Assessment of the feasibility of a new end use in water recycling schemes for urban water

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By

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Certificate of Authorship/Originality

I certify that the work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and that the material has not been submitted, either in whole or in part, for a degree at this or any other university. In addition, I declare that all information sources and literature used are indicated in the thesis.

I acknowledge that I have read and understood the University's rules, requirements, procedures and policy relating to my higher degree research award and to my thesis. I certify that I have complied with the rules, requirements, procedures and policy of the University (as they may be from time to time).

BANDITA MAINALI

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ABBREVIATIONS

ABM	Australian Bureau of Metrology
ABS	Australian Bureau of Statistics
ACT	Australioan Capital Territory
ADWG	Australian Drinking Water Guidelines
ANOVA	Analysis of variance
ARC	Austalian Research council
ARCWIS	Australian Research Centre for Water In Society
ASTM	American Society for Testing and Materials
AUD	Australian Dollar
AWS	Alliance Water Solutions
BOD	Biochemical Oxygen Demand
C	Cotton
CADS	Citizen Against Drinking Sewage
CFU	Choliform Unit
COD	Chemical Oxygen Demand
COAG	Council of Australian Government
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cu	Copper
CWW	City Waste Water
DAFF	Dissoloved Air Flotation and Filtration
De	Denim
df	degrees of freedom
DPR	Direct Potable Reuse
DRS	Dual reticulation System

EDCS	Endocrine Disrupting Chemicals
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organisation
Fe	Iron
GL	Gigalitres
GWA	Global Water Awards
IFPRI	International Food Policy Research Institute
IPR	Indirect Potable Reuse
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
km	kilometres
LSI	Langelier Saturation Index
MAV	Maximum allowable value
Mn	Manganese
MF	Microfiltration
ML	Megalitres
ml	millilitres
NLWRA	National Land and Water Resources Audit
NSW	New South Wales
NWC	National Water Commission
NWQMS	National Water Quality Management Strategy
Pb	Lead
PMRWP	Port Macquarie Reclaimed Water Plant
Po	Polyester
PoC	Polycotton
QLD	Queensland

RHDA	Rouse Hill Development Area
RO	Reverse Osmosis
RW	Recycled Water
S	Satin
SA	South Australia
SEM	Scanning Electronic Microscope
SoE	State of the Environment
SIWI	Stockholm International Water Institute
SOPA	Sydney Olympic Park Authority
SPSS	Software Package for Social Science
STP	Sewage Treatment Plant
SWOT	Strength Weakness Opportunity Threat
TAS	Tasmania
TCC	Toowoomba City Council
TDS	Total Dissolved Solids
TW	Tap Water
TWCM	Total Water Cycle Management
UF	Ultra Filtration
UK	United Kingdom
UN	United Nations
UNDP	United Nation Development Project
UNEP	United Nations Environmental Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific members
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFPA	United Nations Framework for Population Activities
US	United States

US AID	United States Agency for International Development
UV	Ultra Violet
VIA	Virginia Irrigation Association
VIC	Victoria
VPS	Virginia Pipeline Scheme
WA	Western Australia
WBCSD	World Business Council for Sustainable Development
WFT	Water Future Initiatives
WHO	World Health organisation
WSAA	Water Services Association of Australia
WSUD	Water Sensitive Urban Design
WWTP	Waste Water Treatment Plant
Zn	Zinc

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ABSTRACT

Pressure on the availability of Australian freshwater resources is significantly increasing due to emerging climate change and population growth factors. Sustainable urban water consumption has become a critical issue in Australia due to the increasing urbanization, country's dry climate and increasingly variable rainfall. Water recycling is considered vital in alleviating the demand on existing and limited water supplies. It is the process by which wastewater, typically from sewage and/or stormwater collection, is treated to a variety of quality levels depending on the intended use and required safety standards. The benefits of using recycled water include protection of water resources, prevention of coastal pollution, recovery of nutrients for agriculture, augmentation of river flow, savings in wastewater treatment, enhancing groundwater recharge, and sustainability of water resource management. This will help in alleviating the pressure on existing water supplies and on the other hand protects remaining water sources from being polluted. Therefore, demands on water utilities to develop water recycling capacity and supplies are expected to intensify in Australia to cope with the persisting and increasing water stress. Numerous initiatives have been embraced Australia-wide to increase the availability of less-climate dependent water sources. Dual reticulation systems are one of the integral parts of such initiatives. Many cities in Australia are already equipped with dual reticulation system and this is likely to expand in many other cities in the future due to the persisting and increasing water stress. Considerable amount of fresh water conservation has been achieved due to the use of recycled water in urban communities. However, the end uses of the recycled water in such systems are limited and confined to toilet flushing, garden irrigation and car washing. Washing machine involves significant amount of household water (almost 20%) in most of the countries of the world including Australia. In this regards, use of recycled water for washing machine as a new end use of recycled water could be one innovative thought. Hence, this study aims to introduce a new end use to recycled water for urban water.

The recycled water parameters in terms of maximum allowable values of heavy metals in recycled water for laundry were formulated as the result of the study. Vision of community and their major concerns in regards to use of recycled water for washing machine were identified. The investigations with recycled water for washing clothes in washing machines were carried out to address all the major concerns of the general community regarding this new end use. The results indicated that Class A recycled water being supplied to the dual reticulation systems in urban community is safe for this new end use and highly recommended. The conceptual design criteria of educational leaflets for the dissemination of information on use of recycled water for various end uses were presented. Hence, this study proposes clear pathway to assist the adoption of water reform by actively engaging members of the community in this particular new recycled water application. Public acceptance of this new end use would be a significant step forward into sustainable thinking of urban communities. Conclusively, a new end use for recycled water for washing machines is acceptable and considered as a sustainable approach for Australian urban water.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Rapid urbanisation all around the world in conjunction with the climate change and water pollution leads to the huge demands for water which is already beginning to outstrip the available supplies. Sydney, Mexico City, Jakarta, Beijing, Tokyo and many other are some of the urban cities of the world where urban water demands have reached the capacity of the existing water supply system. The huge demands on cities' water supply systems posed by emerging climate change and increasing population has aroused serious concern over existing urban water resources and impels the development of new water resources (Miller, 2005) and new action plans, with the aim of achieving sustainable water management while meeting customer demand (Henderson et al., 2009). Not only in the dry regions, but even in countries with high rainfall such as Japan and England, the need to develop new water resources is acutely observed (Tillman et al., 1999; Dixon et al., 1999; Ogoshi et al., 2001; Janosova et al., 2005). The International Water Management Institute states in one of its report that Australia is one of the world's high water stress region (IWMI, 2006). Pressure on the availability of Australian freshwater resources is significantly increasing due to emerging climate change and population growth factors (Dimitriadis, 2005). After almost five years of continued lower-than-average rainfall across most of the eastern part of the Australian continent, many Australian cities and towns continue to face drought conditions with some water supply reservoirs at their lowest recorded levels (Willis et al., 2010). Almost all Australian capital cities, with the exception of Darwin and Hobart, were then experiencing water supply problems. Recently, flooding rains in eastern Australia have been observed however, it is well evidenced that Australia is associated with highly variable climate and serious precipitation imbalances (Holper, 2011). In addition to this, current water consumption practices in Australia are widely recognized to be unsustainable (Hurlimann and Dolnicar, 2012). Australian National Climate Centre in one of the report showed the decreasing trend of annual rainfall by up to 50 mm per year over the southern half of the continent (CSIRO, 2007). The Australian National Climate Centre in one report demonstrated the decreasing trend of annual rainfall, which has dropped by up to 50 mm per year over the southern half of the continent (CSIRO, 2007). The populations of Australia's mainland capital cities and the lower Hunter and Gold Coast regions are expected to grow by 35%, or about five million people, by 2030 (ABS, 2005). With the limited water supplies in urban areas coupled with increasing urban population, providing safe, reliable and sustainable water services for Australian cities is a major challenge for the 21st century. Sustainable urban water consumption has thus become a critical issue in Australia.

A commitment to the sustainable use of water through appropriate policies can lead to a more water-secure world. Humans have developed many ways of using water more efficiently—that is, obtaining more from each unit of water. In line with this, recycled water as an alternative source has been recognised all around the world and has become a priority for future sustainability. Persisting and increasing water stress contribute to the increased demands on water utilities to develop urban recycled water. Water recycling has long been recognised as a means of achieving more sustainable water management systems. It is the process by which wastewater, typically from sewage and/or stormwater collection, is treated to a variety of quality levels depending on the intended use and required safety standards. The benefits of using recycled water include protection of water resources, prevention of coastal pollution, recovery of nutrients for agriculture, augmentation of river flow, savings in wastewater treatment, enhanced groundwater recharge, and sustainability of water resource management (Angelakis and Bontoux, 2001). Water recycling is therefore considered to be vital because it alleviates the pressure on existing water supplies and at the same time protects remaining water sources from being polluted. As an important element of water resource development and management, the use of recycled water can help to close the loop between water supply and wastewater disposal. Therefore, water recycling is gaining impetus all over the world. In the Australian context, demands on water utilities to develop water recycling capacity and supply are expected to intensify; nevertheless, suitable clients of the recycled water product are difficult to come by.

Household water consumption accounts for the second largest water usage in Australia after agriculture. A study by Birrell et al. (2005) on the impact of demographic change and urban consolidation on domestic water use in Australian cities revealed that, between 2001–2031, water demand in major Australian cities will increase by an average of 37%. Householders in Sydney (Sydney Water, 2010) and Western Australia (Water Corporation, 2006) make use of 70% of the total supplied drinking quality water. Almost 66% of the total supplied water on the Gold Coast, Australia, was accounted for by residential water consumption in 2007–2008 (Willis et al., 2010). Hence, it is of great importance to reduce the potable water consumption of the residential sector.

Water sensitive urban development (WSUD), which aims to optimise the substitution of non-potable water for potable water, has already come into play. Dual water supply systems are a component of WSUD and have already been put into practice in many cities of Australia. The existing dual reticulation schemes in Australia include Rouse Hill in Sydney, Newington in Sydney, Mawson Lakes in Adelaide, New Haven Village in Adelaide, Aurora in Melbourne, Marriott Waters in Melbourne and Pimpama Coomera in Gold Coast (Mainali et al., 2013a). All the schemes provide class A recycled water for non-potable uses. A significant reduction of 32% in peak potable water demand in dual reticulated supply areas of Pimpama Coomera region was revealed when compared with single reticulated supply areas (Willis et al., 2011). Similarly, Rouse Hill and New Haven Village have been known with savings between 35–50% of potable water (Sydney Water, 2008, Fearnley et al., 2004). In future, there is high probability of supply of recycled water in many Australian communities with dual water supply systems (Larzova et al., 2013; Mainali et al., 2011a).

Currently, the existing end uses of recycled water in dual reticulation systems are confined to irrigation and toilet/urinal flushing or car washing. The United Nations Economic and Social Council enunciated a policy in 1958 that, “No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade”. To this date, laundry makes use of drinking quality water in Australia. Adopting laundry as a new end use of recycled water is a complete innovative thought in all over the world because this has been practised very rarely till today. According to statistics in the New South Wales (NSW) State of the Environment Report (2003) on the typical water usage in Sydney metropolitan households, laundry use requires up to 20% of total water consumption. Water efficiency in terms of washing machines the focus of many regulations which have already achieved significant improvements, including water rating machines and subsidising the cost of the more water efficient machines when they are purchased by the general public (Water Corporation, 2006). Offering an incentive to replace top loading washing machines with front loading washing machines is one strategy implemented to fulfil this aim. In addition to this, today’s persisting and increasing water stress drives the need to look abroad for possibilities that will enable further improvement. Currently, dual reticulation schemes in Australia such as those of the Rouse Hill Development Area (RHDA) and Sydney Olympic Park Authority (SOPA) provide recycled water for outdoor garden use and toilet flushing at a total saving of approximately 35% of potable water use. It is estimated that the addition of washing machines as a new end use of recycled water will increase this value to 45% (Ngo et al., 2009). Therefore, the use of recycled water for washing machines is a practical and viable idea.

1.2 Research objectives

This project aims to devise innovative solutions for sustainable urban water management without compromising the quality of life of the people. The main objective of this study is therefore to assess the feasibility of using recycled water in washing machines to introduce a new end use of recycled water for urban households. The specific objectives are as follows:

- Development of a sustainable approach for urban water by introducing a new end use for recycled water – clothes washing machines;
- Establishment and formulation of appropriate criteria and parameters for recycled water use in washing machines;
- Investigation of the customer acceptance of recycled water use in washing machines and their major concerns regarding this new end use;
- Investigation of effects of recycled water on cloth (fabric) and washing machines and comparative study with tap water; and
- Development of the educational and public information materials regarding this new end use.

1.3 Scope of research

Sustainable urban water consumption has become a critical issue in the developed world due to increasing urbanisation and the effects of climate change. Developed and proposed dual reticulation schemes in many parts of the world, including Australia, demand the substantial replacement of tap water with recycled water to ensure system optimisation and the sustainability of water supplies. Households are the second largest users of water in Australia, and laundry makes use of 20% household water. Hence, replacing drinking quality water with recycled water for laundry use can save a considerable amount of drinking water. Laundry is therefore a potential and appropriate end use of recycled water.

Community acceptance of recycled water use is another critical issue. This research investigates community attitudes regarding the proposed new end use. In addition, the development of educational leaflets targeted at the proposed new end use is carried out. Thus, the scope of this research is without doubt very wide.

1.4 Research approach

The research approach involves the literature review followed by community attitude survey and the experimental investigations. The schematic diagram of the research approach is shown in Figure 1.1.

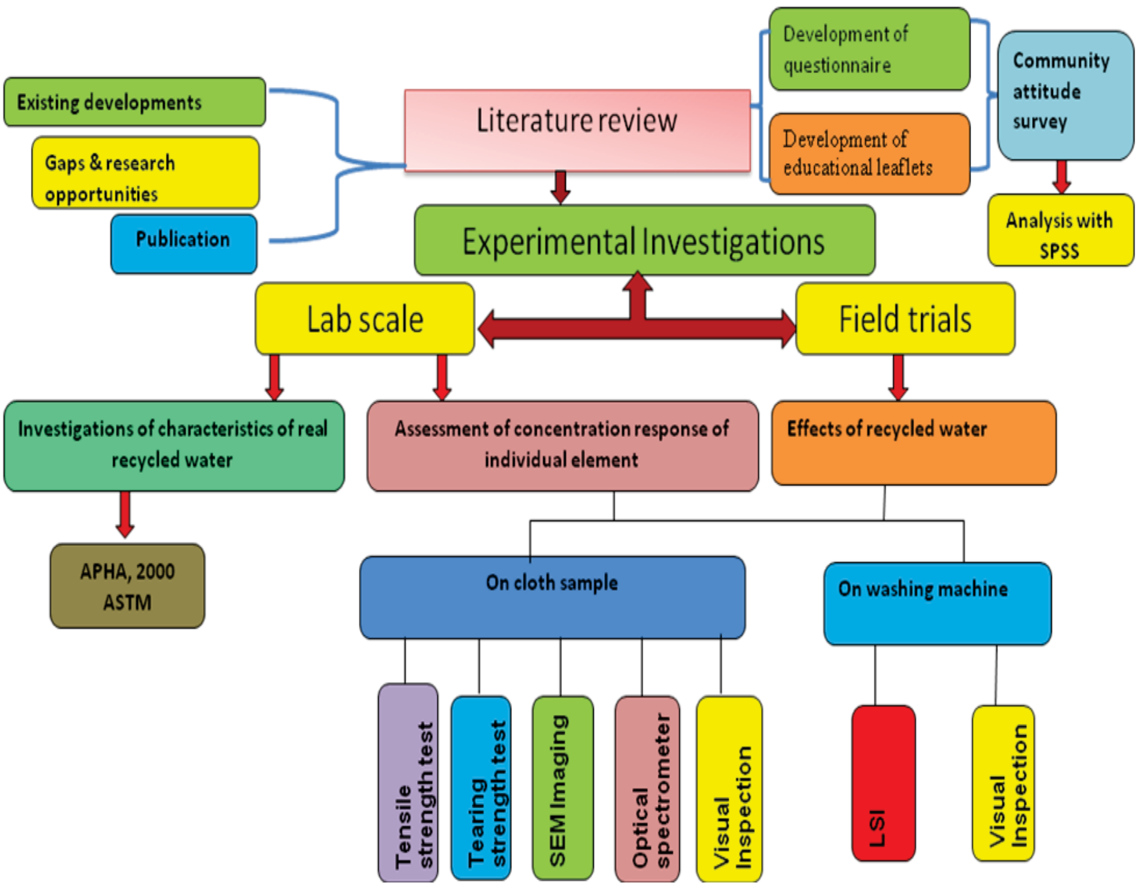

Figure 1.1 Research frameworks.

This thesis comprises eight chapters which are presented in the following manner:

Chapter 1 presents the introduction of the topic that includes the overview of the relevant information of this research. The objectives and research approach are also included in this chapter.

Chapter 2 presents a comprehensive review on the availability of water worldwide and water use, specifically in the context of Australia's water resources. It further presents a review of the literature related to water recycling globally and nationally. The review incorporates the existing end uses of recycled water and the proposed new end use.

Chapter 3 describes the research methodology and presents details of the experimental investigations, establishment of education leaflet and survey methodology.

Chapter 4 continues with the results and analysis of experimental investigations in which the concentration response of various heavy metals on cloth and washing machine is analysed. The chapter concludes by giving the maximum allowable safe values of heavy metals in recycled water for washing clothes in a washing machine.

Chapter 5 presents the results from the on-site experimental investigations of cloth washing with recycled water. This chapter addresses the major concerns of the general public regarding the proposed new end use. The detail study on effects of recycled water on cloth durability, the aesthetic appearance of the cloth, and washing machines, and the microbiological analysis of the cloth samples washed in recycled water are also presented in this chapter.

Chapter 6 presents the importance of educational leaflets in bringing the general public to a state of readiness to accept the use of recycled water in washing machines. This chapter focuses on the design criteria and establishment of educational leaflets on using recycled water in washing machines

Chapter 7 discusses community attitudes towards the use of recycled water. It presents the results of a survey carried out in the community from different parts of Australia regarding the new end use. Basic concerns of the general public about using recycled water in washing machines are presented in this chapter.

Chapter 8 presents the conclusions and recommendations.

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CHAPTER 2

LITERATURE REVIEW

2.1 Current status of water resources of the world

Water is essential to all dimensions of life; however, water has become a scarce resource which faces heavy and unsustainable demand by users of all kinds. In the 20th century, the world population tripled while water use increased six-fold (Cosgrove and Rijsberman, 2000). At present, water resources in several regions of the world are seriously under pressure, and it is anticipated that the situation will worsen during the first half of this century (Cosgrove and Rijsberman 2000). Currently, some 30 countries are considered to be water stressed, of which 20 are absolutely water scarce. It is predicted that by 2020, the number of countries with water scarcity is likely to approach 35 (Rosegrant et al., 2002). A number of literatures with data aggregated at the global or national level have shown that water is less available on the African continent than in Europe, Asia, North America or Latin America. Europe has plenty of water resources compared to other regions of the world; however this position has been challenged in recent decades by growing water stress, both in terms of water scarcity and deterioration in quality. Approximately half the European countries, representing almost 70% of the population, face water stress issues today (Bixio et al., 2006). According to Jiang (2009), the world's most populous country, China, has been facing increasingly severe water scarcity. China's water resource issues have attracted extensive worldwide attention and have been covered by major media outlets such as the New York Times and the Economist. According to a recent survey in China, 60 of 514 rivers ran dry in 2000, while water volume in lakes monitored in the survey fell by 14% (Waterconserve, 2005). With insufficient water resources to meet rising water consumption, over-withdrawal of both surface water and groundwater has occurred in many areas of northern and eastern China, with serious environmental consequences. The huge demands on cities' water supply systems posed by emerging climate change issues, rapid economic growth and increasing population impels the development of new water resources (Miller, 2005), even in countries with high rainfall, such as Japan and England (Tillman et al., 1999; Dixon et al., 1999; Ogoshi et al., 2001; Janosova et al., 2005). Continued lack of attention to persisting water shortage and increasing demands will result in severe water crisis.

