxicological and Microbiological Study of Rainwater used for Drinking Water

Principal Researcher: Mr Emmanuel Chirhakarhula Chubaka

Email: chub0008@flinders.edu.au

Approval Date: 21 April 2015 Ethics Approval Expiry Date: 21 September 2019

The above proposed project has been **approved** on the basis of the information contained in the application, its attachments and the information subsequently provided.

RESPONSIBILITIES OF RESEARCHERS AND SUPERVISORS

1. **Participant Documentation**

   Please note that it is the responsibility of researchers and supervisors, in the case of student projects, to ensure that:

   - all participant documents are checked for spelling, grammatical, numbering and formatting errors. The Committee does not accept any responsibility for the above-mentioned errors.
   - the Flinders University logo is included on all participant documentation (e.g., letters of Introduction, information Sheets, consent forms, debriefing information and questionnaires – with the exception of purchased research tools) and the current Flinders University letterhead is included in the header of all letters of introduction. The Flinders University international logo/letterhead should be used, and documentation should contain international dialling codes for all telephone and fax numbers listed for all research to be conducted overseas.

- the SBREC contact details, listed below, are included in the footer of all letters of introduction and information sheets.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project Number 'INSERT PROJECT No. here following approval'). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au.

2. Annual Progress / Final Reports

In order to comply with the monitoring requirements of the *National Statement on Ethical Conduct in Human Research (March 2007)* an annual progress report must be submitted each year on the **21 April** (approval anniversary date) for the duration of the ethics approval using the report template available from the Managing Your Ethics Approval SBREC web page. *Please retain this notice for reference when completing annual progress or final reports.*

If the project is completed *before* ethics approval has expired, please ensure a final report is submitted immediately. If ethics approval for your project expires please submit either (1) a final report; or (2) an extension of time request and an annual report.

Student Projects

The SBREC recommends that current ethics approval is maintained until a student's thesis has been submitted, reviewed and approved. This is to protect the student in the event that reviewers recommend some changes that may include the collection of additional participant data.

Your first report is due on **21 April 2016** or on completion of the project, whichever is the earliest.

3. Modifications to Project

Modifications to the project must not proceed until approval has been obtained from the Ethics Committee. Such matters include:

- proposed changes to the research protocol;
- proposed changes to participant recruitment methods;
- amendments to participant documentation and/or research tools;
- change of project title;
- extension of ethics approval expiry date; and
- changes to the research team (addition, removals, supervisor changes).

To notify the Committee of any proposed modifications to the project please complete and submit the *Modification Request Form* which is available from the Managing Your Ethics Approval SBREC web page. Download the form from the website every time a new modification request is submitted to ensure that the most recent form is used. Please note that extension of time requests should be submitted prior to the Ethics Approval Expiry Date listed on this notice.

Change of Contact Details

Please ensure that you notify the Committee if either your mailing or email address changes to ensure that correspondence relating to this project can be sent to you. A modification request is not required to change your contact details.

4. **Adverse Events and/or Complaints**

Researchers should advise the Executive Officer of the Ethics Committee on 08 82013116 or human.researchethics@flinders.edu.au immediately if:

- any complaints regarding the research are received;
- a serious or unexpected adverse event occurs that effects participants;
- an unforseen event occurs that may affect the ethical acceptability of the project.

Kind regards

Andrea

Appendix 2. Information sheet to participate to a research

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INFORMATION SHEET

Title: 'Toxicological and Microbiological study of rainwater used for Drinking'

Mr Emmanuel C Chubaka

College of Sciences and Engineering

Flinders University

Ph: 08 7221 8587

Email: chub0008@flinders.edu.au

Dr Kirstin Ross, Dr Harriet Whiley & Assoc Prof John Edwards

Environmental health

College of Sciences and Engineering

Flinders University

Tel: 08 7221 8584

Description of the study:

This study is part of the project entitled '*Toxicological and Microbiological Study of Rainwater used for Drinking*'. This project will investigate the potential contamination of rainwater that is used for drinking water and test the efficacy of current rainwater filtration systems. The project will focus on areas that have a higher likelihood of contamination through sources such as industry or following bushfires. This project is supported by Flinders University, School for the Environment.

Purpose of the study:

1. This research is an assessment of rainwater drinking water quality. We are collecting samples of rainwater and assessing the level of metals, hydrocarbons and microbes in that sample. We will then compare the levels we find in samples to those safe level prescribed in the Australian Drinking Water Guidelines.
2. We are interested in whether levels of contamination change over time and the influence of meteorological factors such as rainfall and wind (dust production).

What will I be asked to do?

1. **You will be asked for access to a sample of rainwater from your tap inside the house.**
2. You will also be asked whether you are willing to provide access for another sample to be taken in four weeks.

What benefit will I gain from being involved in this study?

We cannot guarantee or promise that you will receive any benefits from this research; however, possible benefits may include *having an information* *background on the quality of water stored in every participant tank.*

Will I be identifiable by being involved in this study?

We do not need your name and you will be anonymous. Any identifying information will be removed and the typed-up file stored on a password protected computer that only the principal supervisor, Dr Kirstin Ross will have access to. In any way, tour comments will not be linked directly to you.

Are there any risks or discomforts if I am involved?

There is no risk associated with taking part to this project. Your involvement is limited to allowing free access to your tank for sample taking, and to voluntary responding to some few questions on rainwater quality and best options of rainwater harvest and use for drinking. However, and under the State and Commonwealth Laws, any witness of illegal may be reported by researcher upon deliberation with the Principal Supervisor. However, if you have any complaints about any aspect of the project, the way it is being conducted or any questions about being a research participant in general, you can contact the researcher on 041 323 5143 or the principal supervisor; Dr Kirstin Ross at 08 08 7221 8584 or alternatively, contact *the Committee* Executive Officer of the *Flinders University Social and Behavioural Research Ethics at* 08 8201 3116 and by fax on 08 8201 2035 or alternatively by email: human.researchethics@flinders.edu.au.

How do I agree to participate?

Participation in any research project is voluntary. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. If you do not wish to take part, you do not have to. If you do decide to take part, you will be given this Participant Information and Consent Form to sign and you will be given a copy to keep. Your decision whether to take part or not to take part, or to withdraw will not affect your routine care, your relationship with professional staff or your relationship with the Flinders University and the School of the Environment.

How will I receive feedback?

Outcomes from the project will be summarised and given to you by the investigator if you would like to see them. Thank you for taking the time to read this information sheet and we hope that you will accept our invitation to be involved.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project number 6782*. here following approval). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by emailhuman.researchethics@flinders.edu.au*

Appendix 3. Consent form for participation in research

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CONSENT FORM FOR PARTICIPATION IN RESEARCH

Microbiological and Toxicological Study of Rainwater used for Drinking

I

………

being over the age of 18 years hereby consent to participate as requested in the ………………………… for the research project on *Microbiological and Toxicological Study of Rainwater used for Drinking*

1. I have read the information provided.
2. Details of procedures and any risks have been explained to my satisfaction.
3. I agree to audio/video recording of my information and participation.
4. I am aware that I should retain a copy of the Information Sheet and Consent Form for future reference.
5. I understand that:
   - I may not directly benefit from taking part in this research.
   - I am free to withdraw from the project at any time and am free to decline to answer particular questions.

- While the information gained in this study will be published as explained, I will not be identified, and individual information will remain confidential.
- Whether I participate or not, or withdraw after participating, will have no effect on any treatment or service that is being provided to me.
- Whether I participate or not, or withdraw after participating, will have no effect on my progress in my course of study, or results gained.
- I may ask that the recording/observation be stopped at any time, and that I may withdraw at any time from the session or the research without disadvantage.

6. I agree/do not agree* to the tape/transcript* being made available to other researchers who are not members of this research team, but who are judged by the research team to be doing related research, on condition that my identity is not revealed. ** delete as appropriate*
7. I have had the opportunity to discuss taking part in this research with a family member or friend.

Participant's signature..Date.........................…

I certify that I have explained the study to the volunteer and consider that she/he understands what is involved and freely consents to participation.

Researcher's name: Emmanuel C Chubaka

Researcher's signature Date / / 2015

NB: Two signed copies should be obtained. The copy retained by the researcher may then be used for authorisation of Items 8 and 9, as appropriate.

8. I, the participant whose signature appears below, have read a transcript of my participation and agree to its use by the researcher as explained.

Participant’s signature……………………………………Date…………………..…

9. I, the participant whose signature appears below, have read the researcher’s report and agree to the publication of my information as reported.

Participant’s signature……………………………………Date…………………....