Recent evidence and predictions indicate that climate change is accelerating and will lead to wide-ranging shifts in climate variables. Since 1900, the global mean temperature has risen by 0.7 ± 0.2 °C. The temperature increase since the late 1800s may seem small—0.74 °C —but the impact on people is likely to be profound (UNFPA, 2009). Twelve of the previous thirteen years (1995–2007, excluding the year 1996) rank among the warmest in global surface air temperature records since 1850 (Dlugolecki et al., 2009). Despite slight disagreements on the magnitude, timing and spatial distribution of climate change, scientists agree that recent climate change has been much faster than in the past. If greenhouse gas concentrations at today's levels continue to increase in the same pattern, or even if they remain the same, a temperature increase of 0.1°C per decade in the next 20 years is very likely to occur (Jacob et al., 2008). The impact will be even greater as temperatures continue rise by as much as 6.4 °C by 2100 (UNFPA, 2009). With this emerging climate change on one hand and population growth on the other hand, water usage and demand will continue to increase. A 'low variant scenario' of population growth predicts a population of 8 billion by 2050, whereas a 'medium variant scenario' and 'high variant scenario' predict 9.2 billion and 10.5 billion respectively (UNFPA, 2009). These scenarios are cause of considerable concern in regards to the emerging climate change and the increasing water demand.

Another threat to water security is water pollution. Every day, 2 million tons of human wastes are disposed of in water courses. In developing countries, 70% of industrial waste is dumped untreated into waters where they pollute the usable water supply (UN World water report 2003). Projected increases in fertiliser use for food production and in wastewater effluent over the next three decades suggest there will be a 10%–20% global increase in river nitrogen flows to coastal ecosystems (VIMUN, 2009). The potential impact of population growth, climate change and water pollution on water availability will add urgency to the search for the innovative solutions.

2.1.1 Global water availability

There is no 'creation' of 'new' water on the planet. Water is renewable, but finite. The available volume of water is recycled through a well-coordinated system between the earth and the atmosphere, the 'hydrologic cycle'. This means that regardless of a rapidly growing population, the volume of available and accessible freshwater is limited (Simonovic, 2002). The availability of water on Earth appears to be abundant, since 70% of its surface is covered by water, but the real issue is the amount of fresh water available. The global water supply is about 1.4 billion cubic kilometers (Table 2.1), of which almost 97% is saline. Of the total freshwater of about 35 million cubic meters (around 3% of total global water), almost 70% is frozen in the icecaps of Antarctica and Greenland and most of the remainder (about 29%) is present as soil moisture, or lies in deep underground aquifers as groundwater not accessible to human use. Therefore, less than 1% of the world's fresh water (~0.007% of all water on earth) is accessible for direct human use. This is the water found in lakes, rivers, reservoirs and accessible underground sources.

The most abundant and readily available source of fresh water is groundwater, followed by lakes, reservoirs, rivers, and wetlands. High levels of exploitation of groundwater, with extraction rates often more than 50% of the rate of recharge, are experienced in many countries in the Middle East, Africa, Asia, and Europe (UN WATER/WWAP, 2006). Surface-water sources (such as rivers) only constitute about 93,100 (km^3) cubic kilometers (Shiklomanov, 1993). Only this amount is regularly renewed by rain and snowfall and therefore available on a sustainable basis. Worldwide, hundreds of big and small rivers are found, of which 20 rivers have catchment areas between 3 million to 1 million $km^{2,}$ and 89 rivers have basin areas from 1 million km^2 to 100,000 km^2. Globally, about 15 million lakes are found and their total water surface area is about 2 million km^2 (Shiklomanov and Rodda, 2003). There are 88 large lakes with a water surface area exceeding 1000 km^2, four of which are in Australia. Shiklomanov and Rodda (2003) further note that there are about 2500 reservoirs with a capacity greater than 100 million $m^{3,}$ which is about 90% of the volume and area of all the world's reservoirs. There are approximately 30,000 reservoirs globally that have a volume greater than 1 million m^3. Precipitation is the main source of water for all. As cited by UNEP (2007), an annual average of 110,000 km^3 of rain falls on the earth. About one-third of this (the blue water) reaches rivers, lakes and aquifers, of which only about 12,000 km^3 is considered to be readily available for human use. The remaining two-thirds (green water) form soil moisture or return to the atmosphere as evaporation from wet soil and transpiration by plants (SIWI et al., 2005).

Flow regulation in river systems by impoundment is a global phenomenon of staggering proportions (Postel and Richter, 2003). Among the world's 272 largest rivers, 60% are moderately to greatly fragmented by dams, diversions and canals, with a high rate of dam construction threatening the integrity of the remaining free-flowing rivers in the developing world (Nilsson et al., 2005). There are more than 44,000 large dams spread across 140 countries of the world, about two-thirds of which are in the developing world; nearly half of them are in China (WCD, 2000). These dams, with an estimated capacity of more than 6500 km^3, impound about 15% of global run-off (Nilsson et al., 2005).

The natural water cycle on planet Earth yields an annual renewable water supply of about 7000 m^3 per capita (Shiklomanov, 2000), indicating that there is enough freshwater available every year to fulfil the needs of the present population of this planet. However, most of the freshwater available is concentrated in specific regions resulting in certain regions and countries having an annual renewable supply of water less than 500m^3 per capita (Pimentel et al., 1999; Rijsberman, 2006). According to Qadir et al. (2007), the Middle East and North African regions, and several other countries, ran out of renewable freshwater decades ago, in the sense that these regions are unable to meet their food requirements using the available water resources. Global water resources are under stress as a result of huge abstractions from water sources. Excessive withdrawal of both surface water and groundwater leads to the continuing decline of available water resources.

Decreased water run-off resulting from reduced precipitation and increased evaporation attributed to global warming are other root causes for this. Withdrawals from the world's rivers, lakes and aquifers are surpassing the rate at which nature can replenish them (Shah et al., 2006). By 2025, water withdrawals are predicted to increase by 50% in developing countries, and 18% in developed countries (UNEP, 2007). Rosegrant and Cai (2002) estimated that under their baseline scenario, total global water withdrawals for agricultural, domestic and industrial use will increase by 23% from 1995 to 2025. Major rivers, such as the Yellow, Ganges, and Colorado, do not flow to the sea for much of the year because of upstream withdrawals (Richter et al., 2003). Water resources, in terms of water pollution, have been facing many serious problems and hence are being reduced (Abuzeid, 1998). Most water bodies are now heavily polluted with domestic sewage, industrial effluent, chemicals, and solid waste (UNEP, 2002; UNESCAP, 2005a). The potential direct and indirect impacts of global warming on water resources are to be given special attention as the major reason for water instabilities (Fujihara et al., 2008).

Table 2.1 One estimate of global water distribution (Shiklomanov, 1993)

Water source	Distribution Area (10^3 km^2)	Water volume, (10^3 km^3)	Percentage of Total water	Percentage of Fresh water
Total water	510,000	1,386,000	100	
Total freshwater	149,000	35,000	2.53	100
Oceans, Seas, & Bays	361,300	1,340,000	96.5	
Ice caps, Glaciers, & Permanent Snow	16,230	24,065	1.74	68.7
Antarctic glaciers	13,980	21,600	1.56	61.7
Greenland glaciers	1,800	2,340	0.17	6.7
Arctic glaciers	226	84	0.006	0.24
Mountain glaciers	224	40.6	0.003	0.12
Groundwater		23,500	1.76	
Fresh		10,500	0.76	30
Saline		13,000	1	
Soil Moisture	16 501 832	16,500	0.05	0.001
Ground Ice & Permafrost	21,000	300,	0.022	0.86
Lakes	2,062	176.4	0.013	0.26
Fresh	1,240	91	0.007	0.26
Saline	822	85.4	0.006	
Atmosphere		12.9	0.001	0.04
Swamp Water (Wetlands)	2,680	11.5	0.0008	0.03
Rivers		2.12	0.0002	0.006
Biological Water		1.12	0.0001	0.003
Total		1,386,000	100	

Data on global water availability and demand are cause of significant concern. Global International Waters Assessment (GIWA) has assessed freshwater shortage as being moderate or severe in more than half the regions studied in the assessment (UNEP–GIWA, 2006). Some of the most densely populated regions of the world, such as the Mediterranean, the Middle East, India, China and Pakistan, are predicted to face severe water shortages in the coming decades (Postel and Wolf, 2001; Hanjra and Quershi, 2010). Areas in the southwest United States of America (US), as well as some parts of the midwest, and many parts of Australia are vulnerable to water shortages. By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be living under conditions of water stress (Seckler et al., 1999b; UN Water, 2007; UNEP, 2007; IWMI). Another 20% more water will be needed to feed the additional three billion people by 2025 (Seckler et al., 1999a). Moreover the world's primary water supply will need to increase by 41% to meet the needs of all sectors which can be largely attributed to the increase in the world population (Urkiaga et al., 2008). Access to water as an independent human right was recognised in 2002 (UN, 2002; Chenoweth, 2008). The UN has stated that the absolute minimum water needs are 50 L per person per day—5 L for drinking, 20 L for sanitation and hygiene, 15 L for bathing, and 10 L for food preparation. However, people living in 40 of the world's most water-famished countries currently survive on 7·5 L per day for all their water needs.

2.1.2 Global water use

Global demand for water has tripled since the 1950s, but the supply of fresh water has been declining (Gleick, 2003). According to one report (UNESCO, 2009), the world's population is growing by about 80 million people a year, implying an increased freshwater demand of about 64 billion cubic metres a year. It is further estimated that the population will grow from 6.9 billion in 2010 to 8.3 billion in 2030 and to 9.1 billion in 2050, thereby creating more water demand. The use of water varies greatly from country to country and from region to region. The foremost demands for fresh water in today's world are for irrigation, household and municipal water use, and industrial use. The majority of the supply comes from surface runoff, although the withdrawal of 'fossil water' from underground aquifers is an important source in some areas. The pattern of water extraction over the past 300 years shows the spectacular increases in this century.

Irrigated agriculture is the main source of water withdrawals, accounting for around 70% of all the world's freshwater withdrawals from rivers, lakes, and underground aquifers (Rosegrant et al., 2009). In Asia, agriculture accounts for about 86% of total annual water withdrawal, while in North and Central America this represents some

49%, and in Europe some 38% (Global change, 2000). The average consumptive rate in 2025 is predicted to be 71% (Shiklomanov, 2000). An enormous amount of water use is non-consumptive, which means that the water is returned to surface runoff. It is estimated that almost 22% of worldwide water use is industrial (WBSCD, 2005). Major industrial users include power plants, which use water for cooling or as a power source (i.e. hydroelectric plants), ore and oil refineries, which use water in chemical processes, and manufacturing plants, which use water as a solvent. It is estimated that 8% of water use worldwide is for household purposes (WBSCD, 2005). These include drinking water, bathing, cooking, sanitation, and gardening. Basic household water requirements have been estimated by Peter Gleick at around 50 litres per person per day, excluding water for gardens. Recreational water use is usually a very small but growing percentage of total water use. In 1995 the world withdrew 3,906 km^3 of water for all these purposes. By 2025, water withdrawal for most uses (domestic, industrial, and livestock) is projected to increase by at least 50% (Rosegrant et al., 2002).

About one-third of the world's population lives in countries that are experiencing water stress. In Asia, where water has always been regarded as an abundant resource, per capita availability declined by 40%–60% between 1955 and 1990. Projections suggest that most Asian countries will have severe water problems by the year 2025 (Global change, 2000). Most of Africa historically has been water-poor.

2.1.3 Water availability and use in Australia

Australia is the driest inhabited continent on earth (Australian Bureau of Meteorology, 2007) with an area of 7,615,000 km^2 and is located in the southern hemisphere between 10 $^{\circ}$S and ~45 $^{\circ}$S and between 113 $^{\circ}$E and 153 $^{\circ}$E. Australia has 5% of the earth's land area, but it contributes less than 1% (387,184 GL) to global runoff each year (CRC, 2006; Lake and Bond, 2007). It has the least rainfall of all continents excluding Antarctica. Figure 2.1 shows Australia's position in terms of annual rainfall and river discharge.

Australia's rainfall and river flow have always been naturally variable and could become more variable, especially in southern Australia, as a result of changes in climate and seasonal river flows (Thresher et al., 2004; Beeton et al., 2006). On average, only 12% of Australia's rainfall runoff recharges the groundwater and most of this rainfall is in the sparsely populated northern region (Figure 2.2). Two-thirds of the country's population live in the five capital cities of Sydney, Melbourne, Brisbane, Adelaide, Canberra, and Perth, and household water use is responsible for the second largest water usage (ABS, 2006). The cities in Australia are continuing to grow and the increasing demand for water is causing concern.

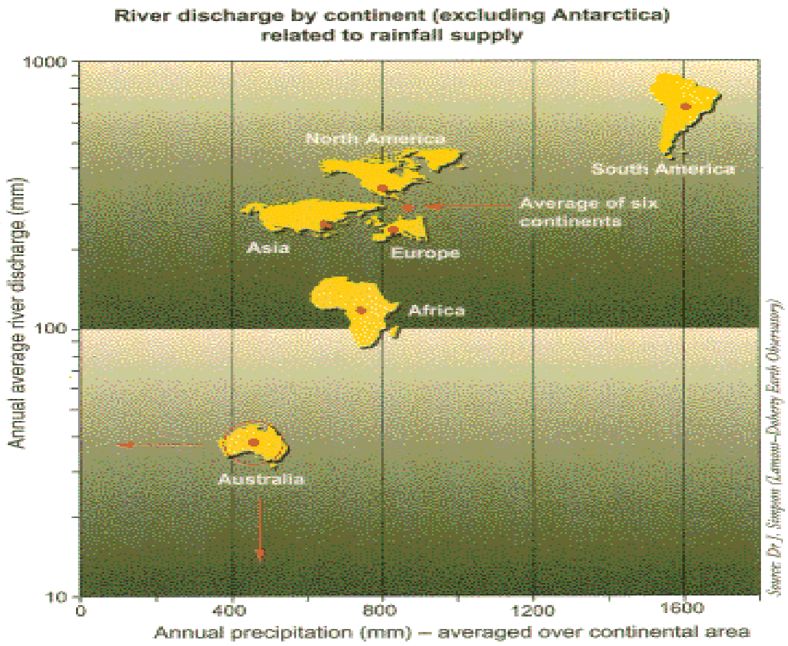

Figure 2.1 Annual rainfall and river discharge globally (adapted from Melbourne Water, 2006).

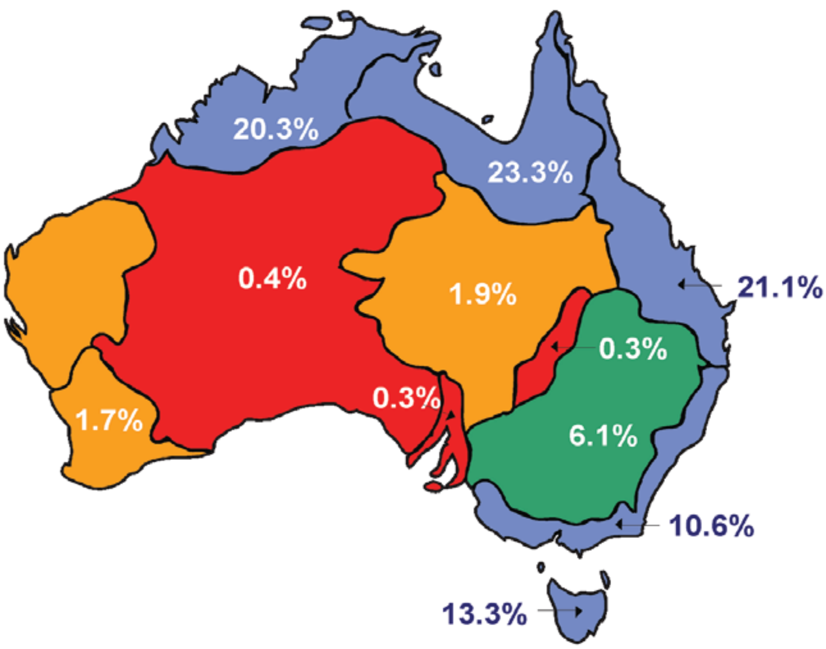

Figure 2.2 Australia's distribution of run-off (adapted from Chartrers and Williams, 2006)

Australia, being a dry country, has a sparse network of rivers and lakes. According to the Australian Bureau of Statistics (ABS) (ABS, 1996; SoE, 2011), there are 12 drainage divisions with 245 river basins in the Australian continent, and most of them are relatively short and coastal or seasonal. In Australia, the runoff is only 5-10mm/year which is very small. The largest runoff of about 1500mm/year occurs in basins along the Great Diving Range, Liverpool Ridge, the Blue Mountains and the Snowy Mountains. The Burdekin, Fitzroy, Herbert, Clarence and Snowy are short rapid rivers which are mostly rain fed and flow to the Pacific Ocean. The Burdekin and Fitzroy are rivers with large mean annual flow of $300m^3/s$ and $182m^3/s$ respectively (Shiklomanov and Rodda, 2003). These rivers have the highest flows and originate in the mountains of Queensland (QLD).

The Murray–Darling is the largest river system in Australia. The Murray–Darling has an average flow of $24km^3$/year but the discharge at the mouth is only $10km^3$/year because its water is intensively used for irrigation (Shiklomanov and Rodda, 2003). More than 80% of Australia's irrigation is located in the Murray–Darling Basin (Lake and Bond, 2007). About 50% of rainfall runoff in Australia does not reach the oceans (Shiklomanov and Rodda, 2003) as a result of dry weather circumstances causing evaporation and transpiration. These conditions, along with extensive water usage for agriculture, make water availability very low, thus the runoff reaching the oceans is limited.

Over a quarter of Australia's river systems have almost exceeded sustainable extraction limits, and two-thirds of water extracted is from these stressed systems (Healey, 2003). A National Land and Water Resources Audit (NWRA) conducted by Australian government during 1997-2008 found that more than 26% of rivers, streams and creeks (surface water) had too much water extracted from them, while about 34% of Australia's groundwater was also being overused (Healey, 2003; Radcliffe, 2004). The major inland groundwater systems in NSW, which represent approximately 80% of the total groundwater extraction in NSW, have already been over-extracted since 2001. According to PMSEIC (2003), many of Australia's largest cities were then experiencing moderate water restrictions as a consequence of the continuous seven years' drought during that period. The situation in Western Australia was particularly severe, with Perth water supply catchments yielding 50% less water than in the years before the mid-1970s, as a result of changes to rainfall as well as revegetation of the catchment (Beeton et al., 2006). This city is largely dependent on groundwater supplies but has experienced a steady decline in aquifer levels due to changes in rainfall patterns and a growing forestry industry (Yesertener, 2005).

The water sources available to Australian cities basically comprise of groundwater, surface water reservoirs, and direct river extractions, as observed from the history. According to NLWRA (2001), of the total annual water extracted, almost 70% is supplied by rivers, 21% is groundwater extraction and 9% is harvesting of overland flows. While groundwater supplies only a relatively small percentage of the total use, extractions have increased dramatically in the last two decades by some 88% overall, but more than 200% in some high-use areas such as QLD, which is now the largest net user of groundwater (NLWRA, 2001; Lake and Bond, 2007). However, extractions are now being increasingly restricted as a result of environmental concerns as well as severe drought conditions between 2001 and 2003, and again from 2006 to the present (Hughes, 2009). Nevertheless, PMSEIC (2007) advocates that high level restrictions are not an option going forward as they impose substantial costs on the community: ongoing harsh restrictions are recognised as a failure of planning.

There are also concerns that climate change will reduce the amount of rainfall on the catchments of southern Australia. Studies by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) have suggested that Melbourne's annual average rainfall may decrease by up to 5% by 2020 and up to 13% by 2050. In the last quarter of last century, a 14% decline in Perth's rainfall reduced its water supply by three times this amount – 52%. A small decline in rainfall can make a very big difference to the amount of water available for consumption. Perth has already experienced a dramatic drop in rainfall and a bigger drop in runoff from the catchments, and some experts believe the East coast will experience a similar shift. The observations from the past few decades and the predictions of various climate models show that runoff into the major dams serving Australian cities will decrease (PMSEIC, 2007).