Appendix 4. Questionnaire given to households on first contact

QUESTIONNAIRE

Name of Investigator: **Mr Emmanuel Chubaka**

Starting Time: ______________________

Ending Time: _______________________

Date: ________________________________

Hello, my name is Emmanuel Chubaka, PhD Student, Faculty of Science and Engineering, School of the Environment at Flinders University. I am conducting a study on rainwater which is being used for potable in the metropolitan area of Adelaide and in rural South Australia. If you do not mind, I have some questions to ask you about your tank and on rainwater.

Should you agree to respond to my questions, please circle the most appropriate response you believe is applicable to your situation.

QUESTIONNAIRE

1. **Does the place where you currently live have any form of rainwater harvesting such as water butt or a rainwater tank?**
    a. Yes

b. No

2. **If yes, what do you have?**

    a. Tank capacity less than 1,000 L
    b. Tank capacity between 1,000 L and 10,000 L
    c. Tank capacity in excess of 10,000 L
    d. Don’t know

3. **Why do you have a rainwater tank?**

    a. To save money
    b. For indoor purpose (drinking and cooking)
    c. For indoor purpose (toilet flushing and clothes washing machine)
    d. For outdoor purpose (gardening and car washing)

4. **How often do you use rainwater for drinking and cooking?**

    a. Very often
    b. Sometimes
    c. Rarely
    d. Not at all

5. **What maintenance is perfromend on your tank/?**

    a. Cleaning gutters
    b. Cleaning downpipes to tank
    c. Removing sludge from tank
    d. No maintenance at all

6. **Do you have a first flush diverter device fitted with your tank?**

    a. Yes
    b. No

7. **Have you had an issue with your tank since installation?**

    a. None until now
    b. Water quality
    c. Leaking pipes
    d. Uncontrolled overflow

8. **How do you get information on rainwater quality?**

a. Radio
b. Television
c. Puratap
d. Facebook

9. **Overall, are you satisfied with your rainwater tank?**

a. Yes.
b. No.

Thank you for completing this survey. It will be only used for the purpose of research. Your details are completely confidential and will not be used for any other purpose.

Appendix 5. Letter to introduce the researcher to households

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LETTER OF INTRODUCTION

Dear Sir/Madam,

This letter is to introduce ***Mr Emmanuel CHUBAKA*** who is a ***PhD*** student in the ***Faculty of Science and Engineering, School of the Environment*** at Flinders University. He will produce his student card, which carries a photograph, as proof of identity.

He is undertaking research leading to the production of a thesis or other publications on the subject of Environment Health, and he is looking at metals and other contaminants in rainwater used for drinking water around the Adelaide and rural South Australia. I would like to invite you to assist with this project by allowing him to freely access to your rainwater tank for sample collection, to cover certain aspects of this topic. Please be assured that any information provided will be treated in the strictest confidence and you will not be individually identified in the resulting thesis, report or other publications. You are, of course, entirely free to discontinue your participation at any time or to decline to answer particular questions. Any enquiries you may have concerning this project should be directed to me at the address given above or by telephone on 08 7221 8584 or alternatively, e-mail to Kirstin.ross@flinders.edu.au

Thank you for your attention and assistance.

Yours sincerely

Dr Kirstin Ross

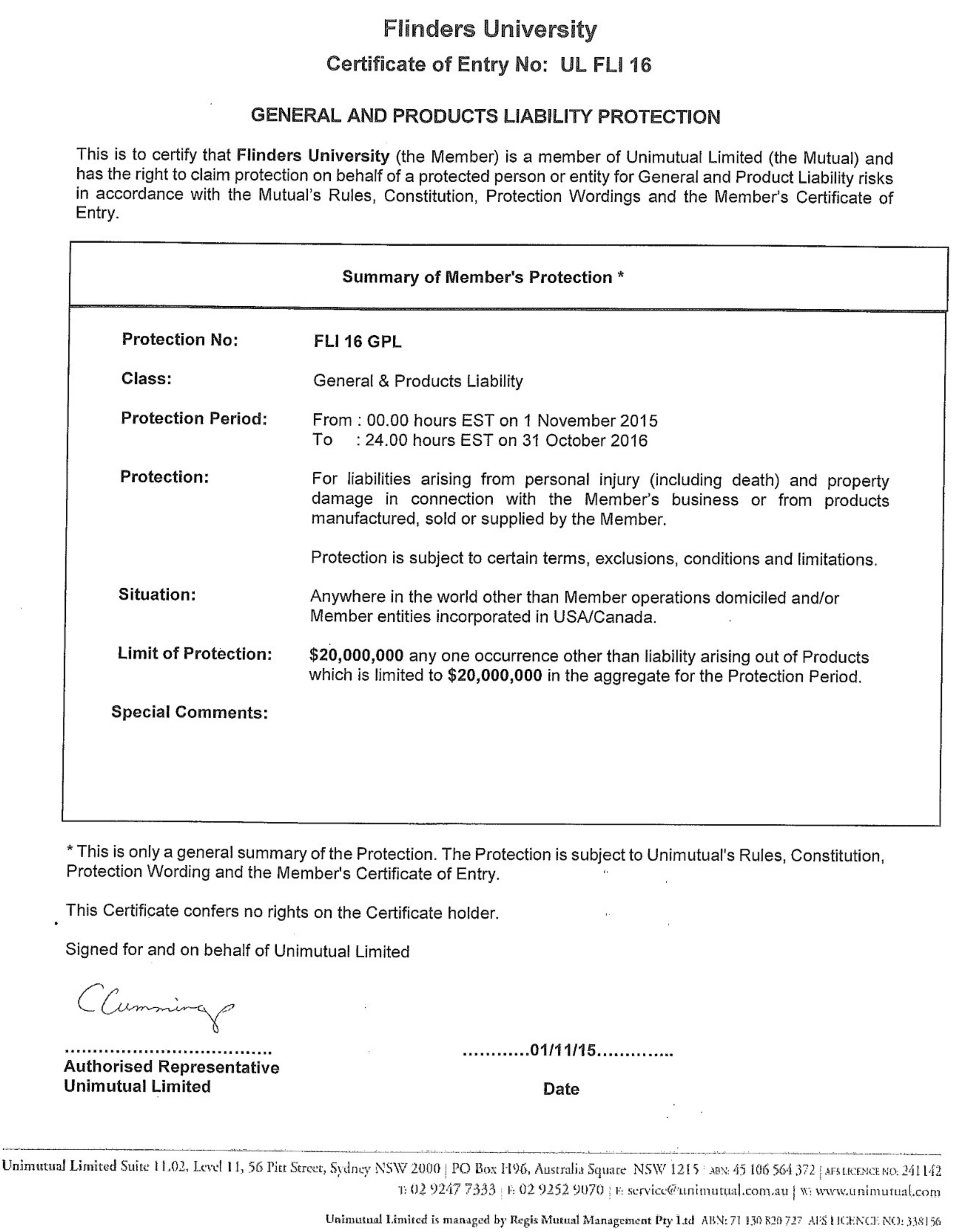
Lecturer, Environmental Health

School of the Environment

Room 5.24 Health Sciences Bldg

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project number INSERT PROJECT No. here following approval). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035

Appendix 6. Flinders University public liability insurance



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Certificate of Entry No: UL FLI 16

GENERAL AND PRODUCTS LIABILITY PROTECTION

This is to certify that **Flinders University** (the Member) is a member of Unimutual Limited (the Mutual) and has the right to claim protection on behalf of a protected person or entity for General and Product Liability risks in accordance with the Mutual's Rules, Constitution, Protection Wordings and the Member's Certificate of Entry.

Summary of Member's Protection *

Protection No:	**FLI 16 GPL**
Class:	General & Products Liability
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Protection:	For liabilities arising from personal injury (including death) and property damage in connection with the Member's business or from products manufactured, sold or supplied by the Member. Protection is subject to certain terms, exclusions, conditions and limitations.
Situation:	Anywhere in the world other than Member operations domiciled and/or Member entities incorporated in USA/Canada.
Limit of Protection:	**$20,000,000** any one occurrence other than liability arising out of Products which is limited to **$20,000,000** in the aggregate for the Protection Period.
Special Comments:	

* This is only a general summary of the Protection. The Protection is subject to Unimutual's Rules, Constitution, Protection Wording and the Member's Certificate of Entry.

This Certificate confers no rights on the Certificate holder.

Signed for and on behalf of Unimutual Limited

C Cummings

……………………………… …………01/11/15…………

Authorised Representative
Unimutual Limited

Date

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Appendix 7. Survey questionnaire

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QUESTIONNAIRE

Name of Investigator: **Mr Emmanuel Chubaka**

Starting Time: ______________________

Ending Time: _______________________

Date: _____________________________

Hi. I am Emmanuel Chubaka, PhD Student, Faculty of Science and Engineering, School of the Environment – Environment Health at Flinders University. I am doing a survey on people drinking water choices. Would you mind if I ask three or four questions about your drinking water preference?