The Cooperative Research Centre (CRC, 2002) states that in Australia only 12% of the annual rainfall runoff recharges the groundwater, the remaining runoff is returned to the atmosphere directly by evaporation or by vegetation through the process of transpiration. The estimated average annual rainfall is 472 millilitres. Table 2.2 shows the average rainfall in major Australian cities.

Table 2.2 Average annual rainfall in cities of Australia (adapted from CRC, 2006).

City	Average annual rainfall (mm)
Alice Springs	270
Adelaide	500
Hobart	520
Canberra	630
Melbourne	660
Perth	790
Brisbane	1180
Sydney	1220
Darwin	1690

Table 2.3 represent the details of the various natural water resources of Australia. Most of the lakes in Australia are shallow salty lakes. Lake Eyre and Lake Amadeus are the largest with no exit to the sea, and both dry out during hot seasons. Australia has a huge groundwater resource from the aquifers that cover about one-third of the Australian continent. The only reliable and permanent water supply for much of the arid outback is the Great Artesian Basin, which is the largest groundwater reserve in the world and underlies 22% of the Australian continent (Pigram, 1986; Shiklomanov and Rodda, 2003). The Murray Artesian Basin follows the topography of the Murray River and is recharged by the same.

Table 2.3 Major Natural Water Resources of Australia (adapted from Shiklomanov and Rodda, 2003).

River	Name	Drainage Area, km^2 x 10^3
	Murray	1072
	Fitzroy	143
	Diamantina	115
	Flinders	108
	Gascoyne	79
	Victoria	77.5
	Burnett	33.4
	Hunter	22
	Warren	9.6
	Derwent	4.3
Lake	**Name**	**Area, km^2**
	Eyre *	to 15,000
*** Salt Lake**	Amadeus *	8,000
	Torrens *	5,800
	Gairdner *	4,780
	George	145
Aquifers	**Name**	**Area, thousand km^2**
	Great Artesian Basin	1751
	Desert	388
	Murray	282
	Eucla	191
	North Western	77.5
	Perth – Coastal area	54
	Ord - Victoria	31

There are five major artesian basins in Western Australia. Rivers supply approximately 70% of the water used in Australia, followed by artesian basins which supply 21%, with the remaining 9% being supplied by rain water harvesting. Surface water usage is the most common in all States and Territories except Western Australia and the Northern Territory. A mere 4% of the total water consumed in Australia is recycled (Dolnicar and Saunders, 2006). In the years 2000–01 and 2004–05, the use of recycled water represented just under 4% of the total water supplied by water providers, and in 1996–97, it was only 1%.

Australians are profligate users of water. The per capita water use in Australia is among the highest in the world at approximately 100 ML/year, despite the fact that Australia is the second driest inhabited continent (Smith, 1998; Melbourne Water, 2006). New Zealand, Canada and the United States are the only nations ahead of Australia in terms of water use. Water Account Australia (ABS, 2010) showed that during 2009–10, 64,076 GL of water was extracted from the environment and used within the Australian economy reflecting a 7% increase on the 59,839 GL extracted during 2008–09 and a 19% decrease on 79,784 GL extracted during 2004-05. Water providers extracted 9,405 GL, which was a 3% decrease on the 9,673 GL extracted during 2008–09 and a 17% decrease on 11,337 GL extracted during 2004–05. Water-using industries (mainly the agriculture industry and hydro-electricity generation) extracted 54,959 GL, which was a 9% increase on the 50,166 GL directly extracted in 2008–09 and a 19% decrease on the 68,447 GL directly extracted during 2004–05).

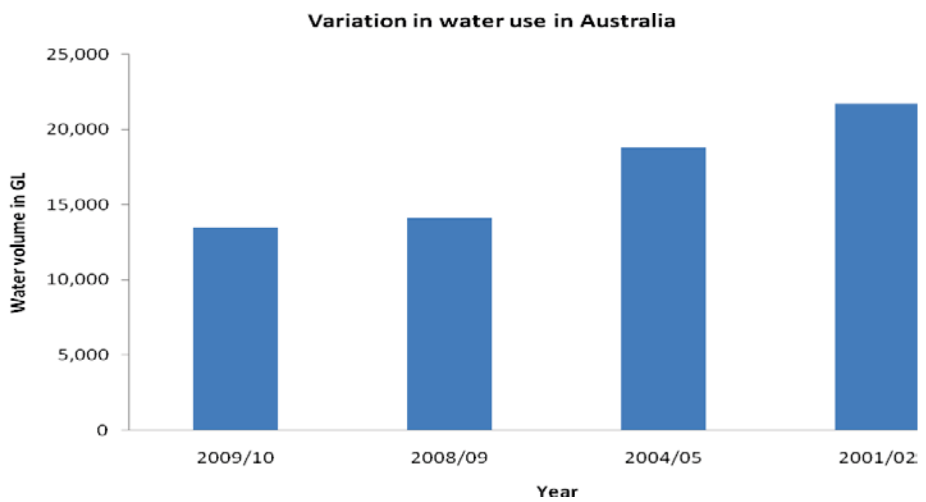

Figure 2.3 Variation in water use in Australia.

Water consumption by all industries and households in Australia was 13,476 GL in 2009–10, from 14,101 GL in 2008–09, 18,767 GL in 2004-–05, and 21,703 GL in 2001–02, a decrease of 4%, 28% and 37% respectively (Figure 2.3). This continuous decrease can be attributed to the restricted supplies resulting from the continuous extended drought in Australia, improvements brought about as supply side management, and behavioural change in water use. In 2009–10, the agriculture industry consumed the largest volume of water at 6,987 GL, representing 52% of Australia's water consumption in that period. Households accounted for a further 14% of consumption (

Figure **2.4**)

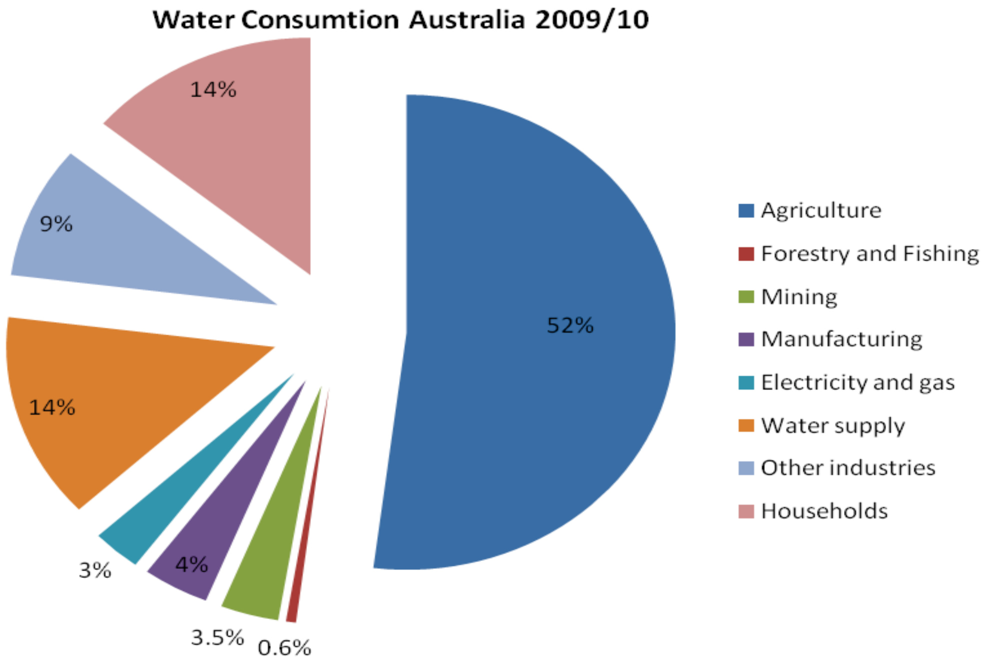

Figure 2.4 Pattern of use of Australian's water resources.

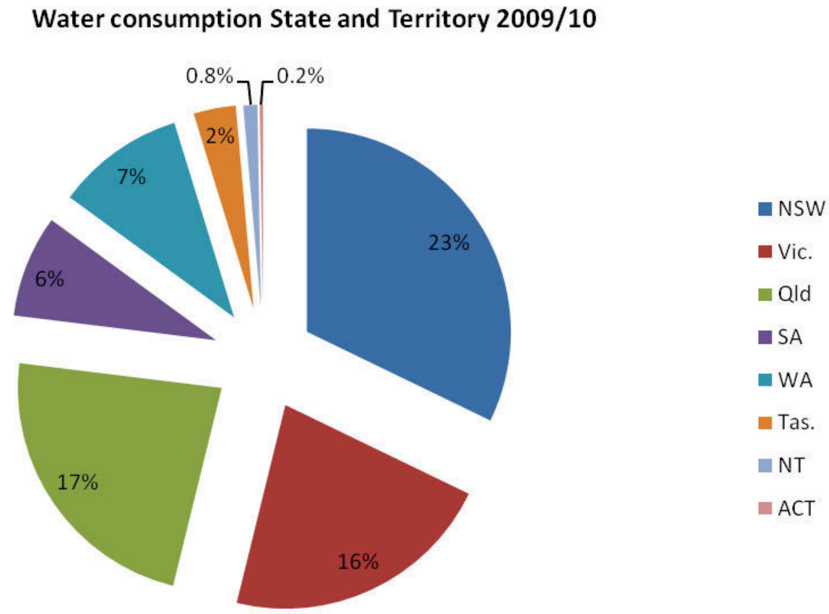

Figure 2.5 Water consumption state and territory 2009/10.

The highest levels of total water usage occur in New South Wales, Victoria and Queensland, which collectively account for almost more than 50% of all water used in Australia in the year 2009–10 (Figure 2.5). This is a significant change from 1996–97, when these states accounted for almost 90% of total usage (Lake and Bond, 2007).

2.2 Current solutions to the problems of water scarcity

The growing population and the accelerating urbanisation leads to the development of demand for increased allocations of fresh water for the domestic, agriculture and industrial sectors resulting into the high pressure on water resources. In addition to this, the climate change which is altering the precipitation and the whole ecosystem is more likely to have threats to the existing water resources. FAO advocates that both the phenomenon lead to tensions, conflicts among users, and excessive pressure on the environment. The increasing stress on freshwater resources brought about by ever rising demand and profligate use, climate change, as well as by pollution worldwide, is of serious concern.

The amount of freshwater available to mankind and nature is limited. Only saltwater resources are abundantly available, but even the quality of these resources is under stress as well. The water demand and the use has been growing at more than twice the rate of population increase in the last century, and, although there is no global water scarcity as such, an increasing number of regions are chronically short of water. It is estimated that by 2025, 1800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions (UN Water and FAO, 2007). The situation will be worsened as rapidly growing urban areas place heavy pressure on neighbouring water resources.

Addressing water scarcity requires actions at local, national and river basin levels. It also calls for actions at global and international levels, leading to increased collaboration between nations on shared management of water resources (rivers, lakes and aquifers), it requires an intersectoral and multidisciplinary approach to managing water resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

2.2.1 Water resources management

The emergence of a global water crisis has highlighted the need for a sustainable approach to water management (Hurlimann, 2007). Since water is fundamental for life without substitution, absolute limits on water are troubling and of serious concern. This limited water availability could lead to national food crisis, yet with a positive approach, the same condition could lead to more efficient use of water, reductions in fresh water demand, substitutions by alternative water sources, increases in the resource productivity of water, and better management of available water resources, leading to the efficient water resources management of that region.

Because it has a key role in sustainable development, water management requires an integrated approach. Integrated water resources management (IWRM) has been gaining momentum in recent years. Water professionals increasingly promote the concept of IWRM, since it is the only approach capable of balancing the growing demand for a limited resource. The IWRM approach takes a holistic view of the catchment by adopting a multi-sectoral approach to all resources – soil, water, biomass, energy –at the same time taking into account both human and environmental needs. Its main concerns are water resources development for rural water supply, including small scale irrigation, and the protection of available water resources against overuse and pollution.

With increasing urbanisation and water stress, urban water management is a crucial challenge for water professionals. Traditional urban water management systems are not very well equipped to address future challenges (Butler and Maksimovic, 1999; Brown et al., 2009). In this regard, many water professionals and researchers increasingly promote the concept of more sustainable urban water management (Butler and Maksimovic, 1999; Maksimovic and Tejada-Guibert, 2001; Newman, 2001; Tjandraatmadja et al., 2005; Brandes and Kriwoken, 2006; Pahl-Wostl, 2007; Wong and Brown, 2008; Brown et al., 2009), which is commonly referred to in Australia as total water cycle management (TWCM). A TWCM approach involves making the most appropriate use of water from all stages of the water cycle (such as rainwater, natural catchment water, groundwater, wastewater, stormwater and seawater) to best deliver social, ecological and economic sustainability (Brisbane City Council, 2007). Despite policy rhetoric supporting TWCM and the diverse water supply approach, there are many social and institutional barriers to effective implementation (Brown et al., 2009). Brown et al. (2009) revealed from their study that a large number of practitioners working in the urban water sector in Australia support the introduction of diverse water source options in a fit-for-purpose context; however, there is a critical lag between best practice sustainable urban water management thinking and current practice, as the practitioner community struggles to develop the requisite association and acquisition to support the effective implementation of diverse water source technologies.

In today’s 21st century world where every drop counts, water management requires two comprehensive strategies: efficient water use and the development of alternative sources of water, i.e. combining demand and supply side management initiatives. On one hand, demand management is essential to conserve every drop of water while on the other, emerging population growth and changing climate will inevitably result in the need for additional supply. Peter Gleick and others coined the concept of a “soft path for water” (Gleick et al., 2009) which incorporates both demand and supply side management for water. A ‘soft path’ is a comprehensive approach for water management, planning and use that emphasises the optimisation of end-use efficiency, small-scale management systems and the incorporation of fit-for-purpose water use (Pinkham, 2004; Fane, 2005). A key characteristic of this new way of water management would be the use of diverse, locally appropriate and commonly decentralised infrastructure. Local reuse schemes for wastewater, and where appropriate for stormwater, forms an important supply option in this ‘soft path’ approach (Fane, 2005). Consequently, considerable must be given to urban development patterns and decentralised technologies, including rainwater harvesting and wastewater reuse.

Worldwide agriculture accounts for almost two-thirds of freshwater consumption. According to Förch (2009), efficiency is often far below 50% (principally in the developing countries), mainly due to conveyance losses in inefficient irrigation systems. Förch (2009) further advocates that more than 50% of all piped water is wasted as a result of leaking pipes. The water demand worldwide will continue to increase, and the provision of high quality drinking water will require treatment that is dependent on the source as well as on the effective demand of end-users. Only 20% of the potable water used in industrialised countries is required for drinking, food preparation and hygiene purposes; the rest is consumed in activities for which a lower quality would suffice. The substitution of that amount of fresh water with water from alternative sources could greatly enhance the accessibility of freshwater; the significance of water recycling in addressing current water scarcity in major cities of the world must therefore not be underestimated, noting particularly that different cities have varying quality and quantity requirements, according to purpose.

After use, the wastewater generated also varies in quality and quantity. Careful linking of the wastewater source with appropriate water demand at a local level, while giving due consideration to quality and quantity, could provide a sustainable source of water for our cities (Hermanowicz et al., 1999). Analysis of a number of water reuse projects in Europe has concluded that a major benefit of water recycling is the production of alternative water resources “near the point of use” (Lazarova et al., 2006).

In Australia, given that only 15% of water used in urban areas is for potable purposes, the potential for non-potable water recycling in urban areas is extremely high, and potable water reuse is being discussed as being critical to fully utilise recycled water as a viable water supply option (WSAA, 2006; NWC, 2007). The absence of potable reuse would mean that uses for recycled water in our major cities would be limited to about 28% of the total water used, which represents the total non-household consumption (industry, commercial, and local government) (WSAA, 2006). However, it should not be perceived as a drawback of non-potable reuse, because in fact, 28% of the total water use in major cities constitutes a very significant amount.

Social research indicates that a majority of people like the idea of using recycled water in general, but a much smaller number of people support the idea of its use in their drinking water supplies. People are more comfortable with recycled water being used outside their homes, rather than in their drinking water (NWC, 2007). The overwhelming support for non-potable reuse projects shown by communities across Australia provides a window of opportunity to build a higher level of familiarity and trust in reuse, which is crucial to the introduction of any new end use of recycled water.

2.2.2 Water recycling

Water has now become a scarce resource, but a commitment to the sustainable use of water, through the implementation of appropriate policies, will lead to a more water-secure world. Humans have developed many ways of using water more efficiently—that is, obtaining more from each unit of water. Water recycling is therefore considered to be one of the most important and common components of water resource planning. In the past, the driving motivation for water reuse was to provide a means of avoiding effluent disposal into surface waters. With increased water demand, coupled with periods of continuous drought, water recycling is perceived as providing an important alternative source of water. Non-potable and potable use of reclaimed water can enable communities to maximise and extend the use of limited water resources, which will help to alleviate the pressure on existing water supplies while also protecting remaining water sources from becoming polluted. The benefits of using recycled water include protection of water resources, prevention of coastal pollution, recovery of nutrients for agriculture, augmentation of river flow, savings in wastewater treatment, enhancement of groundwater recharge, and sustainability of water resource management (Angelakis and Bontoux, 2001). Hence, recycling urban wastewater has been recognised as a key aspect of sustainable water policy and an important alternative water source. It is a promising innovation in urban water management that can increase the sustainability of urban water systems (Bahri, 2009) and is being developed around the world. After reviewing many water recycling projects, Radcliffe (2004) concluded that water recycling is gaining impetus all over the world as one of the most important components of water resource planning, not least because of the increased costs of wastewater disposal and declining opportunities for conventional water supply development.

Through the natural water cycle, the earth has recycled and reused water for millions of years. Water recycling generally refers to projects that use technology to speed up these natural processes, and can include recycling of wastewater from previous uses. This is generally defined as a collection of practices that occur at varying scales ranging from the reuse of treated municipal effluent to the beneficial reuse of stormwater, greywater, and industrial wastewaters for a range of purposes (CSIRO, 2002; Burkhard et al., 2000). Recycled water goes through a number of treatments depending upon the purpose of the end-use. The higher the degree of contact with the human body, higher is the level of treatment required. As long ago as 1958, the UN economic and social council stated that "No higher quality water unless there is surplus of it should be used for a purpose that can tolerate a lower grade", pointing to the need to use recycled water (Okun, 1996). The use of recycled water will contribute to sustained economic development, thereby creating a sustainable water future.

A. Global water recycling

In the past 20 years, significant development in water reuse schemes all over the world has been observed which can be attributed to persisting and increasing water shortage problems as well as new environmental policies and regulations. Many water reuse schemes have been successfully implemented and direct and indirect potable reuse projects have been accomplished in many different countries, such as Singapore, Israel, Namibia, the US, Australia and many European countries. The global water crisis has led to the consideration of water recycling as a useful component of sustainable water management in many parts of the world, and it has been developed as part of sustainable urban water systems in a number of countries. The scope and purpose of these projects vary according to the country's geography and climate, which often determine the degree to which a particular recycled water use is feasible and useful (Angelakis et al., 2003). In many regions of the world, water recycling is becoming increasingly necessary as an alternative supply of water and as an investment in drought-proofing an area (Okun, 2002). The US and Saudi Arabia rank highest as countries associated with total treated wastewater reuse, while Qatar, Israel and Kuwait are the most noteworthy countries when per capita water reuse is considered (Jimenez and Asano, 2008).

The application of recycled water is still predominantly limited to irrigation and industrial purposes. However, growing urbanised populations and fewer opportunities for the development of new water sources have spurred a variety of measures all over the world to conserve and reuse water over the last three decades. As part of this worldwide trend, a small but increasing number of municipalities is considering augmenting the general water supply (potable and non-potable) with highly treated municipal wastewater, and indeed, direct potable reuse is already occurring in some areas. In Windhoek, Namibia, 25% of the municipality's drinking water supply has consisted of treated wastewater since 1968 (Law, 2005). In Singapore, recycled water constitutes approximately 3% of the municipal supply (Seah et al., 2003).

The term 'indirect potable reuse' (IPR) describes the situation where recycled water replenishes the source of drinking water from either groundwater basins or surface water reservoirs (Dimitriadis, 2005). Such systems were first used more than 40 years ago in California whereas the first direct potable reuse (DPR) was introduced in Windhoek, Namibia in 1968 (Po et al., 2003; Marks, 2006). Other states with demonstration or full-scale IPR projects include Arizona, Colorado, Texas (Fred Harvey Water Reclamation Facility located in El Paso), North Virginia (the Upper Occoquan Sewerage Authority Water Recycling Project in) and Florida (Po et al. 2003). In California, Water Factory 21 in the Orange County Water District is the oldest project, with a production capacity of 19 megalitres per day (ML/day). Water Factory 21 was closed in 2004 and the upgraded groundwater replenishment system plant was completed in 2007. In Wulpen, Belgium, IPR is being effected by recharging the groundwater basin with purified water (Rodriguez et al., 2009).

When wastewater is treated and discharged into a river or other water body which is later drawn upon by communities for potable supply, it is referred to as 'unplanned' because the history of the water is not acknowledged in treatment processes, and the communities involved are largely unaware of the source of their water. Unplanned potable recycled water use occurs in numerous parts of the world, including Australia. Examples include the Murray and Hawkesbury Rivers in Australia, and the Thames River in southern England. Numerous cities in Europe rely on unplanned IPR for approximately 70% of their potable water during dry conditions (Durham et al., 2005). In many developing countries, untreated sewage is directly discharged into rivers. According to information provided by UNDP (2008), around 90% of sewage is discharged untreated into rivers in the developing world as a whole.

Non-potable reuse of water has become a common practice, with more than 3300 non-potable water reuse projects registered worldwide in 2005 (Bixio et al., 2005). It is defined as the use of fit for purpose reclaimed water treated for a range of uses that do not require water of drinking quality standard.

B. Water recycling in Australia

Concerned authorities and surveys conducted throughout Australia (Melbourne Water, 1998; Sydney Water, 1999; Water Corporation of WA, 2003; Kaercher et al., 2003) consistently claim that water reuse is one of the most supported sources of water supply and is considered by the community to be responsible long term planning. The Federal Government of Australia has made water recycling a priority for future sustainability and is one of four governments worldwide that have regulations for water recycling, having developed recycled water for a variety of purposes (Angelakis et al., 2003; Radcliffe, 2006). Policy direction and impetus for water recycling was founded primarily in the Council of Australian Governments (COAG) Water Reform of 1994. More recently, water recycling policy has been directly implemented through the National Water Initiative, an intergovernmental agreement which aims to encourage water conservation in cities through better use of stormwater and recycled water (COAG, 2004, Radcliffe, 2006). Recycled water has become an integral part of Australia's water resources. If guidelines are followed and recycled water is used for the purpose intended, risks to human and environmental health are insignificant, but the benefits are significant. The driving force for the recycling of water was formerly environment protection, whereas since the year 2000, following the widespread drought in 2001–2003 and the recognition that water catchment volumes in cities were reducing, the driver for recycling water has become the conservation of fresh water. Various factors such as drought that is possibly attributable to climate change, increased population that leads to the increased urbanisation of Australian cities hence increased water demands, increased agriculture and industrial water demands, the need for fresh water conservation for potable purposes, existing and developing advanced wastewater treatment processes, and more have been cited as driving forces behind the introduction of water reuse in Australia (Stenekes et al., 2001; Higgins et al., 2002; Po et al., 2003; Radcliffe, 2006). Assuming current population projections for 2031 are correct, demand for domestic water supply is expected to increase in the order of 33%–58%, based on future development scenarios across major cities Sydney, Melbourne, Perth and Brisbane respectively (Birrell et al., 2005).

As mentioned previously, many social research reviews indicate wide support for using recycled water, but a smaller number of people support the idea of using recycled water for potable purposes. During the financial year 2000–01, recycled water use accounted for less than 4% of Australia's total water use and was predominantly for agriculture and industry (ABS, 2004). Figures from the ABS show that between 2004 and 2011, the total recycled water use of the country had not been able to exceed this value (ABS, 2010–11). In 2010–11, NSW consumed approximately 161 GL of recycled water per annum—almost 46% of the total water recycled in Australia (Figure **2.6**). According to Mekala et al. (2008), there are almost 600 (over 580) recycled water schemes currently operating in Australia. The reuse projects that have been implemented in Australia are often carried out on a small scale basis and are generally designed for non-potable purposes in agriculture and industry, such as landscape irrigation, agricultural or horticultural irrigation, and industrial water uses. Approximately 270 schemes are agriculture-based (e.g., horticulture, forestry, pasture, cotton, flowers, viticulture and cane). Another 80 are used in the service industry (e.g., washing and cooling) and about 230 schemes use recycled water in the urban environment (e.g., golf courses and recreational parks). Such schemes are also being introduced into domestic contexts via third or purple pipe systems where recycled water is used for limited purposes such as residential garden irrigation and toilet flushing. This is an important step towards sustainable urban water management.

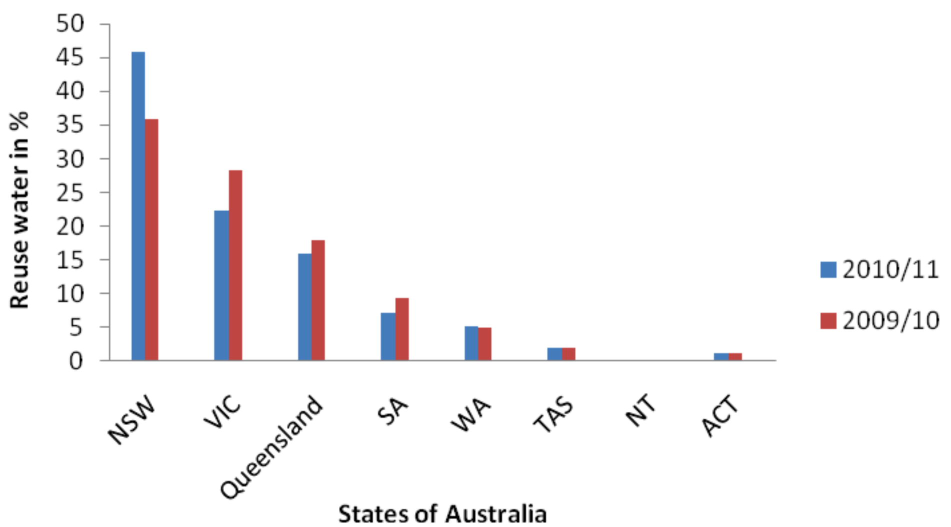

Figure 2.6 Reuse water by state in %.

In Australia, the use of recycled water for potable purposes has not been put into practice. In some states, such as Victoria (VIC), the use of recycled water for potable purposes is not currently policy (Government of Victoria, 2006). In other states, potable reuse proposals have been put forward, such as in the city of Toowoomba, Queensland. However, a public referendum in Toowoomba in 2006 resulted in opposing votes of 16.5% in respect of the use of recycled water for potable purposes (Water Futures Toowoomba, 2006). The then Premier of Queensland (2007) announced in 2007 that potable reuse was inevitable for South East Queensland and that a public referendum to gain approval would not take place.

2.3 End uses of recycled water

End use is defined as the ultimate application for which a product has been designed. Recycled water is a product which may be sourced from stormwater, sewage, grey water, etc. Since water can be a vector for pathogens and substances that may be harmful to human health, it needs to undergo a certain level of treatment to ensure that it is not hazardous. The level of treatment required depends on initial water source quality and the proposed end use.

Recycled water must be treated to a level that is ‘fit for purpose’, that is, it must be treated to a level that is suitable for its targeted end use (Radcliffe, 2004). Prior to introducing any new use of recycled water, it is very important to ensure that the community’s expectations of the product being delivered for a particular use are achievable, otherwise the community will deny the use of recycled water for the targeted end use, leading to the failure of such projects, which are often expensive to establish. Recycled water is classified into four main categories, as shown in Table 2.4.

The concept of the beneficial use of treated wastewater has rapidly become an imperative for water agencies around the world (Okun, 2002; Po et al., 2003). Recycling urban wastewater has been recognised as an important source and a key aspect of sustainable water policy. As noted previously, it is a promising innovation in urban water management and is being developed around the world. Pasqualino et al. (2010) pointed out that replacing potable and desalinated water by recycled water for non-potable purposes (e.g., irrigation, industry, urban cleaning and firefighting) could result in reduced environmental impacts in terms of acidification potential, global warming potential and eutrophication potential. Although the first reuse of wastewater is believed to date back 5000 years, the birth of modern recycled water applications occurred in 20th century with the development of advanced wastewater treatment technologies (Angelakis and Spyridakis, 1996; Okun, 1996). Before the 1990s, 70% of reused wastewater was processed to a secondary treatment level by the conventional activated sludge method and the effluent was only suitable for agricultural use in less developed areas. In a period of two decades, the rapid development and wide acceptance of membrane technologies in wastewater treatment have seen recycled water applications expand from non-potable uses such as irrigation, industry, environmental flow, and residential use, to IPR and DPR in developed countries (Pearce, 2008; Rodriguez et al., 2009).

Table 2.4 Class of recycled water (adapted from Bruvold, 2007)

Class	Treatment Processes	Range of uses
A	Tertiary and pathogen reduction (Advanced)	Suitable for groundwater recharge, urban (garden watering and toilets), agriculture, aquaculture (human food chain) and fire fighting.
B	Secondary and pathogen reduction (including Helminth reduction for cattle grazing)	Suitable for municipal (uncontrolled access), agriculture, aquaculture (non-human food chain), pasture and fodder, and industrial use (non- cooling towers).
C	Secondary and pathogen reduction (including Helminth reduction for cattle grazing use schemes) reduction	Suitable for municipal use (controlled public access), agriculture (no direct contact with crops.) pasture (not for pigs or milking animals), and construction and mining uses.
D	Secondary	Suitable for agriculture use (nonfood crops including instant turf, woodlots, flowers etc.)

The various end uses of recycled water include augmenting drinking water resources, agricultural irrigation, groundwater recharge, landscape irrigation, car washing, toilet flushing, garden watering, urban lawn watering and recreational amenities, road cleaning, snow melting and more. Of all end uses, water reuse for agricultural irrigation is the largest consumer of recycled water in those parts of the world where recycling water is implemented. This is probably because of the large water use in irrigation, relatively low quality requirement, and relatively low cost of infrastructure for irrigation water supply. There are four broad purposes for recycled water use: agricultural irrigation, urban and industrial use, providing water for the environment, and supplementing water resources.

The major reuse application types are as follows:

- Agricultural reuse
- Industrial reuse
- Environmental and recreational reuse
- Urban reuse
- Groundwater recharge
- Augmentation of potable supplies

2.3.1 Persisting end uses of recycled water internationally

Water recycling has been recognised as a promising strategy to alleviate water scarcity and reduce the impact of water shortage on the environment. However, the practical use of recycled water in both developed and developing countries is limited. A high proportion of wastewater is treated, especially in large cities in developed countries, including Australia (Radcliffe, 2004) and many central and northern European countries; however, the reuse ratio is low (Hochstrat et al., 2006). Most of the treated wastewater is released into natural water bodies, indicating that the wastewater treatment is mainly driven by environmental concerns. Hence, the economic benefits of reusing treated wastewater are relatively less significant. In developing countries, on the other hand, the wastewater treatment rate is very low. A high percentage of wastewater from industries and households is released without any treatment (Yang and Abbaspour, 2007). According to the information provided by UNDP (2008), around 90% of sewage is discharged untreated to rivers in the developing world as a whole. Wastewater treatment facilities are operating but not at their full capacity. For those countries and regions, improving wastewater treatment capacity and encouraging the reuse of reclaimed wastewater are of enormous importance for alleviating water scarcity and reducing environmental and health risks. Although some developing countries have begun to conduct municipal wastewater treatment, the treated effluent still fails to fulfil the reuse requirements in some cases (Asano, 2001).

In both developed and developing nations, agriculture is the most prominent persisting end use of recycled water. Monterey in California, Mexico City, the Dan Region in Israel, Virginia in Adelaide, Australia, and Tunisia are examples of some locations where water reuse for agriculture has been successfully implemented (Anderson, 2003). Wastewater reuse in agricultural irrigation has the longest history of some 5000 years (Angelakis and Spyridakis, 1996). In more recent history, some of the earliest recycling projects for irrigation purposes were implemented in the Western US in the late 1920s, together with the publication of initial water reuse standards in California. This end use continued with the increased recognition of notable economic benefits in production as a result of higher nutrient contents, controlled with water reuse guidelines. Currently, agricultural irrigation still represents the most dominant recycled water application throughout the least developed regions (e.g., Middle East, South America and North Africa). In many developing countries with water scarcity, irrigation practices often involve the direct use of untreated wastewater, causing health concerns. One such example is in Kumasi, Ghana where up to 70% of the irrigation water comes from polluted wastewater with a concentration of faecal coliform ranging from 104 to 108 CFU/100 ml (World Bank, 2010). Many European countries such as France, Spain, Italy, and Greece greatly utilise recycled water for agricultural irrigation. All Mediterranean countries and most countries in the Middle East have progressively used recycled water for irrigation, especially Israel, Tunisia, Cyprus and Jordan (Angelakis et al., 2003). The three largest recycling systems are located in Kuwait, Israel and Saudi Arabia, reuse tertiary treated recycled water in agricultural irrigation (Jimenez and Asano, 2008). However, in most developed regions (e.g., Australia, the US and Europe), although agriculture irrigation is a prominent end use, the number of urban reuse schemes are as high or higher than the number of agricultural irrigation schemes (Brissaud, 2010). Water reuse in another developed country, Japan, has essentially non-potable urban water applications (Ogoshi et al., 2001). The main uses of recycled water are for toilet flushing and environmental water, but there are other uses such as irrigation and snow melting in northern Japan, where there are heavy snow falls in winter; treated wastewater is used to melt snow by means of snow damping ditches or tanks to which treated wastewater is supplied.

Landscape irrigation is another persisting end use of recycled water and has been practised around the world for more than 50 years (Stevens et al., 2008). It has become the second largest user of recycled water in the world (Asano et al., 2007), and in Asia, both China and Japan have been involved in water reuse trials for landscape irrigation. The Qinghe Water Reclamation Plant in Beijing, China has successfully provided Ultra filtration (UF) treated effluent for the 2008 Beijing Olympic Games (Chen et al., 2012). Of a total capacity of 80 ML/d, 60 ML/d was used as the water supply for landscaping the Olympic Forest Park, and the remaining 20 ML/d was used for road washing, toilet flushing and other purposes. Nearly half of all landscape irrigation schemes are related to golf courses. The US and Australia have massively implemented this end use of recycled water; in the US, the average annual water consumption of a golf course is 190–230 ML on the East Coast and 300–380 ML in the southwest. As a result of such high demand, the irrigation of golf courses with recycled water has been made mandatory in some states of the US. Golf course irrigation contributes to 36% and 50% of the total water reuse in landscape irrigation in Florida and California respectively (Asano et al., 2007). According to Candela et al. (2007), the compulsory use of recycled water for golf course irrigation in many water basins has been specified in the 2010 Spanish National Water Plan. Golf courses in Costa Brava, in northeastern Spain, have used recycled water as the sole source of irrigation since 2004 (Sala and Millet, 2004). Moreover, the largest project of its kind in the world, which is also the largest private wastewater project to date, is the Jumeirah Golf Estates (220 ML/d) in Dubai, United Arab Emirates, which is equipped with an advanced wastewater collection, treatment and tertiary effluent reuse system. In Tunisia, at least eight golf courses are irrigated with secondary treated effluent using recycled water, which has become an important component of tourism development, (Bahri and Brissaud, 1996; GWA, 2008).

Industrial uses are currently the third largest consumers of recycled water The US, Canada, Japan and Germany have the longest history of recycled water use for industrial purposes. . The major industrial categories associated with substantial water consumption include cooling water, boiler feed water and industrial process water (Chiou et al., 2007; US EPA, 2004).Generally, more than 90% of water consumed by industries in the US is used for cooling purposes compared to 70% in Japan (Schmidt, 2008). Similarly, China (Wang et al., 2006) and India are also in the list of countries using recycled water as cooling water in industries. According to a report from the United States Agency for International Development (USAID, 2009), the thermal power generation plants of MahaGenco Company at Koradi and Khaparkheda, which reuse 110 ML/d of treated water, predominantly for cooling purposes, represent India's largest water reuse project. Reuse rate is highly accelerated almost by 25% in most industrial sectors in Australia which is attributable to the severe drought conditions and mandatory water restrictions (Stevens et al., 2008). Recycled water for boiler feed is also a very popular end use in the industrial sector. Australia, the US, a number of Middle East countries, and China are some of the countries where this end use of recycled water occurs (Chen et al., 2012). The use of recycled water in food processing industries has also been reported in Australia (GWA, 2010), Brazil (Matsumura and Mierzwa, 2008), Egypt (Hafez et al., 2007) and Germany (Blocher et al., 2002).

Recycled water for recreational activities are found in a number of countries, including Australia, China, Japan, and the US. Non-potable urban uses such as air conditioning, fire protection, toilet flushing, garden irrigation and car washing are applications that are mostly observed in well-developed countries and regions, especially in highly urbanised areas occupied by offices and other commercial and public buildings (Asano et al., 2007). St Petersburg, Florida, Irvine Ranch and South Bay in California, Tokyo in Japan, Rouse Hill, Homebush Bay and Newington in Sydney, Australia, and Mawson Lakes in Adelaide, Australia, are some of the successfully implemented projects for urban reuse (Anderson, 2003; Hurlimann, 2008). In Europe, non-potable urban reuse represents a major use of recycled water, accounting for 37% in southern Europe and 51% in northern Europe.

Numerous direct and indirect reuse projects have been launched and proposed around the world. Singapore, Israel, Namibia, the US, Australia and many European countries are the known examples where successful direct and indirect reuse projects have been implemented (Po et al., 2003; Hurlimann, 2008). As already stated above in this chapter, IPR systems began more than 30 years ago in California in the US, whereas the first DPR was introduced in Windhoek, Namibia in 1968 (Po et al., 2003; Marks et al., 2006). Indirect potable water reuse projects in Orange County, (Marquez, 2002), Water Factory 21 in California, the Fred Harvey Water Reclamation Facility in El Paso, Texas, and the Upper Occoquan Sewerage Authority Water Recycling Project in North Virginia are some examples of successful implementation in the US (Po et al., 2003), while NEWater is another highly successful indirect potable reuse in Singapore.

Wastewater reuse can thus have many applications, as shown in Figure 2.7, and the degree of treatment required is based upon the sources of water and types of end use. By using recycled water for these applications, more freshwater can be allocated for uses that require higher quality, such as for drinking, thereby contributing to more sustainable resource utilisation.

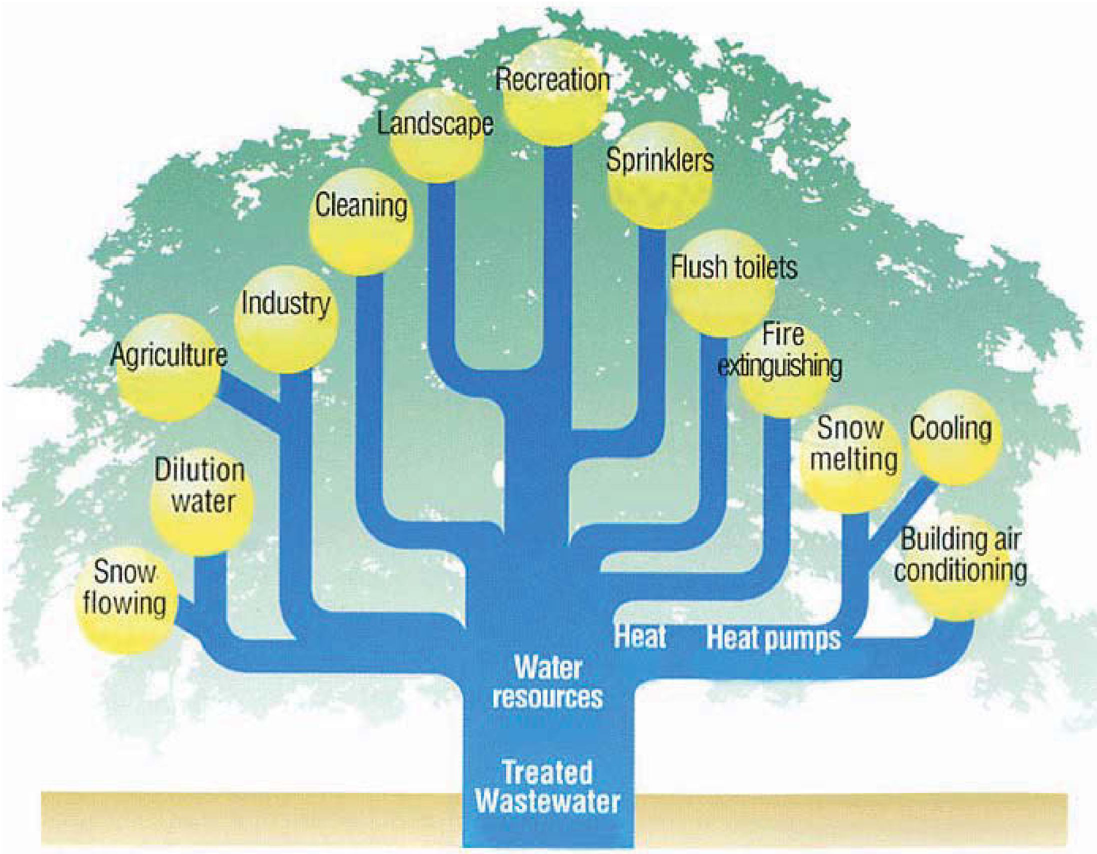

Figure 2.7 Tree of water resources recycling (MLIT 2001).