1. **Which water do you most drink?**

    c. Town water (tap water)
    d. Bottle water
    e. Rainwater

1. **Why do you prefer drinking bottle water / rainwater / town water?**

    a. It is more convenient

b. It is clean water
c. It tastes better

2. Do you have any other reason for choosing town water/bottle water / rainwater?

    a. -
    b. -
    c. -

3. Do you have a rainwater tank?

    a. Yes
    b. No

4. What is your postcode?

Appendix 8: Publication: Potential contaminants in rainwater after a bushfire

Kirstin E. Ross[1*], PhD, Harriet Whiley[1], PhD, Emmanuel Chubaka[1], MEnvSci, PhD Candidate, Malinda Steenkamp[2], PhD, Paul Arbon[3], PhD.

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DOI: http://dx.doi.org/10.5055/jem.2018.0367

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Keywords: bushfires, rainwater, contaminants, potable use, stock watering, irrigation

Potential Contaminants in Rainwater After a Bushfire

Using roof harvested rainwater held in domestic rainwater tanks is a common practice in Australia, particularly in rural areas. This rainwater might become contaminated with ash and other contaminants during or after a bushfire. Current advice can include the recommendation that landholders drain their tanks after a bushfire, which can cause additional distress to landholders who have already been through a traumatic event. This study created artificially contaminated water, spiked with chemicals likely to be associated with bushfires, including chromated copper arsenate treated timber ash and firefighting foam to determine the possibility of contamination. The authors also tested two readily available filter systems and found they removed some but not all contaminants. The artificially created contaminated water fell within guidelines for non-potable uses such as irrigation and stock watering. This suggests that advice to landholders should be that tank water following a bushfire is likely to be safe for use for all purposes apart from drinking. Landholders should be encouraged to retain and use their water for recovery purposes, but not for potable use.

Introduction

The use of domestic rainwater tanks has become an established and relatively common practice in Australia, particularly in rural and remote areas[1]. The increased interest in harvesting rainwater is linked to widespread drought conditions, predictions of worldwide shortages, increased water restrictions and the offering of incentives for installation of domestic tanks[2]. The Australian Bureau of Statistics indicates that 19.3 percent of Australian households have a rainwater tank and 10.1 percent use roof harvested rainwater (RHRW) as their main source of drinking water. In rural areas, this increases to 33.5 percent [3].

Bushfires generate large amounts of ash and debris that can settle on roof catchment areas. It is also possible that fire retardants or foams may be deposited on roofs. Such material can be washed into rainwater tanks, either when water is applied to the roof as part of fire protection or clean-up activities, or when it rains after a bushfire[4]. Ash and debris could affect the colour, turbidity and taste of rainwater, but, more importantly, these substances could introduce contaminants harmful to health.

Contaminants that might pose a risk to health if present in rainwater include PAHs from burnt organic matter and copper, chromium and arsenic, released during the combustion of wood treated with preservatives[5]. The PAH group include more than 100 compounds, such as benz(a)anthracene and benzo(a)pyrene which are classified as probable human carcinogens[6]. These compounds are also present in petroleum and coal-based products, including roofing tar. The PAH compounds can exist as vapors or can be attached to small solid particles such as dust, which means that the compounds can be spread across significant distances to also settle on roofs[5]. Most PAH compounds are not readily water soluble and will break down over some weeks or months[7]. Copper chrome arsenate (CCA) treated wood products are used in fence posts, furniture and structures such as outdoor huts[5]. When such wood is burnt, arsenic can be found in the resultant ash, some of which is in water-soluble form[8]. This ash may also be deposited on roofs from which rainwater is harvested.

In early 2003, after a prolonged drought, extensive bushfires occurred in north-east Victoria and east Gippsland. Over 1.5 million hectares of land were affected, and there were concerns about how smoke, ash, and other contaminants might affect rainwater quality in the affected areas. The major concerns were PAHs and ash from burned CCA-treated wood, although other sources of metals post bush fire are possible. It was thought that increased microbial contamination due to higher levels of burnt organic matter being washed into tanks might also be a problem[5]. Spinks et al.[5] conducted a study involving 49 rainwater tanks in north-east Victoria. Rainwater tank samples were taken and analysed for a variety of parameters including organic compounds, microbiological indicators, metals, nutrients and physicochemical parameters. The tank owners also completed a survey administrated concurrently. The study[5] found levels of PAHs below the ADWG[9] values. No other study on bushfires and rainwater quality has been found and the study mentioned above is the only one that used ADWG to evaluate rainwater quality after bushfires.

The current fire retardant commonly used in bush firefighting is classified as nontoxic (1 percent Bush Masters 'A' Class Foam)[10] however, community concerns over the use of firefighting foam have been raised as a result of recent revelations of environmental contamination by firefighting foam in used by the Australian military (ABC News, August 7, 2016). Anecdotal evidence suggests the community is now concerned about toxicity associated with any firefighting foam being used (EnviroLab Services, Adelaide, personal oral communication, January 17, 2017).

Current guidelines in South Australia state that ash and debris deposited on a roof should be removed and that the first flush of water after a bushfire should not be collected[11]. If material has been washed into a tank in sufficient quantities to affect the “smell, taste or appearance of rainwater”, the tank should to be drained and cleaned, or alternatively the water could be used for non-potable purposes (SA Health, 2012). Notwithstanding, anecdotal information from environmental health officers involved in emergency response in South Australia indicates that advice on the ground following bushfires is to drain rainwater tanks. The additional distress this could cause landholders is of great concern. This contrasts with advice given by the Victoria Health Department, who do not suggest draining the tanks, rather “Water that is not suitable to drink may be used to … water the garden[12]. Western Australian advice also suggests tank draining and cleaning, although notes that contaminated rainwater can still be used for many purposes[13]. The NSW Department of Health does not recommend drinking rainwater, with no specific advice regarding rainwater after a bushfire[14].

The first aim of this study was to try to represent contamination that might be expected in rainwater after a bushfire, based partly on Spinks et al.[5]. To do this, we measured the concentrations of metals, PAHs, and firefighting foam in water artificially spiked with contaminated ash. This was done under laboratory test conditions by burning timber and adding the resultant ash and firefighting foam to water. We also sought to assess whether two commercially available filtration systems (a Brita Maxtra® filter jug and a Puratap® under bench water purification system) could remove these contaminants. This was also done under laboratory test conditions using the spiked water described above then filtering the mixture to assess contaminant removal. The primary aim of the study was to determine whether health advice could include rainwater filtration if water is to be used for potable purposes.

Materials and Methods

To replicate burnt treated timber ash settling on roofs and then being washed by rain into rainwater tanks, CCA-treated timber purchased from a local hardware store was burned until self-extinguished to ash and coals. The ash and coals were allowed to cool and sieved through a sieve (900 µm). The sieved portion was sealed in an airtight container until further use. A 1:100 (weight/volume) stock solution (5 g ash + 500 mL water) of sieved ash was made using tap water. This was shaken vigorously for 1 minute and then left to settle for 24 h. Dilutions of this stock solution were created by pipetting the liquid from the middle of the supernatant (avoiding extracting both the settled and floating particulate material). Test spiked (range finding) solutions of 100, 10, 1, and 100 µL made up to 1 L with tap water were made up (hereafter called 100SS, 10SS, 1SS and 0.1SS). Duplicate samples of each of the solution was then filtered through a Brita® filter jug using a new Brita Maxtra® filter cartridge for each concentration. The filtrate was subsampled in duplicate for analysis. Blanks (tap water) of both filtered and unfiltered tap were also created.

Unfiltered and filtered samples of CCA-treated ash were tested for the following metals: arsenic, chromium, copper, cadmium, lead, manganese, zinc and iron (note: tests were conducted for total not speciated metals, including for chromium). The following polyaromatic hydrocarbons were tested: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo (b,j+k) fluoranthene, benzo(a)pyrene, indenol(1,2,3-c,d)pyrene, dibenzo (a,h) anthracene, benzo (g,h,i) terylene, benzo(a)pyrene TEQ, total positive PAHs and p-Terphenyl-D14. Note: higher molecular weight (HMW) PAHs are defined as PAHs with greater than or equal to four rings and with molecular weight greater than or equal to 202 amu[15]. Parent HMW PAHs include pyrene, fluoranthene, benz(a)anthracene, chrysene, benzo(a)pyrene, perylene, benzo(e)pyrene, benzo(b) fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i) perylene, indeno(1,2,3-cd) pyrene, and dibenz(a,h)anthracene[16].

To replicate firefighting foam deposited on roofs and then being washed by rain into rainwater tanks, a 0.1 percent BushMaster A Class firefighting foam® solution was created (2 mL in 2 L tap water). The firefighting foam is recommended to be applied as a 1percent solution. Duplicate pre- and post- filtering samples were sub-sampled.