2.3.2 Persisting end uses of recycled water in Australia

The Australian Government is one of four governments worldwide that have regulations for water recycling and have developed recycled water for a variety of purposes

(Angelakis et al., 2003). Recycled water has become an integral part of Australia's water resources. The reuse projects implemented in Australia are often carried out on a small scale basis and are generally designed for non-potable purposes in industry and agriculture, such as landscape irrigation, agricultural or horticultural irrigation, industrial water uses, non-potable urban uses and recreational uses.

There are approximately 270 agricultural irrigation schemes across Australia, using 106 GL of recycled water per year. The highest consumption of recycled water is the cotton industry followed by the grain and sugar industries. These three types represent almost 47% of the total agriculture recycled water consumption. However, considering the annual total water consumption in agriculture (7300 GL in 2008–09), the contribution of recycled water was small, accounting for only 2% (ABS, 2010). Several large-scale irrigation schemes have been successful implemented in Australia, including the Hawkesbury Water Recycling Scheme in Sydney (500 ML/yr of treated wastewater together with 200 ML/yr of treated stormwater), the Virginia Pipeline Scheme in Adelaide (18 GL/yr), the Eastern Irrigation Scheme in Melbourne (11 GL/yr) and Shoalhaven Water's Reclaimed Water Management Scheme in New South Wales (4GL/yr).

Out of a total of 600 recycled water schemes in Australia, approximately 240 are applied to urban environmental irrigation. Many have been operating for more than 20 years without any negative impact on human health or the environment (Stevens et al., 2008). The Dunheved Golf Club in St Marys, NSW, is supplied with up to 1 ML/d of tertiary treated and disinfected effluent from the St Mary's Sewage treatment plant (STP). The scheme started in June 2000 with a contract of over 20 years and proved to be of great value during the severe drought of 2002–03. Another successful scheme in Australia is at the Darwin Golf Course, Tasmania, where 450 ML/year effluent provided by Darwin Golf Course STP effectively contributes in the golf course irrigation.

Industrial recycling schemes have expanded to about 80 in Australia. 1 GL/yr of recycled water, processed through tertiary and nitrification treatment in Wetalla STP, Toowoomba, QLD, is supplied to the Millmerran powerhouse for cooling purposes through an 80 km pipe (Radcliffe, 2004). Recycled water from the Dora Creek STP is supplied to Eraring Power Station at Lake Macquarie, NSW, where the water is further treated by Microfiltration/ Reverse Osmosis (MF/RO) and demineralisation and is used as boiler feed to provide steam for the power station turbines, saving 1.2 Mm^3/yr of potable water previously supplied from the town water supply system (Cole and Deans, 1994). Similarly, in Brisbane, QLD, 10.6 to 14 ML/d of recycled water from MF/RO membranes at the Luggage Point STP is supplied to the BP Amoco Company refinery as boiler feedwater (Don, 2001; Barr, 2002; Radcliffe, 2004). The Port Kembla Steelworks in NSW, which belongs to the BlueScope Steel Company, uses 20 ML/d of recycled water from the Wollongong STP, saving 130 ML of freshwater each year (BlueScope Steel, 2006).

Use of recycled water in food processing industry has not been well adopted in Australia. The Mars Food Water Recycling Project in NSW uses UF, RO and Ultra Violet (UV) disinfection to treat both wastewater streams from the food manufacturing process and storm water onsite and reuse them for non-product utility purposes, saving 355 ML/yr of water. It was awarded first prize for its excellent achievements at the 2010 Global Water Awards in the category of Industrial Water Project of the Year (GWA, 2010).

Recreational uses of recycled water also account for significant use, especially in densely populated areas and scenic tourist spots. The annual flow rate at Rutherglen, Gisborne and Woodend in VIC was 372, 450 and 210 ML respectively and approximately 50% of the effluent was reused for recreational purposes (Radcliffe, 2004). Lake Weeroona, a popular recreational lake in the middle of Bendigo, VIC, constructed over 100 years ago is one of the other example where recycled water is being used to top up the fresh water since 2008 (Chen et al., 2012). Recycled water for artificial snow making is also common in Mt. Buller and Mt. Hotham areas in VIC, as well as at animal viewing parks in Taronga Zoo, Sydney (Asano et al., 2007; Tonkovic et al., 2002).

Non-potable urban residential uses are being implemented in areas where there is supply of recycled water via a dual pipe system. Communities in suburbs of Sydney, Adelaide, the Gold Coast (QLD) and Melbourne are experiencing this. The six schemes currently operating in Australia are Rouse Hill (Sydney), Mawson Lakes (Adelaide), New Haven Village (Adelaide), Aurora (Melbourne), Marriott Waters (Melbourne) and the Pimpama Coomera scheme (Gold Coast) (Willis et al., 2010a). Third pipe systems have also been considered for the Heathwood/Brazil development in Brisbane (Mitchell et al., 2003). There are three well-known and relatively large Australian examples of recycled water use through dual water supply systems. These are at new residential developments at Rouse Hill and Newington in Sydney, and Mawson Lakes in Adelaide. The largest residential dual reticulation wastewater reuse scheme to date is in the Rouse Hill development area, Sydney. It is an area of 13,000 ha that can support a population of 320,000 people with progressive development occurring over a period of 25 years and more. Since 2001, residents in the development have been supplied with recycled water for toilet flushing, garden watering and fire fighting (Sydney Water, 2001; Po et al., 2003). A water recycling scheme at Homebush Bay, the site of the Sydney 2000 Olympics is being operated. Up to 7000 m^3/d of recycled water is used for toilet flushing, watering lawns, gardens and parks around the former Olympic venues and facilities, and at the Newington Village to 2000 residential houses for gardens and toilet flushing (Anderson 2003). The scheme will reduce demands on Sydney's freshwater supplies by about 850,000 m^3/yr (Cooney, 2001). Mawson Lakes (428 ML/yr) is another large scale water recycling scheme serving residential properties in Adelaide, South Australia (Hurlimann, 2008). This is housing 10,000 people in 3700 houses and also serves a university and a commercial and industrial estate. Wastewater from the estate is treated and recycled for toilet flushing and landscape irrigation. Other examples include the use of recycled water for non-potable purposes in office buildings, including the Melbourne City Council, Council House 2 building and the head office of Bendigo Bank in Bendigo (Hurlimann et al., 2007).

2.3.3 Proposed new end use

Recycled water has proven to be effective and successful in creating a new and reliable water supply. Non-potable reuse is a widely accepted practice that is likely to continue to grow. The uses of recycled water are expected to expand in order to accommodate the needs of the environment and to satisfy water supply demands. As discussed above, the DRS are expected to intensify even more in future however; the existing enduses of recycled water in such systems are very limited and confined only within garden irrigation, car washing and toilet flushing. The existing and emerging DRS demand substantial replacement of drinking water with recycled water and hence exploration of more enduses of recycled water is very important.

Household water use is the second largest water consumer in Australia (ABS, 2004 - 05). Almost all households (97%) in Australia have washing machines (ABS, 2008). Water is the single most important resource to a laundering operation. Large amounts of water are regularly used in laundering facilities for operations that include the wash and rinse cycles of washing machines. Prolonged drought conditions in most of Australia's major cities during the past decade have led to serious national calls for less consumption of potable water (Hurlimann and McKay, 2006). Non-potable reuse is a widely accepted practice that is likely to continue to grow. The uses of recycled water should expand further in order to accommodate increasing needs of the environment and to satisfy growing water demands. Even if Australia were to cut per capita water use by 7% and one-quarter of new suburbs were to use recycled water for outdoor activities and toilet flushing, Australia would still face a shortfall in supply of 800 GL by 2030 (Howe, 2005). Current recycled water initiatives in Australia include the use of reclaimed wastewater and stormwater for urban, residential, industrial and agricultural purposes but not for washing clothes. According to statistics in the NSW State of the Environment Report on typical water usage in Sydney metropolitan households, laundry use requires up to 20% of total water consumption. According to the estimation by Newton (2008), laundry washing in Sydney accounts for about 27% of household water use. Thus, a significant reduction in household drinking water demand could be achieved if drinking water currently used for clothes washing were to be replaced with recycled water. The introduction of this new end use of recycled water would increase the amount of saving of potable water use by 10%. Pakula and Stamminger (2010), suggest that the volume of water used for laundry washing significantly influences the total water consumption of households in most of other countries in world including Australia. The influence of laundry water consumption is significant on household water consumption of different states of Australia as shown in Figure 2.8 (ABS, 2004).

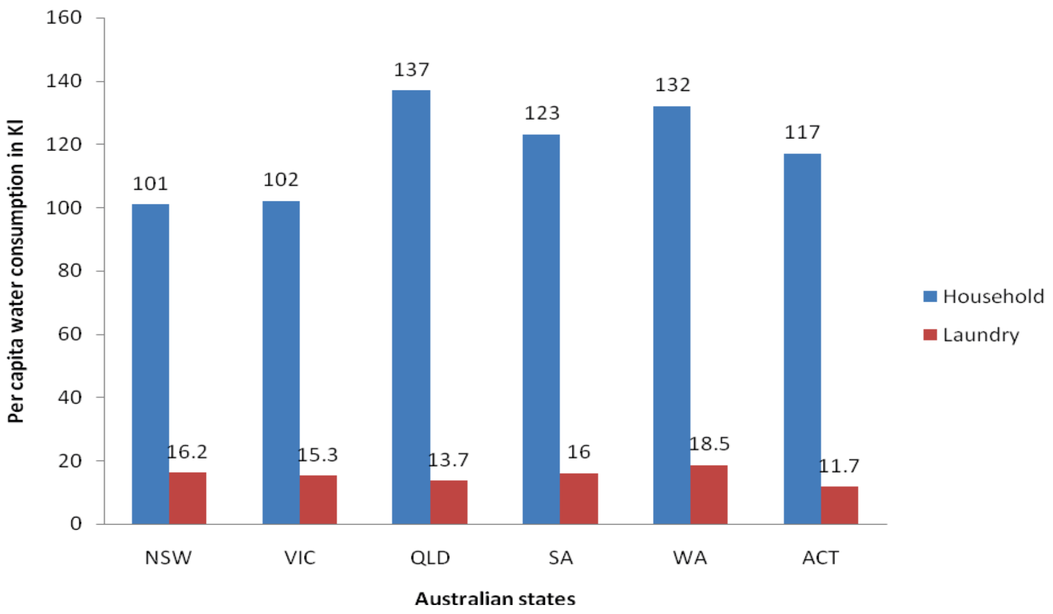

Figure 2.8 Annual per capita water consumption by location of use in 2001 (Kl). (adapted from Mainali et al., 2011 a)

Note: NSW: New South Wales; VIC: Victoria; QLD: Queensland; SA: South Australia; WA: Western Australia and ACT: Australia Capital Territory

The significant laundry water consumption in households can be observed in major cities like Sydney, Melbourne and Perth of Australia as shown in Figure 2.9.

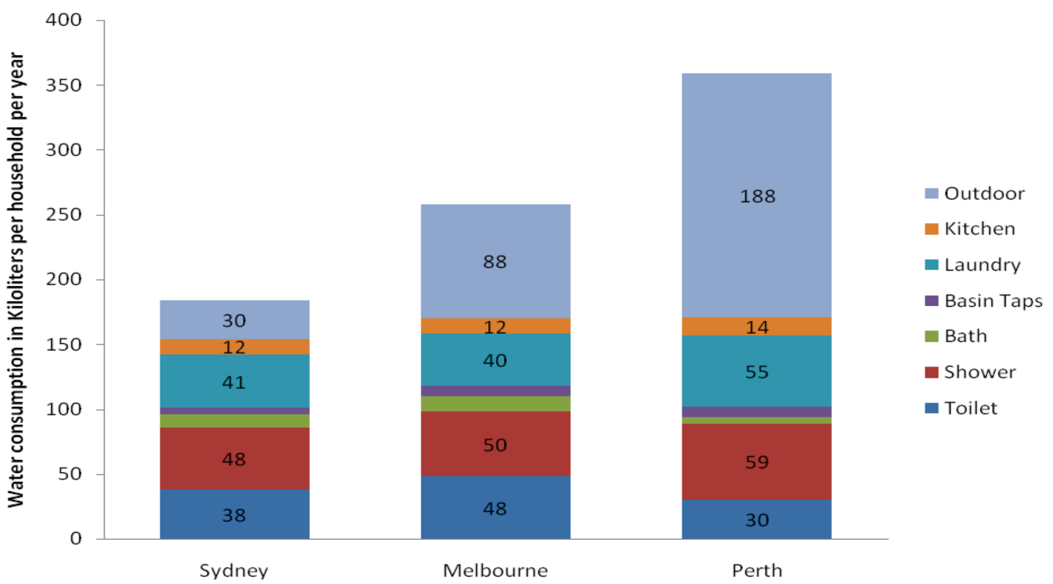

Figure 2.9 Estimated use of water by households in Sydney, Melbourne and Perth. (adapted from Mainali et al., 2011 a)

In Australian DRS, there is higher demand for recycled water during hotter (and generally drier) summer months than in cooler months as a result of increased outdoor watering. The inclusion of washing machines as a new end use will provide almost constant demand throughout the year, because washing clothes is a year round activity, and hence would provide a means to even out the demand. In addition, the residential use of recycled water for laundry purposes would bring down the cost of residential dual water reticulation systems.

For the successful implementation of any recycled water scheme, special consideration must be given to community concerns. In a review of eight studies in different parts of Australia regarding the attitudes of the community towards the use of recycled water in washing machines, the percentage of respondents (irrespective of the number of participants and locations) who oppose the use of recycled water for use in washing machine is 25% (Figure 2.10).

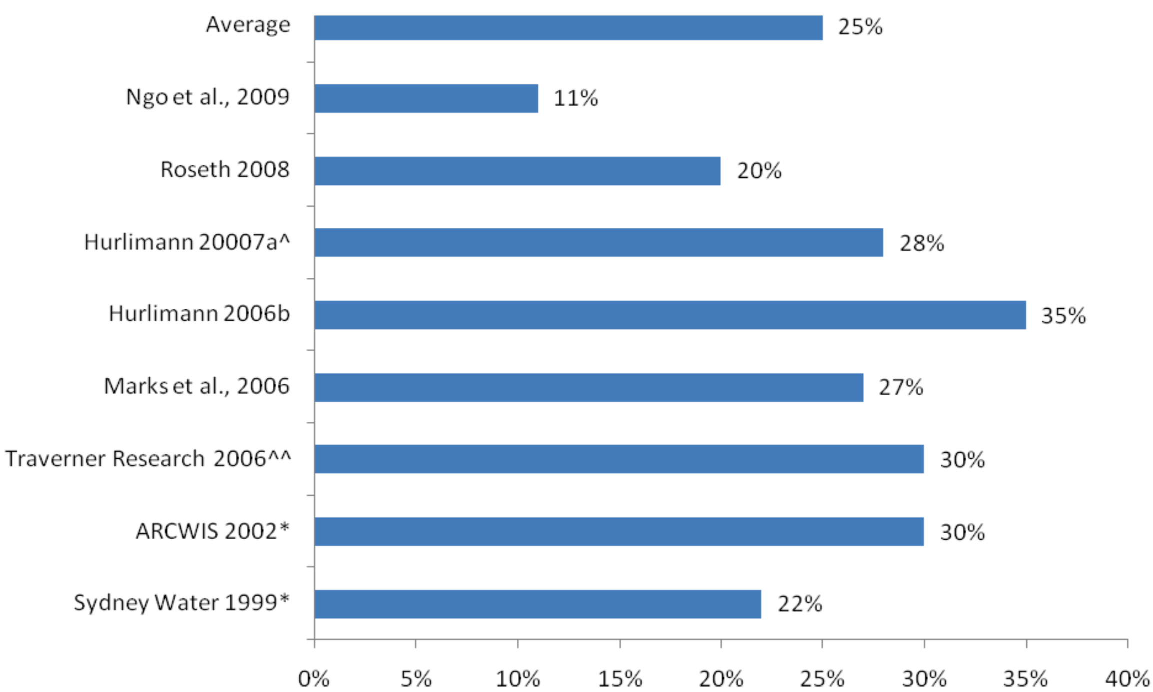

Figure 2.10 Respondents (%) opposed to use of recycled water in washing machines in Australia.

*Note: * Cited in Radcliffe 2004, ^^ Cited in Storey 2009 ^ Cited in Hurlimann 2008, ARCWIS= Australian Research Centre for Water in Society*

Dolnicar and Saunders (2006) suggest that the average support for using recycled water for laundry is 80%, which was the outcome of reviewing eight studies in different parts of the world that assessed the willingness of people to adopt certain forms of usage of recycled water. Roseth (2008) concludes that on average, more than 80% of respondents from Australian cities are willing to use recycled water for washing clothes (Figure 2.11).

The Department of Epidemiology and Preventive Medicine at Monash University revealed that class A recycled water such as that being used in the Rouse Hill scheme, if used in washing machines, will not lead to the transmission of micro-organisms at concentrations likely to cause enteric diseases (Storey, 2009). O'Toole et al. (2008) specifically investigated the microbiological safety of using recycled water in washing machines and concluded that the use of highly treated recycled water in washing machines will not lead to the transmission and consequent exposure of users to numbers of micro-organisms likely to cause enteric diseases.

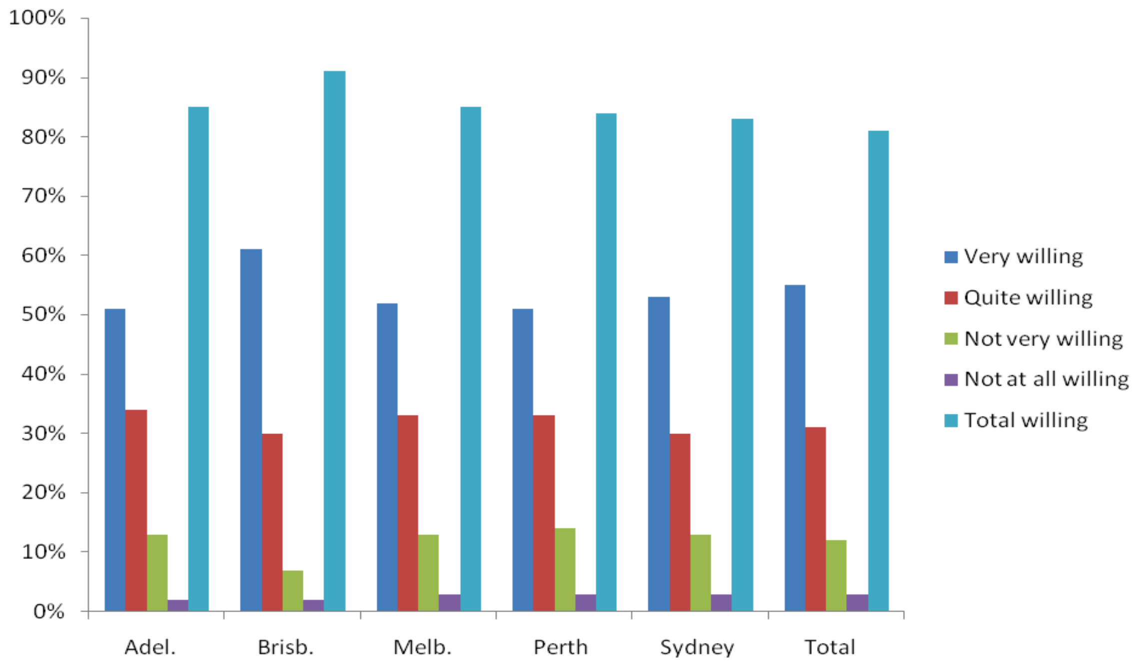

Figure 2.11 Willingness to use recycled water for washing clothes.