Unfiltered and filtered samples of firefighting foam were tested for perfluoro-compounds (perfluorohexane sulfonic acid, perfluorooctanesulfonic acid and perfluorooctanoic acid), contaminants of concern historically associated with firefighting foams. While it is apparent from the BushMaster® firefighting foam Material Safety Data Sheet that the toxicity of this compound is low, there is still concern within the community that these foams are toxic. Therefore, we tested the foam for these chemicals to be sure that the new formulation of foam does not contain the perfluoro-based compounds.

A second experiment was conducted to determine the volume of sample that could be put through the filter before its removal capability was impaired. To do this, 300 L of 1 stock: 10 tap water (v/v) was made up and put through one new Brita Maxtra filter cartridge® (hereafter jug filter) and one new a Puratap® under bench water purification cartridge (hereafter bench filter). Duplicate samples were subsampled after 1, 5, 10, 25, 50, 100, 200 and 300 L (jug filter) had been through the filter (note: Brita Maxtra® filter cartridge recommends changing after 150 L) and 1, 6, 36, 86, 186, 386, 686 L (bench filter).

All samples were tested by EnviroLab Services Western Australia, NATA Accreditation number 2901. Practical quantitation limits (PQLs) are reported in results. The first experiment was undertaken to determine the concentration of PAHs and metals that became associated with the water column and provide some preliminary understanding of the success of the jug filer. The metal concentration found in the "Before" (before filtering, Table 1) were compared with those concentrations reported by Spinks et al., (2006). The 10SS concentration was chosen for the second filtration experiment as the 10SS dilution most closely reflected the concentrations reported by Spinks et al.[5].

Results

First experiment (using a wide range of stock concentrations)

In the first experiment, using a wide range of stock concentrations, only arsenic and chromium were above the ADWGs (Table 1) (hereafter ADWG)[9]. All PAHs were below the PQL, pre- and post-filtration. [PQL 0.1 µg/L for all PAHs except benz(a), pyrene TEQ, which was 0.5 µg/L.] The limit for PAHs specifically benzo(a) pyrene, is 0.00001 mg/L (0.01 µg/L). This suggests that low molecular weight (LMW) PAHs volatilized away[17].

Perfluoro compounds were below the PQL for perfluorohexanesulfonic acid, perfluorooctanesulfonic acid, and perfluorooctanoic acid (<0.01 µg/L for each analyte) in all samples, pre- and post-filtration. Chromium in the experiment using a wide range of stock concentrations was removed by the jug filter (between 76 and 85 percent removal; Table 1). Notably, in the 10SS, filtering reduced the concentration from above the guideline to below (reduction of 81 percent). Arsenic was above the guideline in samples 1SS, 10SS, and 100SS, both before and after filtration, and below the guideline in the 0.1SS. Measured cadmium was below the PQL (0.0001 mg/L), and copper, lead, manganese, zinc, and iron were all below the ADWG guideline values (Table 1).

Second experiment (10SS only)

The second set of experiments indicated that the jug filter was better at lowering the concentration of chromium compared with the built-in filter, although the jug filter failed to remove any of the chromium after 75 L had been put through the filter (Figure 1). Only the first filtered 1 L was below the ADWG guideline concentration for the jug filtration, and at 6 L for the built-in filter experiment, suggesting the built-in filter might need to be wetted before metal adsorption takes place [the guideline is based on Cr (VI) only, and we measured total Cr]. Notwithstanding, the chromium was only reduced by less than a quarter after 100 L had passed through the filter.

Arsenic was removed comparatively poorly by the jug filter (by 21 to 28 percent; Table 1), and only slightly better by the built-in filter (Figure 2). Both filters were very successful in removing copper (Figure 3) and zinc (Figure 4), although these metals were below the drinking guideline concentrations. Table 2 presents an estimate of risk, based on the addition of CCA-treated ash representing realistic worst-case scenario for bushfire ash entering rainwater tanks. If we assume 10 g ash per m^2 (~1mm deep on the roof), a close-to-full 20,000 L rainwater tank, a 160 m^2 roof catchment area and pure CCA-treated timber ash, the concentration of metals, PAHs, and perfluoro compounds is likely to be equivalent to 10SS. The 0.1 percent BushMaster A Class firefighting foam® solution is equivalent to 2,000 L firefighting foam entering the rainwater tank as firefighting foam is recommended to be applied as a 1 percent solution. While these are rough estimates, Table 2 shows that the concentrations for documented guidelines for non-potable uses of water.

Arsenic was removed comparatively poorly by the jug filter (by 21 to 28%) (Table 1), and only slightly better by the built-in filter (Figure 2). Measured cadmium was below the PQL (0.0001 mg/L) and copper, lead, manganese, zinc and iron were all below the ADWG guideline values (Table 1). Both filters were very successful in removing copper (Figure 3) and zinc (Figure 4), although these metals were below the drinking guideline concentrations.

Table 2 presents an estimate of risk, based on the addition of CCA-treated timber ash representing a realistic worst-case scenario for bushfire ash entering rainwater tanks. If we assume 10 g ash per m^2 (-1 mm deep on the roof), a close-to-full 20,000 L rainwater tank, a 160 m^2 roof catchment area and pure CCA-treated timber ash, the concentration of metals, PAHs, and perfluoro compounds is likely to be equivalent to 10SS. The 0.1 percent BushMaster A Class firefighting foam® solution is equivalent to 2,000 L firefighting foam water entering the rainwater tank as firefighting foam is recommended to be applied as a 1 percent solution. While these are rough estimates, Table 2 shows that the concentrations of contaminants fall below guideline concentrations for documented guidelines for non-potable uses of water.

Discussion

Bushfires cause emotional and financial distress for months and at times years after the event. For example, in November 2015, the Pinery bushfires burnt 82,600 hectares in the Balaklava and Roseworthy area in South Australia's mid-north. This devastating fire cause loss of life and damaged homes and properties[23]. Events such as this cause significant emotional, physical, financial, and other stress that is often of extended duration and associated with the complex process of recovery and re-establishment of a sense of safety and certainty. Management of the home environment is of paramount importance for survivors and one aspect will be the safety of water quality. The SA Health "Bushfires and rainwater quality" fact sheet[11], under the heading "Removing contamination", suggests that landholders: "Drain and clean the tank and allow it to refill with clean rainwater or fill with water purchased from a water carter". Anecdotally, as reported by local government representatives, the distress that landholders feel about draining their water tanks is reported to be significant.

Table 1 shows that Spinks et al.[5] reported arsenic and chromium concentrations comparable to our 0.1SS (before filtering) and copper, lead, zinc and iron concentrations comparable to our 10SS (before filtering). As with our data, Spinks et al.[5] reported that copper, lead, zinc and iron were below ADWG limits. Cadmium was not detected in any of the samples in our study but was reported by Spinks et al.[5] study. This suggests that cadmium detected in tanks in the Spinks et al.[5] study was from impurities in galvanized fittings, solders, and brasses (as suggested by Spinks et al.[5] and not from burned treated timbers. Fire retardants (used in aerial bombing) and other suppressants (such as gels and other foams) were not tested, a limitation of this study.

Spiked samples were created by avoiding the surficial water and the sediments in the stock solution. This means that sediments-associated metals and PAHs were not included in the sample, nor was anything floating on the top of the water. This is important, as the concentrations of contaminants at the surface or the sediments could be substantially higher that those we measured. Rainwater tanks must be regularly cleaned and maintained to avoid a build-up of sediment and to ensure that the delivery tap, or pipe is extracting water from above the sediments. Additionally, the tank must not run dry, nor the surface water used.

The commercially available filters were able to reduce cadmium concentrations in small quantities of water, by between 2 and 85 percent, and in sometimes to below ADWG levels (Table 1 and Figure 1). It was found that arsenic could be removed by a small amount (<25 percent) and that both filters were very efficient at removing copper and zinc, although these metals were below guideline concentrations in the prefilter samples (Figures 2-4). These data suggest that commercially available household filters are capable of removing some contaminants associated with bushfires. However, more importantly, our work demonstrates that the concentrations even in highly artificially spiked water samples are below the guideline concentrations that we could find for non-potable uses such as irrigation and stock watering. This suggests that recommended advice to landholders should be that water is safe for use for all purposes apart from drinking, provided that surface and sediment water is not used, and that regular tank maintenance, especially cleaning, was being followed prior to the bushfire. Provision of bottled water for potable purposes is an appropriate emergency support response. Landholders should be encouraged to use their water for non-potable purposes to expedite recovery. This clear advice will cause a significant reduction in additional distress caused when landholders are advised to drain their water tanks as a precautionary measure. Further research needs to be undertaken to; (1) determine whether other filtration systems can provide water quality improvements and (2) to field validate our contaminant concentrations by taking tank water samples before and after bushfires.

Conclusion

The research demonstrates that contaminant concentrations, even in highly artificially spiked water samples, are low and acceptable for mon-potable uses and that comparison with guidelines for irrigation and stock watering uses demonstrates that our spiked sample concentrations were within these guidelines' limits. This indicates that RHRW contaminated in bushfires is likely to be suitable for all purposes apart from drinking. These data suggest further work needs to be undertaken with other filtration methods to determine whether there is an efficient and affordable way to remove contaminants that might be associated with bushfires.

Table 19. Metal levels in duplicate samples before and after filtering 1 L of spiked solution through the jug filter (green = below ADWG, red = above ADWG, note guideline for Cr is Cr (VI), we measured total chromium).

Table 1. Metal levels in samples before and after filtering 1L of spiked solution through the jug filter								
	Arsenic, mg/L	Chromium, mg/L	Copper mg/L	Cadmium mg/L	Lead mg/L	Manganese mg/L	Zinc mg/L	Iron mg/L
0.1SS Before filtering	0.005 (0)	0.002 (0)	<0.001	<0.0001	0.001 (0)	<0.005	<0.001	<0.01
0.1SS After filtering	0.004 (0)	<0.001	<0.001	<0.0001	<0.001	<0.005	<0.001	<0.01
1SS Before filtering	0.047 (0.001)	0.0165 (0.0005)	<0.001	<0.0001	0.001 (0)	<0.005	0.0033 (0.0005)	<0.01
1SS After filtering	**0.038 (0)**	0.004 (0)	<0.001	<0.0001	<0.001	<0.005	<0.001	<0.01
10SS Before filtering	**0.46 (0)**	**0.155 (0.005)**	0.009 (0.005)	<0.0001	0.002 (0)	<0.005	0.0073 (0.0005)	0.012 (0)
10SS After filtering	**0.335 (0.005)**	0.0305 (0.0005)	<0.001	<0.0001	<0.001	<0.005	<0.001	<0.001 (0)
100SS Before filtering	**4.6 (0)**	**1.5 (0)**	0.1742 (0)	<0.0001	0.002 (0)	<0.005	0.0548 (0)	0.012 (0)

100SS After filtering	**3.4 (0)**	**0.225 (0.005)**	<0.001	<0.0001	<0.001	<0.005	<0.001	0.002 (0)
ADWG guideline	0.01	0.05 (CrVI)	2	0.002	0.01	0.1	3 (aesthetic)	0.3 (aesthetic)
Spinks et al.[5]	0.001-0.007	0.001-0.008	0.005-0.58	0.002-0.0067	0.001-0.006	Not measured	0.003-17	0.05-0.78
Normal font, below ADWG; bold font, above ADWG; note guideline for Cr is Cr(VI), we measured total chromium. In brackets: standard deviation								

Table 20. Contaminant concentrations in the artificially contaminated water sample 10SS (representing a realistic worst-case scenario for bushfire ash entering rainwater tanks) and comparison with available non-potable guidelines.

Arsenic	0.46 mg/L (1st expt) 0.25 mg/L (2nd expt)	0.01 mg/L	0.001 mg/L	A concentration of total arsenic in drinking water for livestock exceeding 0.5 mg/L may be hazardous to stock health. If arsenic is not provided as a food additive and natural levels of arsenic in the diet are low, a level of 5 mg/L in drinking water may be tolerated. (National Health and Medical Research Council (NHMRC), 2008) Short term irrigation water = 2 mg/L (ANZECC and ARMCANZ 2000) Drinking water for cattle = 0.2 mg/L (Cooperative Extension Service University of Kentucky, no date)	Safe for livestock in the short term Safe for irrigation in the short term
Chromium	0.16 mg/L (1st expt) 0.19 mg/L (2nd expt)	0.05 mg/L	0.001 mg/L	Long-term trigger value in irrigation water = 0.1 mg/L and Short-term trigger value in irrigation water (short-term use) = 1.0 mg/L (National Health and Medical Research Council (NHMRC), 2008)	Safe for irrigation in the short term Safe for livestock

				Chromium (total Cr) 1.0 mg/L (Cooperative Extension Service University of Kentucky, no date) Hexavalent Cr 0.5 mg/L and trivalent Cr 0.5 mg/L for long term protection (Environment, 1999)	
Cadmium	Below PQL	0.002 mg/L	0.0001 mg/L		Below ADWG
Lead	At or near PQL	0.01 mg/L	0.001 mg/L		Below ADWG
Copper	0.0142 mg/L (1st expt) 0.83 mg/L (2nd expt)	2 mg/L (health) 1 mg/L (aesthetic)	0.001 mg/L		Below ADWG
Zinc	0.0073 mg/L (1st expt) 0.068 mg/L (2nd expt)	0.3 (aesthetic)	0.001 mg/L		Below ADWG
Iron	0.012 mg/L (1st exp) 0.017 mg/L (2nd expt)	3 (aesthetic)	0.01 mg/L		Below ADWG
Perfluorohexanesulfonic acid	All below PQL		0.01 µg/L		Below ADWG

Perfluorooctanesulfonic acid Perfluorooctanoic acid					
PAHs	Below PQL	*	0.1 µg/L*	Drinking Water Risk-Based Screening Levels (for LMW PAHs range from 2.01 – 28.3 mg/L and HMW PAHs 0.402 – 5.65 mg/L for cattle, sheep, goats, camels, horses (American Petroleum Institute, 2004) Domestic non-potable groundwater use [just benzo(a)pyrene 0.1 µg/L] (LIA, 2010) Fresh water [just naphthalene 16 µg/L] (ANZECC and ARMCANZ, 2000)	PQL higher than the ADWG However, safe for livestock Safe for irrigation

*Benzo(a)pyrene should not exceed 10 ng/L (0.01 µg/L). Data are inadequate to set guidelines for other PAHs, however comparative carcinogenic potency can be used to determine an approximate risk when complex mixtures of PAHs are present in drinking water (National Health and Medical Research Council (NHMRC), endorsed 2011, revised 2016)

Low molecular weight PAHs are the sum of acenaphthalene, anthracene, fluorene, 2-methylnaphthalene, naphthalene and phenanthrene. High molecular weight PAHs are the sum of benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene (from WA Department of Environment and Conservation 2010).

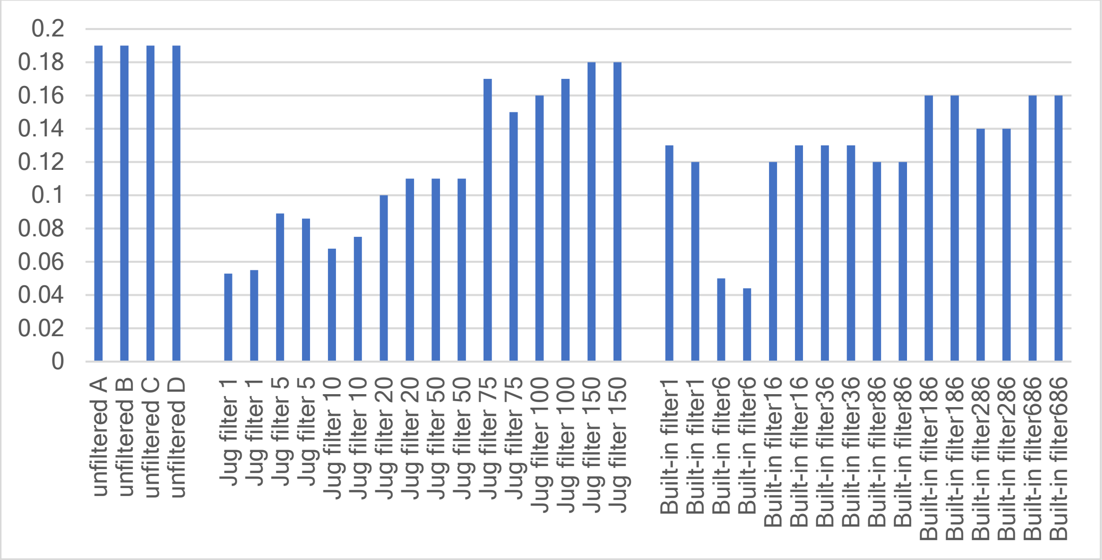

Figure 36. Chromium concentrations pre and post filtering (mg/L) (error bars = standard deviation of duplicate samples).