Note: Adel. - Adelaide, Brisb. - Brisbane, Melb. – Melbourne.

This proposed end use is very big in scope and market because the development and expansion of water recycling capacity in Australia has huge potential. The benefits of water recycling have been recognised and have already undergone initiation and expansion in many parts of the world. However, the application of recycled water is limited predominantly to irrigation and toilet/urinal flushing or car washing in households. The rate of ownership of washing machines in Australia is 97% and in most developed countries is over 90%. In a survey of 780,000,000 households in 38 countries of the world with a total of about 2.3 billion people (about one third of the world's population), it was found that 590,000,000 households owned washing machines (Pakula and Stamminger, 2010). Therefore, the associated opportunity of this new end use is that it has the potential to expand worldwide in developed countries where laundry is one of the most important water users in the household. The use of cold water in washing machines has been steadily increasing in Australian households, rising from 61% in 1994, to 74% in 2008 (ABS, 2008). This is a positive trend in relation to using recycled water in washing machines because the supply will be cold water.

There are a number of associated weaknesses which should be given due consideration and addressed adequately through research. The use of recycled water for washing clothes is more closely related to close physical contact with water. The results of various surveys (Bruvold, 1984; Denlay and Dowsett, 1994; Jeffrey and Jefferson, 2003) have revealed that unfavourable responses the reuse of water are directly proportional to the perceived degree of human contact with the reclaimed water. Prior to introducing any new recycled water use, it is very important to ensure that the community's expectations of the delivered product for the particular use are achievable, otherwise the community will deny the use of recycled water for the targeted end use, leading to the failure of the project, which may have been expensive to establish. In customer research commissioned by Sydney Water, a residents' strategy survey in Australia and many other related studies show support for the concept of using recycled water in washing machines. However, deep concerns have been raised by participants, including the effects of recycled water on public health, aesthetics and the discolouration of laundry, washing efficacy, and machine durability (Storey, 2009; Ngo et al., 2009). The greater possibility of physical contact with the water may in part explain the high importance of these concerns. From the aesthetic point of view and because of public health concerns, higher quality water is required for reuse in washing machines (Ngo et al., 2009). The study by Hurlimann and McKay (2006) concerning the importance of various attributes of recycled water for various uses also concluded that the general public demands a higher quality of recycled water to use for washing clothes compared to that required for garden watering and toilet flushing. Higher quality recycled water requires a higher level of treatment, which is accordingly more expensive and more energy intensive.

Although people show their willingness to accept the use of recycled water in washing machines during the survey phase, the scenario may be different when it comes to practical implementation. Because agriculture is the largest consumer of water for irrigation, detractors of this new end use may recommend confining the use of recycled water only to agriculture and other existing end uses. There has been no recognition of this new end use of recycled water in the Australian guidelines for the use of recycled water (Hurlimann and McKay, 2006) and even where it has been recognised, as in draft guidelines for the use of recycled water in Western Australia (Department of Health, Government of Western Australia, 2009), it has been considered as a high risk end use. The practical implementation of this new end use is very rare in the world till date. There is a noticeable lack of social research in understanding in detail the general public perceptions of this application, and only a few studies (Hurlimann and McKay, 2006; Pham et al., 2011) have been carried out that address this specific issue. Detailed research and study to address all the issues considered to reflect the basic concerns of the general public to the use of recycled water in laundry is lagging. Most state health authorities in Australia currently do not endorse the use of recycled water for laundry and machine washing because of the lack of safety data (Roseth, 2008). Strengths and weaknesses of this new end use along with the associated opportunities and threats were analysed using SWOT (Strength, Weakness, Opportunity, Threats) Analysis tool and presented in Mainali et al. (2011a).

2.4 Relevant issues in the use of recycled water

2.4.1 Public perception of recycled water

Today’s advances in technology have enabled the achievement in recycled water of qualities often superior to current potable water standards (Bixio et al., 2005), however the notion of accepting potable water reuse has not yet benefited from absolute public support. The general public often strongly rejects water recycling activities. In fact many recycling water projects around the world have failed because of public resistance to accepting those projects (Okun 2002; Po et al 2003; Hartely 2003; Radcliffe 2004; Hurlimann 2008). Therefore, although the need to use recycled water is gaining more impetus, which can be attributed to the severe water restrictions in countries, clients for this recycled water often cannot be found. This public resistance or hesitation to use recycled water is largely attributed to the public perception of recycled water, perceptions of risk, level of knowledge, trust in regulatory authorities and water scarcity. Reasons for community opposition to reuse schemes are a combination of prejudiced beliefs, fear, attitude, lack of knowledge and general distrust, which are often not unjustified, judging by the frequent failures of wastewater treatment facilities worldwide (Wegner-Gwidt, 1991; Jeffrey and Temple, 1999). Recycled water has an image problem. Consumers are not familiar with the benefits of recycled water and are suspicious about its origin and the safety. The general feeling about wastewater is very clearly that it is filthy and disgusting, regardless of the degree of treatment. The association of sewage and wastewater with the recycled water generates a feeling of disgust among the general public which is technically termed as the 'yuck factor'. Public consultation studies (Sydney Water, 1999; Dolnicar and Schäfer, 2006; Hurlimann, 2008; Roseth, 2008; Ngo et al., 2009) have been carried out in different parts of Australia to explore attitudes towards different modes of recycled water use. Only a small number of community surveys (Dolnicar and Schäfer, 2006; Roseth, 2008; Ngo et al., 2009) incorporate the level of knowledge of the respondents on recycled water as a survey question. Dolnicar and Schäfer (2006) revealed from their survey that the respondents (the general public) clearly understood that recycled water is the more environmentally friendly option, but gaps in the general level of knowledge exist. From the online survey of 3050 randomly selected residents of five main cities in Australia, Roseth (2008) revealed that about one half of respondents claim to "know a little bit" about recycled water while just under one quarter know "quite a bit" and a minority, 7%, know "a lot" but that one in five knows next to nothing. General public knowledge, especially about water from alternative sources such as recycled and desalinated water, is relatively low among the general population (Dolnicar and Schäfer, 2009). Ngo et al. (2009) from their study observed that most of the people interviewed admitted that they knew "very little" to "quite a bit" on recycled water.

People's knowledge of basic information on recycled water at the moment is low and wrong perceptions are fertile ground for scare campaigns. Dolnicar and Schäfer (2009) revealed from their study that 71% of respondents perceive desalinated water as being acceptable drinking water, while only half of respondents perceive recycled water as being drinkable; 61% of respondents have health concerns about drinking recycled water, while only 33% have those concerns about desalinated water. Even with respect to clarity and odourless, respondents perceive desalinated water as outperforming recycled water. Recycled water is also believed to contain more chemicals such as disinfectants as well as micro-organisms. However, Dolnicar and Schäfer (2009) revealed that respondents clearly understand that recycled water is the more environmentally friendly option.

Wastewater reuse is a sensitive issue directly involving the general public, therefore the consideration of community attitudes to the use of recycled water is a critical component for the successful implementation of any recycled water project. Bruvold et al. (1981) reflects the same opinion and emphasises the need to allocate funds, time and expertise to objectively assess public attitudes and opinion regarding proposed recycled water projects. The traditional approach of 'decide, announce, defend' (DAD) has now been commonly acknowledged as ineffective (Po et al., 2003; WSUD, 2004; Hurlimann, 2008). A number of projects have been unsuccessful because of community opposition including those at Quakers Hill, Sydney, Maroochy in Queensland, and San Diego in the US (Hurlimann, 2008). The results of various surveys (Bruvold, 1984; Denley and Dowsett, 1994, Jeffrey and Jefferson, 2003) have revealed the fact that the unfavourable responses towards the reuse of water are directly proportional to the perceived degree of human contact with the reclaimed water. The support of the respondents decreased as the proposed use of recycled water came closer to personal eye and skin contact (only 19% for home pool and 6% for showering). These findings agree well with those of Bruvold (1984), Ismail (1992), Sydney Water (1999), Marks (2004), and Dolnicar and Schäfer (2006).

A presentation at the Environmental Health Symposium hosted by the Department of Health in Western Australia in December, 2004 titled "Public Perceptions of Wastewater Reuse" summarised that the closer the recycled wastewater is to human contact or ingestion, the more people are opposed to it and public acceptability decreases dramatically when its use changes from external usage to use within the home.

2.4.2 Risk associated with use of recycled water

Water is a vector of pathogens. The outbreak of dangerous bacteria or viruses is one of the most crucial risks associated with the use of recycled water. The general public are highly concerned about this issue because it is directly related to their health. The health risks associated with the use of recycled water judged by regulatory and health authorities include the risk of contamination by microbiological contaminants and chemical products (Toze 2006). This concern refers to an actual, rather than a perceived risk. Since the source of recycled water is considered to be more prone to contamination by microbiological contaminants and chemical products, special attention to minimising the associated risks to acceptable levels before recycled water can be used in any specific situation (i.e. the water must be fit for purpose) is of utmost importance. Reducing this risk can be achieved by placing multiple barriers in the treatment process (Toze, 2006). While sound treatment processes have been established, there is still debate in the scientific community about risk assessment. Additionally, little is known about community attitudes to the risk involved with recycled water use. Hurlimann (2007) suggested that the perception of risk increased as the use of recycled water became increasingly personal. Perception of risk was significantly negatively related to trust, perception of fairness and information. Trust in the Water Authority to manage risk was significantly related to perceptions of trust, communication and the integrity of the Authority. Increasing the understanding of risk perception could facilitate increased recycled water acceptance and use (Hurlimann, 2008). Besides health risks, environmental risks are also associated with recycled water. In most cases, these environmental and health risks can be managed through the level of wastewater treatment or by the carefully managed use of recycled water. However, in some cases these risks are too costly to manage and certain reuse schemes may not be economically viable. Individual state/territory environment and/or health-related authorities are generally responsible for ensuring the water recycled is fit for the intended use.

All of these risks detailed below are manageable if guidelines and appropriate risk management principles are followed. Key potential health risks are associated with microbial pathogens, and microbial pathogens in wastewater from sewage effluent are the major concern for human health when recycling water. The major groups of pathogens are:

- Bacteria (e.g. *Escherichia coli, Salmonella spp*)
- Viruses (e.g. Enteroviruses, Rotavirus, Hepatitis A)
- Protozoa (e.g. *Giardia Lamblia, Cryptosporidium parvum*)
- Helminths (e.g. *Taenia spp* (Tapeworm), *Ancylostoma spp* (Hookworm)

There has been little empirical research that investigates community perceptions of risk associated with recycled water use. The analysis of perceptions of risk has often formed a small component of a larger survey. Greater insight could be provided by conducting more detailed research. In a research paper for the CSIRO, Po et al. (2003) highlighted the importance of investigating judgement strategies used in assessing risk acceptability so that effective risk communication strategies relating to recycled water can be tailored to cater for different people.

The experience of failed recycled water projects has shown that perceptions of risk related to recycled water use can cause emotional reactions. A study by Sydney Water (1999) found that 11% of respondents considered the health risk associated with cooking or drinking recycled water to be a disadvantage. Research conducted in the UK by Baggett et al. (2006) investigated stakeholder attitudes to many aspects of recycled water use and management, including perceptions of risk. They found that 15.6% of domestic customers surveyed thought a lack of appropriate monitoring or control over wastewater quality was a risk. Christen (2005) posited that a major element of the success of recycled water projects is community confidence that the treatment system is effective. A groundwater recharge project in the San Gabriel Valley in the US which aimed to use tertiary treated effluent to recharge depleting groundwater resources faced significant opposition from a local community group who perceived that the potential health risks, however small, were unacceptable (Stenekes et al., 2001).

Risk perception was explored in a Survey at Mawson Lakes by Anna Hurlimann. Key findings (Hurlimann, 2007b) included the fact that the perception of risk increased as the use of recycled water becomes increasingly personal. The perception of risk was significantly negatively related to trust, perception of fairness and information, while trust in the water authority to manage risk was significantly related to perceptions about communication and the integrity of the authority.

It is nevertheless of utmost importance to acknowledge that several dangerous bacterial or viral outbreaks in conventional drinking water supply systems (non-recycled water) have occurred. A Canadian professor Steve Hrudey along with co-author E. J. Hrudey, released a very interesting book called “Safe Water Drinking” which is essentially a review of all of the water-borne illness outbreaks that occurred in developed countries in the previous ten or 20 years (Hrudey and Hrudey, 2004). This book gave many such examples. Cities such as Milwaukee in the US and Walkerton in Canada, for example, have experienced very distressful situations because of the outbreak of organisms such as cryptosporidium and giardia, which are protozoan organisms causing illness. A number of people were reported to have died as a result of those outbreaks. The supply systems were conventional drinking water treatment processes, not water recycling schemes, which in hindsight were shown to have been relatively poorly managed, or not optimally managed. This illustrates the importance of taking great care and paying cautious attention to the way in which we manage the risks associated with drinking water production and drinking water distribution. Because these risks are real, there is the very real possibility of people becoming ill and dying if processes are not carried out correctly. The possibility of such outbreaks may be higher in the use of recycled water.

A chronic problem which needs to be managed in all irrigation systems is salinity. This can result in reduced plant growth and plant damage and can impact on freshwater plants and invertebrates in natural ecosystems if it is discharged directly with little dilution. The most common salt is sodium chloride, and sodium can be toxic to some plants if it accumulates in the soil as a result of ongoing irrigation. Moreover, salinity and sodicity are very difficult to remove. Chloride can be toxic to plants if sprayed directly on leaves, and also if it accumulates in the soil as a result of irrigation, but it is usually more important as a component of salinity. Nitrogen and phosphorous are of benefit to cultivated plants but both can cause eutrophication (excessive nutrient levels) in land and aquatic ecosystems. By-products of disinfection processes (chlorine residuals) may be harmful to aquatic or marine ecosystems if discharged directly with little dilution.

Plant toxicity may arise in some plants in some soils if Boron (Bo) accumulates from ongoing irrigation. Some organic and inorganic surface active agents (surfactants) from detergents can remain in recycled water and be harmful to some aquatic organisms. A broad range of chemicals has been identified as having the potential to alter normal endocrine function in animals, i.e. endocrine disrupting chemicals (EDCs). At this stage, there is no evidence that environmental exposure to low levels of potential EDCs (potentially present in recycled water) affects human health because the exposure is relatively low. Pharmaceutical chemicals and their metabolites, potentially found in recycled water, raise similar issues to EDCs. Health impacts from pharmaceuticals should also be minimal because of the relatively low exposure. However, ongoing monitoring is required to ensure good risk management.

In Australia, recycled water plumbing and taps are identified by their colour. Generally, Australian design standards (AS/NZS 3500.5:2000) require all plumbing outlets, and in most cases pipes, to be marked with the colour lilac/light purple and the instructions "DO NOT DRINK".

By following the guidelines and risk management principles, any risk associated with using recycled water can be overcome. Australia has drafted national guidelines for recycled water which refers to water being fit for the intended purpose.

2.5 Critical factors in the successful implementation of water reuse schemes

Water recycling is a promising innovation in urban water management and is being developed around the world. Numerous direct and indirect reuse projects have been launched and proposed; however, not all these projects have been successful in implementation. Some have been successful, some are still controversial, and some have been completely rejected by the general public and hence unsuccessful. Singapore, Israel, Namibia, the US, Australia and many European countries are the known countries where successful direct and indirect reuse projects have been implemented (Po et al. 2003; Radcliffe 2004). Nevertheless, there are also failed water reuse schemes in the US, Australia and some European countries (Po et al., 2003; Hartley, 2003; Hurlimann, 2008).

Many water reuse surveys have come to the conclusion that the best water reuse projects, in terms of economic viability and public acceptance, are those that substitute reclaimed water for potable water for use in irrigation, environmental restoration, cleaning, toilet flushing, and industrial uses (Po et al., 2003). Critical factors for the successful implementation of water reuse schemes have been always a key concern for water professionals and researchers. To reduce the risk of potential failure of alternative water projects, it is always of great benefit to understand the context of such projects well. Unfortunately, cases in which public opposition has vetoed water recycling schemes are not well documented, which prevents planners at other locations for the introduction of alternative water sources from learning from these experiences (Hurlimann and Dolnicar, 2010).

2.5.1 Successful water reuse schemes

In the past 20 years, significant development in water reuse schemes all over the world has been observed which can be attributed to persisting and increasing water shortages problems as well as to new environmental policies and regulations. There are many water reuse schemes that have been successfully implemented. Monterey in California (US), Mexico City (Mexico), Dan Region (Israel), and Virginia in Adelaide (Australia) are some locations where water reuse for agriculture has been successfully implemented (Anderson, 2003). St. Petersburg in Florida, Irvine Ranch and South Bay in California (US), Tokyo (Japan), Rouse Hill, Homebush Bay and Newington in Sydney, and Mawson Lakes in Adelaide (Australia) are some of the urban reuse projects that have been successfully implemented (Anderson, 2003; Radcliffe, 2004). Indirect potable reuse systems began more than 30 years ago in California in the US, and the first potable direct reuse was introduced at Windhoek, Namibia in 1968 (Po et al., 2003; Marks, 2006). Indirect potable water reuse projects in Orange County, Water Factory 21 in California, the Fred Harvey Water Reclamation Facility in El Paso, Texas, and the Upper Occoquan Sewerage Authority Water Recycling Project in North Virginia are some examples of successful implementation in the US (Okun, 2002; Po et al., 2003). NEWater in Singapore is another example of successful potable reuse. Two of these successful reuse schemes, Virginia in Adelaide, Australia, and NEWater in Singapore, are discussed in case studies in the following sections.

A. Virginia Pipeline Scheme (VPS), Australia

The Virginia Pipeline Scheme (VPS) was commissioned in 1998 in Virginia, Adelaide and is the first large-scale water recycling scheme in Australia for irrigation purposes to use treated wastewater from the Bolivar Waste Water Treatment Plant (WWTP)

(Krackman et al., 2001). The region is popular as South Australia's 'Veggie Bowl' because of its reputation for delivering high-quality horticultural products to local and interstate markets. VPS is a co-operative undertaking of the Virginia Irrigation Association (VIA), representing market gardeners and other irrigators; SA Water, the government body; and Water Reticulation Systems Virginia (WRSV), a private company.

As a result of the over-exploitation of the groundwater resources in this region (extraction of about 18 GL, sustainable limit 8–10 GL) beyond sustainable limits (Radcliffe, 2004), the water levels in the aquifers, formerly the main source of irrigation, declined and groundwater became a scarce resource. Local farmers thus recognised the value and potential of a new source of water to provide a secure supply for irrigating their crop lands.

Increasing public sensitivity to environmental issues, which heralded the establishment of the Environmental Protection Act (EPA), drove the urgency to implement changes to the Bolivar WWTP which would significantly reduce nutrient discharge to Gulf St. Vincent (Stevens et al., 2006). The state government secured an AUD 10.8 million Federal Government grant from the building better for our cities program to assist this scheme. As a consequence, the production of highly treated Class A equivalent recycled water that met the standards for irrigating agricultural crops without any restrictions was implemented by VPS (Stevens et al., 2006) after the secondary effluent from the Bolivar WWTP had received treatment in a Dissolved Air Flotation Filtration system to improve the water quality to less than 10 E. Coli/ 100 ml – the Australian standard for irrigation for crops eaten raw (EPA, 2004). Good communications and effectively designed partnerships existed between the key stakeholders through contractual agreements (Keremane, and McKay, 2006). Communication campaigns were carried out at different levels to train and educate the key stakeholders, and adequate promotion and social marketing of the scheme was undertaken and included the endorsement of the scheme by the South Australia Department of Human Services and the EPA (Keremane and McKay, 2006).