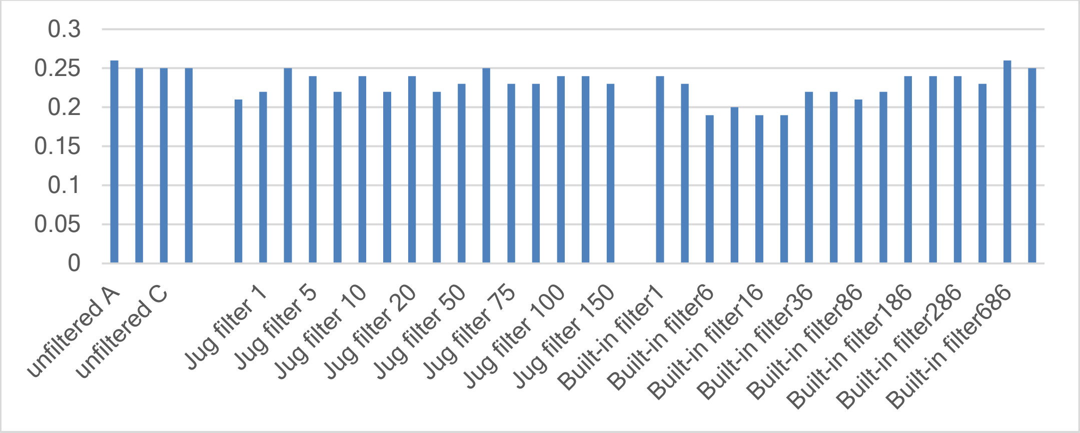

Figure 37. Arsenic concentrations pre and post filtering (mg/L) (error bars = standard deviation of duplicate samples).

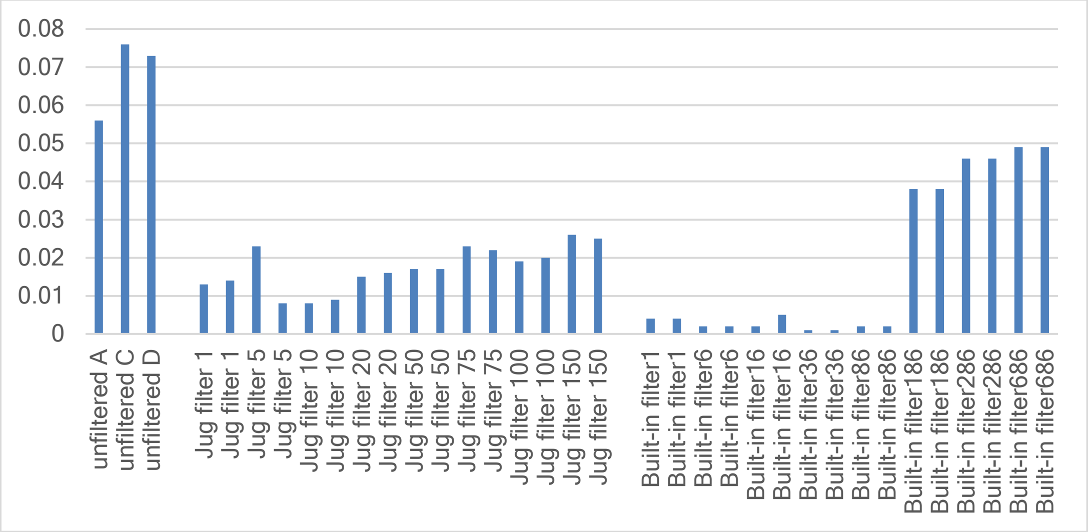

Figure 38. Zinc concentrations pre and post filtering (mg/L) (error bars = standard deviation of duplicate samples).

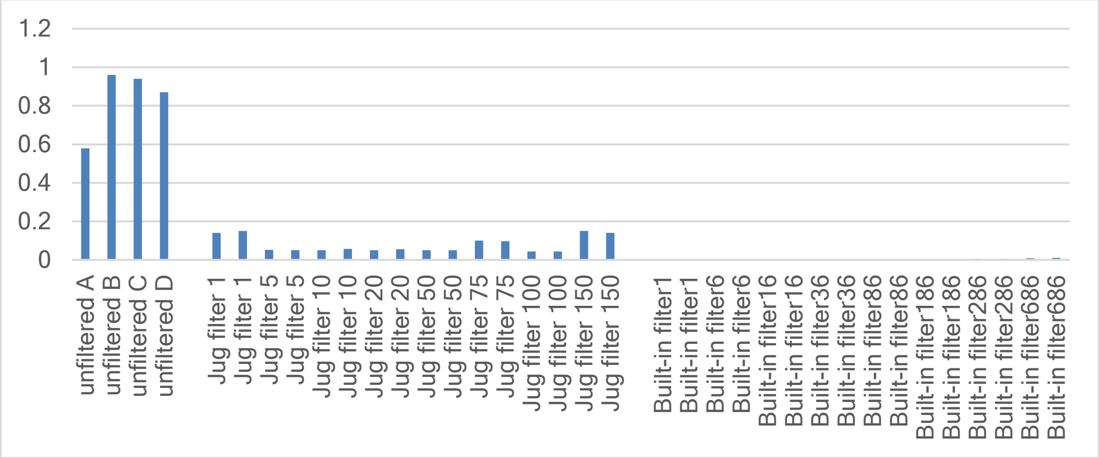

Figure 39. Copper concentrations pre and post filtering (mg/L) (error bars = standard deviation of duplicate samples).

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Appendix 9. Laboratory rainwater filtration unit

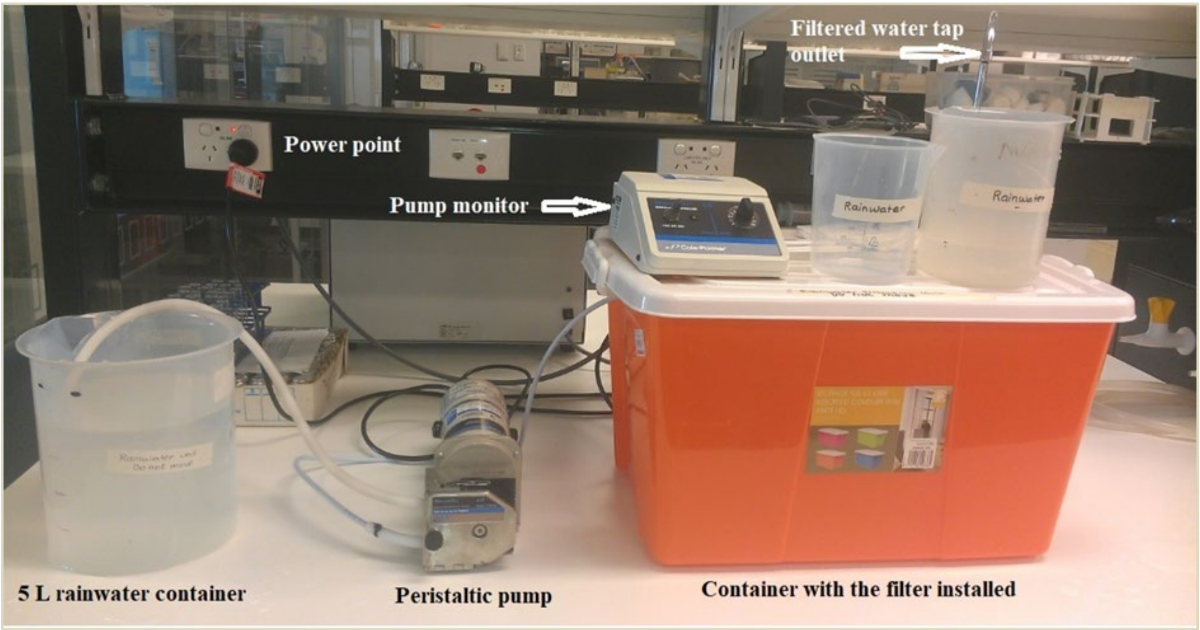

Figure 40. Laboratory bench mounted water filtration unit

Photo 2018

Appendix 10. Table 3 revised

Table 21. Trace metals found in rainwater in key Australian towns and cities (in ppm) *Aesthetic only for zinc, lead* - total lead

Location	Metal concentration	Health limit	Times above limit	Value description	Reference
Adelaide, SA	15.8 – zinc	3*	5.2 times higher	Highest	Rodrigo et al., 2011
Port Pirie, SA	0.06 – lead	0.01	6 times higher	Average	Sinclair et al., 2005
Adelaide, SA	0.03 – lead*	0.01	3 times higher	Highest	Rodrigo et al., 2010
	16.1 - zinc	3*	5,3 times higher	Highest	
Melbourne, VIC	0.42 – lead	0.01	42 times higher	Highest	Magyar et al., 2008
	0.1 – chromium	0.05	2 times higher	Highest	
	0.17 – nickel	0.02	8.5 times higher	Highest	
Melbourne, VIC	0.5 - lead	0.01	50 times higher	Highest	Magyar et al., 2014

Newcastle, NSW	0.02 – cadmium	0.002	10 times higher	Average	Morrow et al., 2010
	0.14 – arsenic	0.01	14 times higher	Average	
	0.81 – chromium	0.05	16 times higher	Average	
	15 – copper	2	7.5 times higher	Average	
Newcastle, NSW	0.21 – chromium	0.05	4.2 times higher	Average	Martin et al., 2010a
Sydney, NSW	0.55 – arsenic	0.01	55 times higher	Average	Sinclair et al., 2005,
	2.78 – lead	0.01	278 times higher	Average	
	0.34 – lead	0.01	33 times higher	Average	Kandasamy et al., 2016
Esperance, WA	0.1 – lead	0.01	1.2 times higher	Average	Heyworth and Mullan, 2009
	0.03 – nickel	0.02	1.5 times higher	Average	
Karumba, QLD	0.006 – cadmium	0.002	3 times higher	Highest	Gulson et al., 2016
	0.10 – lead	0.01	10 times higher	Highest	
	10.8 – zinc	3*	3.6 times higher	Highest	

Brisbane, QLD	0.85 – lead	0.01	85 times higher	Highest	Huston et al., 2012
	0.03 – arsenic	0.01	3 times higher	Highest	
	0.009 – cadmium	0.002	4.5 times higher	Highest	
	26 – zinc	3*	9 times higher	Highest	

Appendix 11. Table 4 revised

Table 22. Average trace metals seasonal variability in rainwater harvested in Newcastle (Martin et al., 2010a) (in ppm).

		Site 1 Carrington, Newcastle		Site 2 Cardiff South, Newcastle	
Parameters	Health limit	Winter	Summer	Winter	Summer
Silver	0.1	0.032	0.009	0.047	0.014
Cadmium	0.002	**0.18**	**0.17**	**0.05**	**0.10**
Lead	0.01	**2.78**	**10.5**	**3.59**	**5.77**
Uranium	0.017	0.003	0.003	0.002	0.002
Manganese	0.5	**20.0**	**82.3**	**6.95**	**12.1**
Chromium (Cr^6)	0.05	**0.09**	**0.21**	0.03	0.05
Arsenic	0.01	**0.25**	**0.55**	**0.08**	**0.09**
Zinc	3*	**518**	**725**	**77.2**	**150**
Copper	2	0.08	0.25	0.10	0.16
Nickel	0.02	**0.29**	**0.16**	**1.47**	**2.72**

*Aesthetic only for zinc

Appendix 12. Dates of sampling events over the study period

Table 23. Sampling dates and observed dates of significant rainfall events

Adelaide plains		Adelaide foothills		Adelaide Hills	
Date sampling	Significant rainfall	Date sampling	Significant rainfall	Date sampling	Significant rainfall
05 August 2015	NDA	17 August 2015	NDA	07 August 2015	NDA
27 August 2015	NDA	23 September 2015	NDA	10 September 2015	NDA
24 September 2015	NDA	24 October 2015	NDA	21 October 2015	NDA
12 November 2015	NDA	11 November 2015	NDA	09 November 2015	NDA
25 January 2016	NDA	26 January 2016	NDA	05 February 2016	NDA
24 March 2016	NDA	09 March 2016	07 March & 10 March 2016*	05 March 2016	03 March & 10 March 2016*

19 May 2016	NDA	16 May 2016	NDA	24 May 2016	NDA
30 June 2016	NDA	30 June 2016	NDA	29 June 2016	NDA
03 August 2016	ND A	01 August 2016	ND A	01 August 2016	ND A

* 17 mm and 18 mm of rainfall were recorded at Blackwood – Wittunga rain gauge station, on March 7, 2016 and March 10, 2016 respectively

* 14.6 mm and 23.4 mm of rainfall were recorded at Gumeracha on March 03, 2016 and March 10, 2016 respectively

* 23.4 mm of rainfall were recorded at Kersbrook on March 10, 2016

Appendix 13. Summary table of all tanks sampled for microbes

Table 24. Summary table of all tanks sampled, water use and conditions of rainwater harvesting

Characteristic	Number of tanks (out of 53)	Percentage
Have filters	8 tanks	15.0%
Have first flush installed	17 tanks	32.0%
Presence of TV mounted antennas	26 tanks	49.0%
Presence of hanging canopy	15 tanks	28.3%
Water used for drinking	11 tanks	20.7%
Polyethylene tanks	34 tanks	64.1%
Galvanised tanks	17 tanks	32.0%

Appendix 14. Transformed bacterial data statistical analysis

Table 25. R-squared values for transformed bacterial data (*E. coli* Log values)

Predictors	R-squared (R^2)	P-values
Total coliforms	0.145	< 0.01
Water temperature	0.321	< 0.001
Water pH	0.005	> 0.05
Roof mounted TV antennas	0.025	< 0.001
Overhanging tree canopies	0.026	< 0.001
First flush devices	0.003	> 0.05
Filters on tanks	0.007	> 0.05
Lead	0.0003	> 0.05
Zinc	0.0033	> 0.05

Appendix 15. Null hypothesis table

Table 26. Parameters null and alternative hypotheses

Parameters	Hypothesis or research question	Null hypothesis	P-value
Tanks and roof structure materials	Do structure materials (tank and roof material) have an influence on stored rainwater microbiological values?	Tank and roof material have no effect on bacterial numbers in stored rainwater	< 0.05
Roof mounted TV antennas and hanging canopies over catchment areas	Does the presence of mounted TV antennas or overhanging tree canopies over catchment areas affect stored rainwater bacterial values?	Having mounted TV antennas and overhanging canopies over catchment areas are among contributors to bacteria numbers in stored rainwater	< 0.01
Rainwater for potable use	Does having municipal water supplied prevent households from drinking rainwater?	Having municipal water supplied does not prevent people giving preference to rainwater as their source of drinking water	< 0.0001
Rainwater use	Does using rainwater for plant watering stop households from using rainwater for potable purposes?	Using rainwater for plant watering has no effect on people's tendency to use rainwater for potable purposes	< 0.0001

Rainwater temperature and pH at collection from tanks	Does the temperature and pH of rainwater at collection from the tank have an influence on stored rainwater bacteriological values?	Rainwater temperature and rainwater pH at collection from tanks have no effect on bacteria numbers in stored rainwater	<0.05
First flush devices on tanks	Do first flush devices on tanks reduce stored rainwater bacteriological numbers?	First flush devices have no effect on bacteria numbers in stored rainwater	<0.05
Structure materials and metals in rainwater	Do galvanised roofs or tanks affect the quality of stored rainwater, particularly rainwater zinc and lead content?	There is no difference in rainwater zinc and lead levels between different tank and roof structure materials.	<0.05 (zinc) 0.086 (lead)
Tank ownership and rainwater consumption	Does having a rainwater harvesting system installed on the property influence household drinking water choice?	Households express no tendency to drink rainwater because they have rainwater harvesting systems installed on their properties	< 0.0001
Rainwater consumption and households SEIFA ranking	Does living in areas of higher SEIFA index influence household drinking water choice?	Living in areas of higher SEIFA has no effect on people’s tendency to drink rainwater, whether municipal water is supplied	< 0.0001