Po et al. (2003) advocates that developing a genuine partnership with the community to involve them in the decision making process to build and maintain trust is essential. The co-operative undertaking of the various stakeholders is one of the major strengths of the project. Virginia has a large market for its horticultural products and irrigation is essential The Virginia region accounts for about 35% of South Australia's horticultural production, which equates to about Australian Dollar (AUD) 120 million (Krackman et al., 2001). The community recognised the water scarcity problem and its consequences, and the potential of the new alternative source of water to provide a secure supply for irrigating their crop lands. This realisation by the target group of growers, coupled with the social, economic and the environmental drivers, is the greatest strength of the project and led to the development of the VPS (Thomas, 2006). The VPS produces Class A water after very high level treatment (i.e. full secondary plus tertiary filtration plus disinfection and coagulation when necessary). According to Keremane and McKay (2006), this water is better than water frp, many polluted river sources. This technical soundness is also a major strength of the project.

A strong role and well-defined responsibility exists for each stakeholder, and their enhanced participation, good communications and effectively designed partnerships between key stakeholders are enabled through contractual agreements. Hartley (2003) advocates that incorporating stakeholder priorities in water reuse programs is very important for the successful implementation of those programs. Each group of stakeholders performs their job with individual and organisational motivation such as-VIA educates growers in relation to water reuse, and the benefits of the enhanced nutrient levels on soils and natural groundwater from the use of reclaimed water are well explained to irrigators. The VIA also monitors the effects of the reclaimed water on the soils closely. In the early stages, communication campaigns were carried out at different levels to train and educate key stakeholders – industry, retailers, and the public. In addition, wholesalers were kept informed of the development of the scheme and reassured that product quality would not be compromised. Promoting communication and public dialogue to provide information about the benefits of the schemes has been considered an important concern for Hartley (2003) and many other researchers. Moreover, the endorsement of the scheme by the South Australia Department of Human Services and the EPA was also helpful in building up consumer confidence levels. The acceptance level of the products grown with reclaimed water was encouraging at all levels in retail markets. The scheme is associated with many social, environmental and economical benefits, and new scope has arisen for the development of export markets, providing more job opportunities for the locals. In addition, the discharge of sewage effluent from the Bolivar wastewater treatment plant into Gulf St. Vincent has been reduced to a large extent.

Thus, with sound policies, effective planning and management, sufficient financial commitment, and public awareness, support and participation, the VPS has operated successfully since its commission and has resulted in the economic, social, and environmental sustainability of the region.

B. NEWater, Singapore

Singapore is a small island with no natural resources where half of the country's water supply is imported from Malaysia (Seah et al., 2003). Ongoing negotiation between the two countries regarding price threatens Singapore's future water supply, and this has been regarded as a very sensitive issue by both the government and the people (Radcliffe, 2004). Hence an immense need for a local alternative source of water is perceived thus, based upon the recommendations of the US National Research Council, the NEWater project was commissioned in May 2000. Mindful of possible community resistance to consuming NEWater, only indirect reuse by mixing the recycled water with reservoir water was introduced initially (Seah et al., 2003). At present, recycled water makes up 3% of the potable water supply in Singapore, and the aim is to increase this to 20% by 2015 (Hurlimann, 2008).

Intensive education campaigns by Singapore's Public Utilities Board (PUB) were launched to raise people's awareness of NEWater, making use of documentary feature films, media exposure, information briefings at community centres and schools, and a NEWater Visitor Centre (Collins, 2003). There were reports of public hesitation to use NEWater; according to Seah (2002), some people were ready to pay more for imported water rather than having to drink NEWater. However, an independent poll by Forbes Research (Collins 2003), which the government often cited, did not confirm these findings. The poll indicated an overwhelming level of NEWater acceptance among Singaporeans. Despite signs of public puritanism at drinking recycled water, NEWater has been mixed with the local water supply since 2003 (Po et al., 2003).

Singapore's future water supply was under threat, and this was regarded by both the government and the people of Singapore as a very sensitive issue. The success of the projects is largely attributed to the realisation of the need for a secure and self-sufficient water supply, and a belief in the government's ability to effectively address that need. Community concerns and attitudes were given special consideration, and planning was undertaken accordingly. Citing the fact that there had been no ill-health impact on US citizens who had consumed recycled water for the past 20 years, NEWater assured the general public of the quality of the water, and this was one of the strongest strategies for ensuring belief and trust among the general public. Po et al. (2003) advocates that heightening people's awareness of water issues by providing information about successful reuse projects is advantageous in addressing people's health risk concerns. In a residential strategy survey conducted in different parts of Sydney, one third of participants said that they would accept the use of recycled water if they knew that other cities were safely using it (Ngo et al., 2009). A major element of the success of recycled water projects is community confidence that the treatment system is effective (Christen, 2005). Advanced technology has been adopted for producing drinking quality recycled water, and a comprehensive study concluded that the reclaimed water produced met both the US-EPA and WHO guidelines for drinking water and is purer than tap water (Po et al., 2003; EPA, 2004). US-EPA and WHO guidelines for drinking water are very popular among the general public and they owe their beliefs to these guidelines.

The conveyance of information to the general public was managed very well, and along with adequate information, was a major strength of the project. Its success can also be attributed to the intensive education campaigns with innovative approaches that were launched to raise people's awareness of NEWater. According to Kyodo News International 2003, 1.5 million bottles of NEWater were distributed to the general public by the government for the general public evaluate for themselves (Po et al., 2003). Top government officials and experts were photographed savouring the water. Singapore is a country where the government is strong and carries authority, which was also a forceful factor in implementing the use of recycled water for drinking purposes (Marks, 2006). Over time, the NEWater project has become a matter of pride for the people of Singapore

2.5.2 Controversial water reuse schemes

Wastewater reuse incorporates the general public as the consumer and is hence a sensitive issue. A number of water reuse projects have been observed to be unsuccessful because of a lack of community confidence in the project. These include water reuse projects in Europe, Australia and the US. Quakers Hill in Sydney, Toowoomba QLD (Australia) and San Diego, Tampa (US) (Hurlimann, 2008) are some of the controversial water reuse schemes. There are many issues that can be attributed to the failure of those projects, and San Diego (US) and Toowoomba (Australia) are considered as case studies in the sub-sections below.

A. San Diego, United States of America

Prior to the 1990s, Southern California benefited from water imported from the Colodo River Aqueduct which constituted of about 90% of San Diego's supply (Hartley, 2005). The increasing demand in San Diego and the decreasing supply from an imported source gave rise to the idea of introducing recycled water as a supplement to the city of San Diego's drinking water supply during the 1991–92 drought.

A comprehensive research project was established to understand public willingness to use recycled water and to identify potential issues that needed to be addressed. The research included public opinion studies, focus groups, and individual interviews with community leaders and policy makers. Various public outreach works were undertaken, including the distribution of brochures and related fact sheets, video presentations about the project, feature stories in newspapers and other media outlets, and a telephone enquiry line.

According to Katz and Tennyson (1997), a high number of respondents to a telephone survey of more than 300 San Diego residents indicated support for the use of recycled water. This project proposal was also submitted to the scrutiny of an Independent Advisory Panel and a citizens' review committee to give greater assurance to the general public; which concluded that recycled water was an acceptable option, and would provide a much-needed source for the region (Wegner-Gwidt, 1998). At the time of the project's final approval, and regardless of the strong support from a wide variety of community organisations, the project became entwined in political campaigns and became a political issue, which eventually brought the whole project to a halt. Political campaigners claimed that the city intended to take wastewater from prosperous communities to distribute as drinking water to less prosperous communities, and health dangers from the project were specifically highlighted. The State Department of Health Services consequently called a hearing for the project. Many emotionally concerned and worried residents attended the hearing after seeing advertising posters carrying the slogan "Toilet to Tap" (Po et al., 2003). Ultimately, the project was put on indefinite hold by the San Diego City Council.

The realisation of the fact that their water is being imported and there is a water supply problem in the city of San Diego seems to fail to be recognised by the general public (Hartley, 2005; Christen, 2005). This information lag is one of the major weaknesses of the project. There is a failure to provide an adequate and understandable explanation of the purification system and water quality to the general public. Extensive public education and outreach programs were launched, but only after the project's conception, with the result that planning was perceived to have taken place without public participation or knowledge, thus creating an atmosphere of distrust. Po et al. (2003) states that it is very important to involve the general public from the planning phase to maintain belief and trust. A lack of transparency in the earliest stages of planning, and limited community outreach, characterised the public consultation efforts in San Diego (Marks, 2006). Marks (2006) advocates that non-potable reuse is another feasible option that would allow a gradual approach to the use of recycled water by the general public, but this idea was not fully developed or not established when potable reuse was being proposed in San Diego, neither was non-potable reuse offered as an option in surveys of public opinion conducted at that location. Okun (2002) advocates where nonpotable reuse is feasible, it should be a higher priority because it carries the least public health risk and the greatest likelihood of public acceptance.

Social marketing of the product, which should include adequate promotion of the benefits of the project and adequate information about the source and quality of the product, was lacking. The public campaign for the project did not adequately address public perceptions about water quality and water sources, and purification systems, and lacked understandable explanations that might have changed public perceptions. Huge communication gaps between the water reuse organisation and key stakeholders existed, and no adequate priority was given to each group of stakeholders. This type of gap in information is frequently used by opponents of a project to build a counter-campaign. In the case of San Diego, this led to opposing campaigns which made claims about water distribution and health, as already outlined above. Health in particular has been always a sensitive issue and is a core concern of people in regard to using recycled water. The failure of reuse organisations to allay stakeholder doubts about possible health risks associated with water reuse was very detrimental and contributed to the failure of the project (Khan and Gerrard, 2006).

B. Toowoomba, Australia

The water situation in regional areas of Australia such as Toowoomba is critical. A policy result of the prevailing drought was the implementation of restrictions to water use. Toowoomba residents had faced restrictions to water use since 2003. Level 1 restriction began in 2003, ultimately reaching Level 5 restrictions in 2006, which have not been lifted. With the aim of addressing the city's water challenges, the 'Water Futures Initiative' (WFT) was announced by Toowoomba City Council (TCC) at the beginning of July 2005. The construction of an advanced water treatment plant to provide potable quality recycled water for the town was one of the most prominent parts of the project (TCC, 2008). As part of the proposal, TCC planned to undertake a three year community engagement program (TCC, 2005). This was all in policy document but till then there exists no sign of communication with the general public. The opposition group 'Citizens against drinking sewage' (CADS) formed on 21st July 2005 and made its first move against the WFT by providing detailed arguments against potable recycled water to the public. Six months later, on 24th February 2006, 10,000 people signed a CADS petition against the potable recycled water initiative. Hence, CADS benefited from a 'first mover advantage' (refer Lieberman and Montgomery, 1988, quoted in Hurlimann and Dolnicar, 2010).

The appeal lodged on 30 June 2005 by the Toowoomba Council to the National Water Commission for funding towards the project was already supported by all nine councillors (elected representatives at local government level), and by all local members of the State and Commonwealth Parliaments (Hurlimann and Dolnicar, 2010). However, probably because of the increasing opposition of the public to the project, a referendum was announced on 24th March 2006 by Malcolm Turnbull (Parliamentary Secretary to the Prime Minister) to assess the attitude of the residents of Toowoomba in regard to the Water Futures Project (Hurlimann and Dolnicar, 2010). The Federal Government promised to contribute AUD 22.9 million towards the project only if the public supported the project.

Toowoomba City Council thus found itself in the situation of condensing a proposed three year community engagement program into a two and a half month information campaign. By the time Council started informing the public, CADS had been communicating with Toowoomba residents for more than six months. Also, by contrast with CADS, Council was bound by a Code of Conduct and thus had to ensure that campaign content was at all times 'above board' (Hurlimann and Dolnicar, 2010). On 29th July 2006, the referendum was held in Toowoomba. The majority, 62% of residents, voted against the proposed recycled water scheme (Sydney Morning Herald, 2006). As a consequence, the Water Futures Project was abandoned.

Toowoomba was the first and only project in Australia to propose the use of recycled water for drinking purposes. A community engagement program was decided upon but not implemented in the initial planning phase, and a significant communication gap existed between the water reuse organisation and the local stakeholders, which was used by CADS to construct a huge wall of information against potable recycled water. This gave CADS the first mover advantage of becoming the benchmark of information to the general public. The absence of an adequate and understandable explanation of the purification system and water quality to the general public was detrimental, and the move towards providing that information came too late and was too brief. Also, the health related issues presented by CADS were not well addressed or justified by the water reuse organisations. The concept of 'toilet to tap' is somewhat emotionally charged – a response that is understandable given the breadth of human experience with disease resulting from drinking water contaminated with sewage. Similarly, the potential loss of fertility or other human functions that could result from the presence of an ever-increasing number of designer pollutants and drugs in the water supply caused alarm (Schäfer and Beder, 2006). Politics and vested interests were also reasons behind the failure; Hurlimann and Dolnicar (2010) summarise the reasons for the failure of the project as being the combination of public opposition, politics, vested interests, timing, and information manipulation.

2.6 Conclusions

Best practice measures for the successful implementation of water reuse schemes can be very diverse and can vary from region to region for a number of reasons. The feasibility of water reuse schemes from social, economical and technical aspects plays an important role. Consideration of community attitudes to the use of recycled water has been observed as being a critical component for the successful implementation of any recycled water project, and the following key elements for community acceptance and the successful implementation of water reuse schemes will be considered in this study: adequate social marketing and public outreach from the initial phase; a political situation that is in favour of the project; strong financial means arranged by the government and stakeholders; the level of water stress and its recognition by the general public; public awareness of the potential of the reuse scheme and the availability of alternative water resources; the trust and belief of the general public in water reuse authorities; the variety of end uses available for recycled water; the advanced technology used to produce water that is fit for purpose; and the geographical properties of the catchment. Finally, the integration of this diverse spectrum of issues, all of which are critical to the successful implementation of water recycling projects, but none of which can achieve progress alone, is the most important step.

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CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This research aims to develop a sustainable approach for urban water by introducing a new end use for recycled water- clothes washing machines. The research methodology was designed to define maximum allowable values of heavy metals in recycled water for household laundry (clothes and washing machines), to investigate the effects of recycled water on cloths and washing machines and identify the general public acceptance regarding the new end use of recycled water. The detail research methodology is presented below.

3.2 Methodology for experimental investigation with heavy metals

3.2.1 Experimental set up and aqueous solution preparation

The laboratory-scale experimental unit consists of two main components, namely a feeding system (water tank and feed pump) and a washing machine. The experiments were designed for estimating the concentration response to risks caused by the contaminants in terms of appearance, stains on fixtures and clothing, odour, white deposits on fixtures, hard-to-lather soap, corrosion of washing machine etc. A single component (individual element) based aqueous solution with various concentration of the component was prepared with tap water for all targeted study elements (Cu, Fe, Mn, Pb and Zn). All metals were sourced from corresponding metal nitrates except lead which was sourced from lead hydroxides. The concentration variation was formulated according to a thumb rule of 20 times the normal availability of that element in normal drinking water (WHO, 2004; ADWG, 2004; EPA, 2011). In addition, the normal trend of availability of these heavy metals in the recycled water supplied in dual supply systems of few suburbs in Sydney (Storey, 2009) was used as reference value and a thumb rule of 10 times those values was used for pre-determining the tested concentration.

For instance, the health-based guideline value of 0.4 mg/L of Mn (WHO, 2004) and 0.5 mg/L of Mn according to the Australian Drinking Water Guidelines (ADWG, 2004) should be adequate to protect public health. However, concentrations below 0.05

mg/Litre in drinking water is suggested (WHO, 2004). Normal availability of Mn in potable water is 0.002 mg/L and recycled water is 0.02 mg/L (Storey, 2009). Therefore, the concentration range from 0.01 mg/L to 2 mg/L has been chosen for investigations with Manganese. The health-based guideline value of 2 mg/L of Cu and aesthetic-based guideline value of 1mg/L of Cu has been suggested by ADWG (2004). A provisional guideline value of 2 mg/L of Cu was established in the second edition of the WHO Guidelines which was subjected to review (WHO, 2004) whereas 1.3 mg/L of Cu in drinking water has been suggested by EPA. EPA has set this level of protection based on the best available science to prevent potential health problems (EPA, 2011). Therefore, the concentration range from 1mg/L to 20 mg/L has been chosen for investigations with Cu. The aesthetic-based guideline value of 0.3 mg/L of Cu has been suggested by ADWG (2004). The maximum contaminant level of Fe in drinking water according to EPA is 0.3 mg/L (Colter and Mahler, 2006). Normal availability of Fe in potable water is 0.02 mg/L and recycled water is 0.04 mg/L (Storey, 2009). Therefore, the concentration range from 0.1 mg/L to 6 mg/L has been chosen for investigations with Fe. It has been suggested that taking into account the recent studies on humans, the derivation of a guideline value of Zn is not required at this stage of time. However, drinking-water containing Zn at levels above 3 mg/L may not be acceptable to consumers. According to the WHO (2003), drinking water containing Zn at levels above 3 mg/L tends to be opalescent. The ADWG (2004) also suggested only the aesthetic-based guideline value which is 3 mg/L of Zn. Hence, for our research purpose the concentration range from 1 mg/L to 60 mg/L was chosen for investigations with Zn. The health-based guideline value of Pb according to WHO standards and ADWG is 0.01 mg/L (WHO, 2004; ADWG, 2004). Hence, for our research purpose, the concentration range from 0.01mg/L to 2 mg/L was selected for investigations with Pb. The details of the concentration range of heavy metals chosen for aqueous solution preparation are summarized in Table 3.1.

Table 3.1 Concentration range of heavy metals in drinking water

Heavy metals	WHO, 2004 (Health/Aesthetic) (mg/L)	ADWG, 2004 (Health/Aesthetic) (mg/L)	EPA, 2011 (mg/L)	Concentration for lab investigations (mg/L)
Fe	0.3	0.3	0.3	0.1 - 6
Zn	3	3	3	1- 60
Pb	0.01	0.01	NA	0.01 - 2
Mn	0.05/0.4	0.5/1	NA	0.01 - 2
Cu	2	2/1	1.3	1 - 20

The most sensitive colour (white coloured fabrics) was selected for washing. Five types of representative cloth textile (polyester, satin, polycotton, denim and organic cotton) were used for the tests. They were cut by 25 cm x 20 cm for washing by Simpson (5.5 kg), top loading. Omo is chosen as a washing powder. Washing of the selected cloth samples were performed for 50 wash cycles in normal tap water as well as the aqueous solution of heavy metals of various concentrations. After washing, the test samples were progressed for drying at 1st, 5th, 10th, 20th 30th and 50th wash cycles. The details of the lab set up are summarized in Table 3.2.

Table 3.2 Summarized details of the lab set up

Washing machine type	Simpson (5.5 kg), Top loading
Mode of washing	Light and fast
Washing powder	Omo
Water supply	Cold form of supply of tap water at room temperature
Size of cloth swatches	25 cm x 20 cm
Cloth category	Polyester (Po), Satin (S), Polycotton (PoC), Denim (De) and Cotton (C)

3.2.2 Testing methods

Various testing methods have been adopted with the aim of analysing the durability and aesthetic appearance of cloth materials washed in aqueous solutions of varying concentrations of individual element. The cloth swatches are washed in normal tap water and those aqueous solutions for same number of wash cycles. Then the comparative study is carried out to see the change in properties of cloth swatches. The detail of the test methods is summarised in **Figure 3.1**.