Appendix 16. Figure 31, Figure 32, Figure 33 and Figure 34 revised

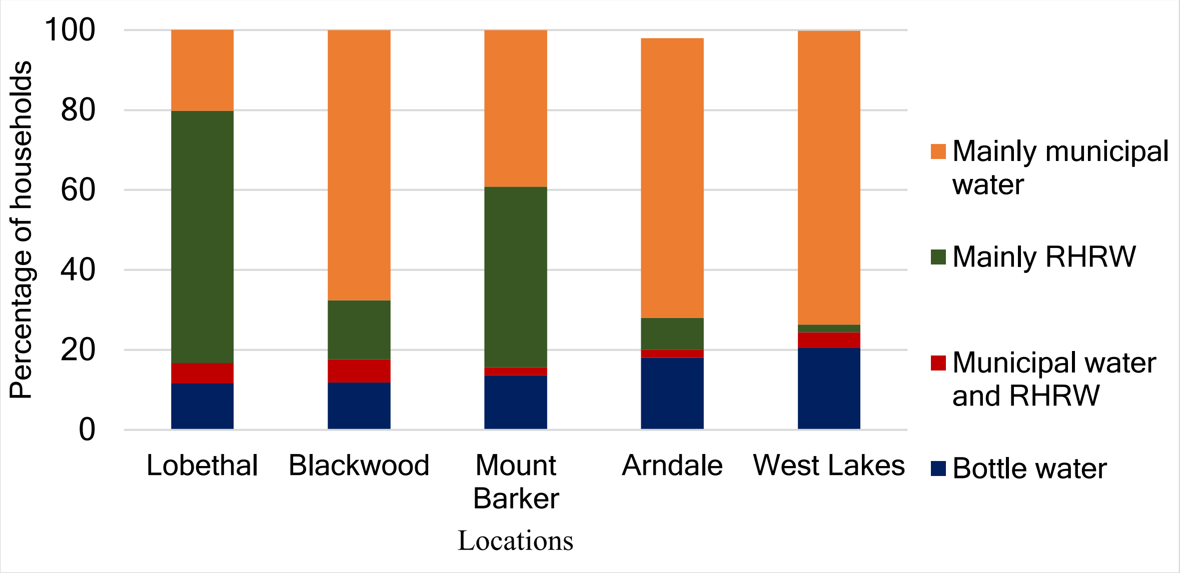

Figure 31. Responses to the question: What water do you most drink, by location

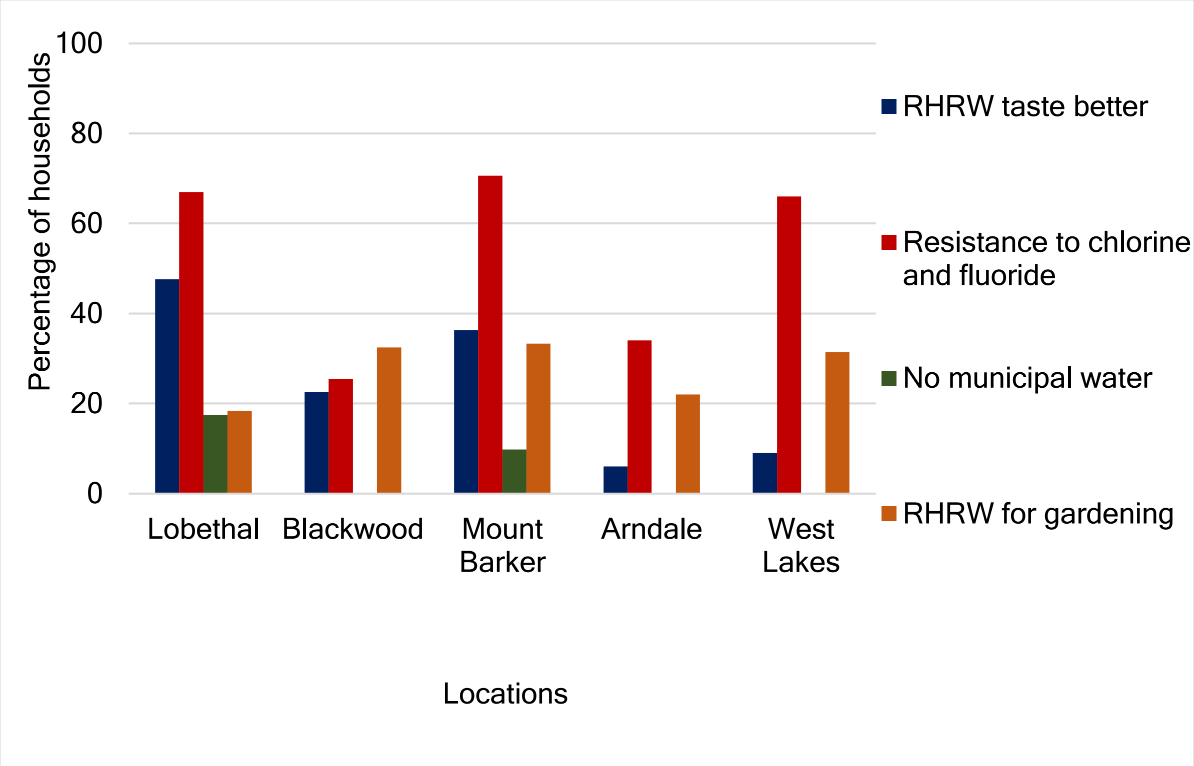

Figure 32. Factors affecting drinking water choice, by location ("Why do you prefer drinking a specific water?)

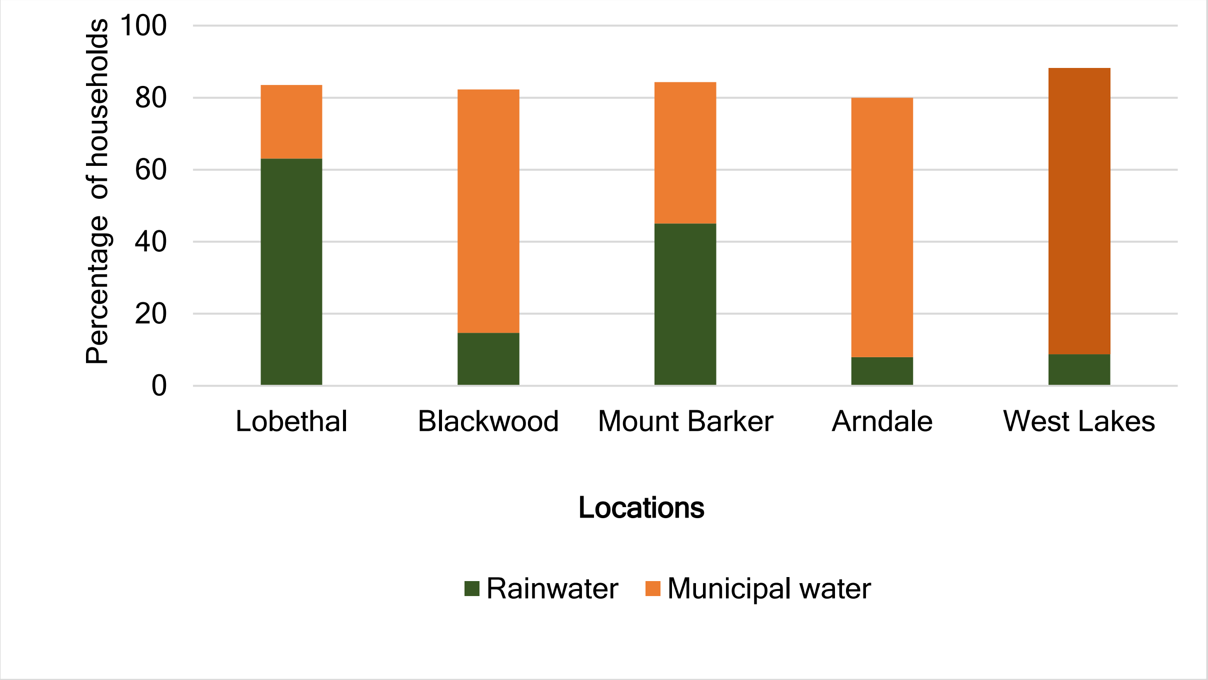

Figure 33. Number of households using a filtration system, by location

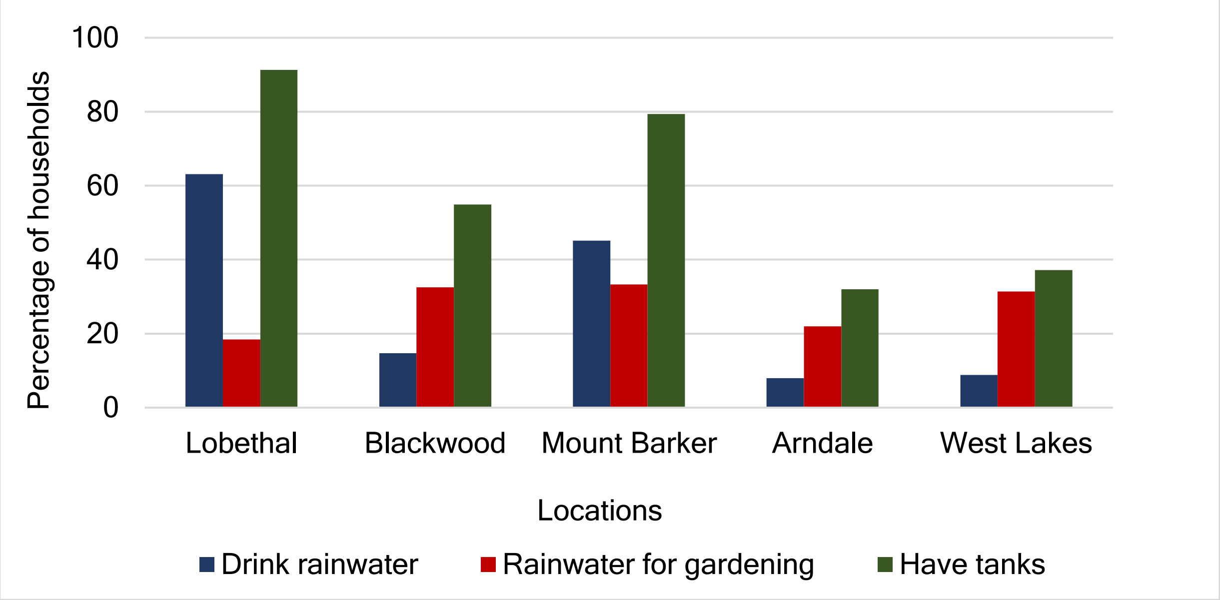

Figure 34. Number of households having a tank and drinking rainwater, by location

Appendix 17. Drinking water patterns and trigger to drinking water preference (% of households)