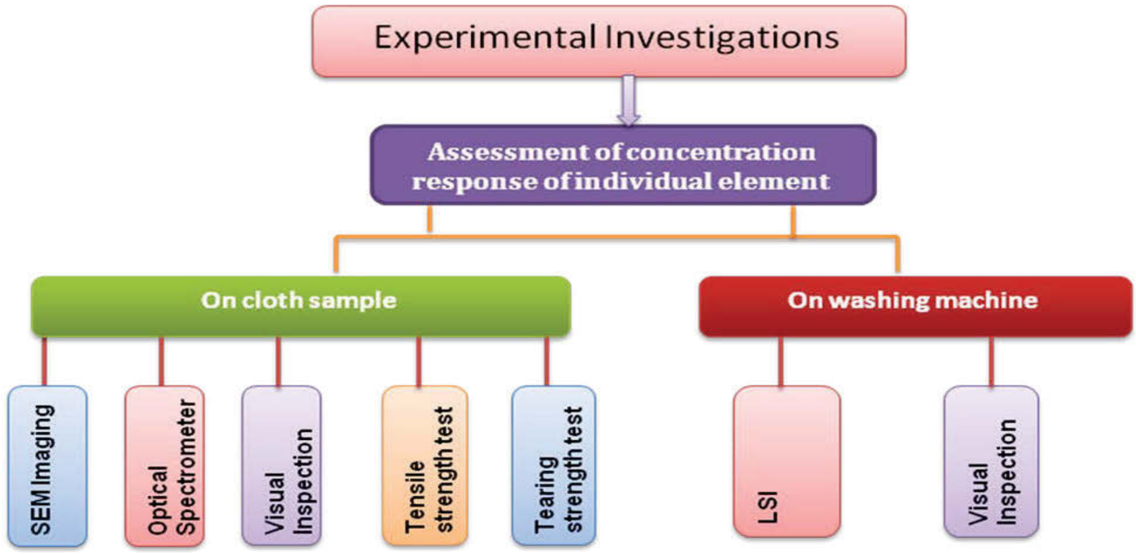

Figure 3.1 Testing methods.

A. Tensile and Tearing strength tests

To investigate the effects of aqueous solutions on cloth durability, tearing strength tests and tensile strength tests of the washed cloth samples were carried out using Instron 6022 10kN Universal Testing Machine (Figure 3.2) according to the ASTM standards (ASTM, 2006; ASTM, 2010). The washed cloth samples were prepared according to the test standard as per ASTM and then applied for the tests. For the tensile strength test, each specimen was cut such that the width is 25 mm (±1) and at least 150 mm in length with the long dimension accurately parallel to the direction of testing and force application. Specimens were cut with their long dimensions parallel to the warp (machine) direction. A test specimen is clamped in a tensile testing machine and a force is applied to the specimen until it breaks. Values for the breaking force and elongation of the test specimen are obtained from a computer interfaced with the testing machine. Similarly for tearing strength tests, each specimen was cut such that the sample size is

75 mm by 200 mm. It was made sure that specimens were cut with their long dimensions parallel to the cross-machine direction. A preliminary cut of 75 mm (length wise) was made at the centre of the 75 mm width. Then the two cut edges of the specimen are clamped in a tensile testing machine and a force applied to the specimen until it breaks. Firstly, the tensile and tearing strengths of original samples were measured. Similarly, tensile strengths of the same cloth samples washed in tap water and aqueous solutions of various concentrations of Cu were then determined. Basically, the measurement of tensile and tearing strength of the samples at 1st wash, 5th wash, 10th wash, 20th wash, 30th wash and 50th wash were conducted. MINITAB 16 as a statistical tool was used and ANOVA One way test was applied for the significance analysis (Tukey's test $p < 0.05$).

Figure 3.2 Instron 6022 10kN Universal Testing Machine interfaced with computer.

B. Colour measurements and colour difference calculation

The human eye is more sensitive to some areas of colour and less sensitive to others and to compensate for the inadequacies of the human eye, colour is defined in a uniform three dimensional space known as the CIELAB space (Figure 3.3). The CIELAB space is a uniform three dimensional space defined by the colorimetric coordinates L*, a* and b* - L* (lightness, ranging from 0 to 100 with higher numbers being brighter), a* (green–red coordinate), b* (blue–yellow coordinate) (C.I.E., 1986). The CIE L*a*b* space can calculate the distance between the points representing different colour stimuli, this distance is called the colour difference, usually designated as ΔE_{ab} (Billmeyer and Allesi, 1981; Kuo et al., 1995; Hirschler, 2010). There are three different formulas to choose from CIELAB76 (ΔE76); CIE94 (ΔE94); CIEDE2000 (ΔE2000) (Brigeman, 1987; Luo et al., 2001 and Kim and Ann, 2012). All these formulas have been used for the analysis of the colour change of cloth materials.

Figure 3.3 Colour plotting diagram for L*, a* and b*.

CIELAB76 (ΔE76)

$$\Delta E_{ab}^{*} = \sqrt{\left(L_1^{*} - L_2^{*}\right)^2 + \left(a_1^{*} - a_2^{*}\right)^2 + \left(b_1^{*} - b_2^{*}\right)^2} \qquad \textbf{(3.1)}$$

where,

L_1^{*}= L standard

L_2^{*}= L sample

a_1^{*}= a standard

a_2^{*}= a sample

$b_1^* =$ b standard

$b_2^* =$ b sample

CIE94 (ΔE94)

$$\Delta E_{ab}^* = \sqrt{\left(\frac{\Delta L^*}{K_L}\right)^2 + \left(\frac{\Delta C_{ab}^*}{1+K_1 C_1^*}\right)^2 + \left(\frac{\Delta H_{ab}^*}{1+K_2 C_1^*}\right)^2} \qquad \textbf{(3.2)}$$

where,

$$\Delta L^* = L_1^* - L_2^*$$

$$C_1^* = \sqrt{a_1^{*2} + b_1^{*2}}$$

$$C_2^* = \sqrt{a_2^{*2} + b_2^{*2}}$$

$$\Delta C_{ab}{}^* = C_1^* - C_2^*$$

$$\Delta H_{ab}^* = \sqrt{\Delta E_{ab}^{*\,2} - \Delta L^{*2} - \Delta C_{ab}^{*\,2}} = \sqrt{\Delta a^{*2} + \Delta b^{*2} - \Delta C_{ab}^{*\,2}}$$

$$\Delta a^* = a_1^* - a_2^*$$

$$\Delta b^* = b_1^* - b_2^*$$

and where the weighting factors K for textiles:

$K_L = 2$

$K_1 = 0.048$

$K_2 = 0.014$

CIEDE2000 (ΔE2000)

$$\Delta E_{00}^* = \sqrt{\left(\frac{\Delta L'}{S_L}\right)^2 + \left(\frac{\Delta C'}{S_c}\right)^2 + \left(\frac{\Delta H'}{S_H}\right)^2 + R_T \frac{\Delta C'}{S_C}\frac{\Delta H'}{S_H}} \qquad \textbf{(3.3)}$$

Where

$$\Delta L' = L_2^* - L_1^*$$

$$\overline{L} = \frac{L_1^* + L_2^*}{2}$$

$$\overline{C} = \frac{C_1^* + C_2^*}{2}$$

$$a_1^{'} = a_1 + \frac{a_1}{2}(1 - \sqrt{\frac{\overline{C}^7}{\overline{C}^7 + 25^7}}$$

$$a_2^{'} = a_2 + \frac{a_2}{2}(1 - \sqrt{\frac{\overline{C}^7}{\overline{C}^7 + 25^7}}$$

$\overline{C^{'}} = \frac{C_1^1 + C_2^{'}}{2}$ and $\Delta C^{'} = C_2^{'} - C_1^{'}$ where $C_1^{'} = \sqrt{a_1^{'2} + b_1^2}$ and $C_2^{'} = \sqrt{a_2^{'2} + b_2^2}$

$h_1^{'} = \tan^{-1}\left(\frac{b_1}{a_1^{'}}\right) \bmod 2\pi \quad h_2^{'} = \tan^{-1}\left(\frac{b_2}{a_2^{'}}\right) \bmod 2\pi$

$\Delta h' = h_2' - h_1'$ if $| h_1^{'} - h_2^{'} | \leq \pi$

Or $\Delta h^{'} = h_2^{'} - h_1^{'} + 2\pi$ if $| h_1^{'} - h_2^{'} | > \pi$, $h_2^{'} \leq h_1^{'}$

Or $\Delta h^{'} = h_2^{'} - h_1^{'} - 2\pi$ if $| h_1^{'} - h_2^{'} | > \pi$, $h_2^{'} > h_1^{'}$

$\Delta H^{'} = 2\sqrt{C_1^{'} C_2^{'}} \sin\left(\Delta h^{'}/2\right)$

$\overline{H^{'}} = (h_1^{'} + h_2^{'} + 2\pi)/2$ if $| h_1^{'} - h_2^{'} | > \pi$

Or $\overline{H^{'}} = (h_1^{'} + h_2^{'})/2$ if $| h_1^{'} - h_2^{'} | \leq \pi$

$$T = 1 - 0.17\cos(\cos(\overline{H}' - \pi/6)) + 0.24\cos(\cos(2\overline{H}'))$$
$$+0.32\cos(3\overline{H}' + \pi/30) - 0.20\cos(4\overline{H}' - 21\pi/60)$$

$$S_L = 1 + \frac{0.015(\overline{L} - 50)^2}{\sqrt{20 + (\overline{L} - 50)^2}}$$

$$S_C = 1 + 0.045\overline{C'}$$

$$S_H = 1 + 0.045(\overline{C'})T$$

$$R_T = -2\sqrt{\frac{\overline{C'}^7}{\overline{C'}^7 + 25^7}}\sin\left[\frac{\pi}{6}\exp\left(-\left[\frac{\overline{H'} - 275^0}{25}\right]^2\right)\right]$$

where,

ΔL* = difference in lightness/darkness

+ ΔL* means sample is lighter than standard,

– ΔL* means sample is darker than standard

Δa* = difference on red/green axis,

+Δa* means sample is redder than standard

–Δa* means sample is greener than standard

Δb* = difference on yellow/blue axis,

+Δb*means sample is yellowier than standard

–Δb* means sample is bluer than standard

ΔC* = difference in chroma,

+ΔC*means sample is brighter than standard

–ΔC* means sample is duller than standard

ΔE* = total colour difference value

ΔE meaning:

0 - 1: meaning a normally invisible difference

1 - 2: very small invisible difference, only obvious to a trained eye

2 - 3.5: medium difference, also obvious to an untrained eye

3.5 - 5: an obvious difference

> 6: a very obvious difference

C. Scanning Electron Microscope

The surface characteristic change in fabrics can be identified by scanning electron microscope (Figure 3.4). A scanning electron microscope helps to detect at high spatial resolution. It is a type of electron microscope that copies a sample by scanning it with a high-energy laser of electrons in a raster scan pattern. The very small piece of those washed cloth samples were subjected to test in Scanning electronic microscope to investigate the aesthetic appearance of the cloth materials and to detail the condition of the internal structure of the cloth material with the increased number of washing and increased concentration of targeted elements that were discussed above. The images of the cloth samples washed in tap water and washed in various aqueous solutions were taken and observed. The images of the sample at 1st wash, 5th wash, 10th wash and 50th wash were compared to see the change.

Figure 3.4 Scanning electronic microscope.

3.3 Methodology used for the experimental investigation with recycled water

3.3.1 Experimental set up

The Port Macquarie Reclaimed Water Plant (PMRWP) in Port Macquarie, City West Water (CWW) in Melbourne and Sydney Olympic Park Authority (SOPA) in Sydney were the three providers of recycled water for the experimentations. The laboratory-scale experimental unit consists of two main components, namely a feeding system (water tank and feed pump) and a Simpson (5.5 kg), top loading washing machine. Five types of representative cloth fibers (polyester (Po), satin (S), polycotton (PoC), denim (De) and cotton (C) were used for the tests. The cloth swatches were cut in to the size of 25 cm x 20 cm. Cold form of supply of tap water and recycled water was used. The lifespan of a fabric is directly related to the number of wash cycles it can endure. According to the International fair claims guide for consumers textiles products, assuming normal wear, most of clothes are expected to last somewhere between two and three years (Mainali et al., 2013a). This leads to around 50 laundering of the cloth fabrics in an average during its normal life span. Therefore, washing of the clothes was performed up to 50 wash cycles in tap water as well as in recycled water from Port Macquarie, Melbourne and Sydney. After washing, the test samples were progressed for drying at 1^{st}, 5^{th}, 10^{th}, 20^{th}, 30^{th} and 50^{th} wash cycles.

3.3.2 Testing methods

The physical, chemical, biological and microbiological analyses of recycled water from three different providers are carried out. Various testing methods as per the objectives have been adopted for the in depth study regarding this new end use of recycled water. The cloth swatches are washed in normal tap water and recycled water for same number of wash cycles. Then the comparative study is carried out to see the change in the properties of cloth swatches. The microbial analysis of cloth samples are also carried out. The detail of the test methods is summarised in Figure 3.5.

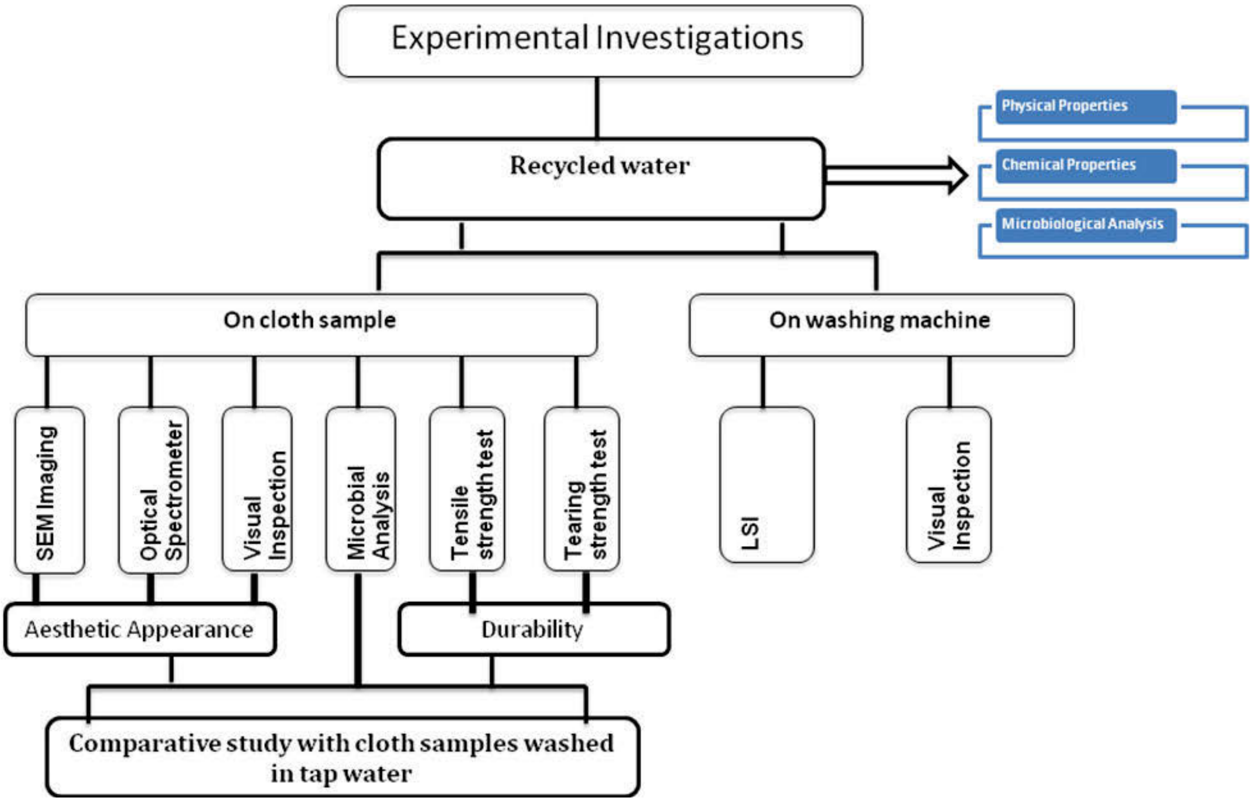

Figure 3.5 Summarized test methods.

A. Tensile and Tearing strength tests

Tensile strength and tearing strengths both are the most important strength parameters of cloth fibres exhibiting the durability of the cloth material (Witkowska and Frydrych, 2005). To investigate the effects of recycled water on cloth durability, tearing strength tests and tensile strength tests of the washed cloth samples were carried out using Instron 6022 10kN Universal Testing Machine (Figure 3.2) according to the ASTM standards (ASTM, 2006; ASTM, 2010; Mainali et al., 2013 a). Constant-rate-of-extension (CRE) tensile testing machine was used which moves with a speed of 300mm ± 10mm per minute. The washed cloth samples were prepared according to the test standard as per ASTM. The observation of tensile and tearing strength of the samples at 1^{st} wash, 5^{th} wash, 10^{th} wash, 20^{th} wash, 30^{th} wash and 50^{th} wash were conducted. A comparative study was carried out to see if there is any significant reduction in tensile and tearing strengths of cloth samples washed in recycled water compared to the strengths of cloth samples washed in tap water at identical washing conditions. ANOVA One way test (Tukey's test $p<0.05$) was applied to see if the values differ significantly or not.

B. Colour measurements and colour difference calculation

The change in colour of cloth samples washed in tap water and recycled water are analysed by measuring the colour difference using Spectrometer Perkin Elmer LAMBDA 950. The human eye is more sensitive to some areas of colour and less sensitive to others and to compensate for the inadequacies of the human eye, colour is defined in a uniform three dimensional space known as the CIELAB space. The CIE L*a*b* space can calculate the distance between the points representing different colour stimuli, this distance is called the colour difference, usually designated as ΔE_{ab} (Fred et al., 1981; Kuo et al., 1995; Hirschler, 2010). There are three different formulas CIELAB76 (ΔE76), CIE94 (ΔE94) and CIEDE2000 (ΔE2000) (Brigeman, 1987; Luo et al., 2001; Sharma et al., 2004 and Lucassen et al., 2008). All three formulas have been made used here and a comparison in values has been presented.

C. Scanning Electron Microscope

The change in surface morphology of fabrics can be identified by scanning electron microscope (SEM) as shown in Figure 3.4. A scanning electron microscope uses electrons instead of light to form an image of a sample by scanning it with a high-energy laser of electrons in a raster scan pattern. The very small piece of those washed cloth samples were subjected to test in Scanning electronic microscope. The images of the cloth samples washed in tap water and recycled water from three providers were taken and observed. The images of the sample at 1st wash, 5th wash, 10th wash and 50th wash were compared to see the change.

D. Microbial Analysis of Recycled water and cloth samples

The microbiological analysis of the tap water, recycled water and the cloth samples washed in recycled water were carried out in AMS Laboratories Pty. Ltd. The analyses were performed in wet cloth samples, machine dried cloth samples and air dried cloth samples. The microbiological study is represented in terms of faecal Coliform, E.coli count, Saureus count and Pseudomonas count.

E. Langelier Saturation Index

The effects on washing machine durability was investigated using Langelier Saturation Index (LSI= $pH_{calc} - pH_{msr}$) method, which is the pioneer method for prognosticating the corrosive and scale forming tendency of the aqueous solutions (Imran et al., 2005; Prisyazhniuk, 2007). The method was formulated in the thirtieth of the last century by Langelier (Langelier 1936; Degremont 1991) who brought the encroachment in the theory of solutions to analysing the properties of water. The Langelier Saturation Index or LSI was the first attempt which makes it possible to estimate the ability of water to cause corrosion or to quantify the tendency to form scale. Hence, this index provides a simple criterion by which the likelihood of corrosion or scaling can be predicted. LSI is a numerical index which is defined as the difference between the pH_{calc}, calculated from the data of the chemical analysis, and the pH_{msr} measured.

$$LSI = pH_{calc} - pH_{msr}$$

$$pH_{calc} = (9.3 + A + B) - (C + D)$$

where,

$$A = (\text{Log}_{10}[\text{TDS}] - 1)/10$$

$$B = -13.12 \times \text{Log10}(^{o}\text{C} + 273) + 34.55$$

$$C = \text{Log}_{10}[Ca^{2+} \text{ as } CaCO_3] - 0.4$$

$$D = \text{Log}_{10} [\text{alkalinity as } CaCO_3]$$

If the LSI < 0 (negative value), the water causes corrosion of steel. If the LSI = 0, the water is neutral and stable and does not cause corrosion or scaling and when LSI > 0 (positive value), the water can cause scaling on the surfaces of pipelines, heat-exchangers, and other technological equipment. Since the Langelier Saturation Index is rather a qualitative than a quantitative characteristic, its being equal to zero should not be taken too literally. Besides, no one has cancelled the possibility of instrumental errors and errors of approximation (calculation by conventional equations). Therefore, the values of the LSI in the range of -0.5 to +0.5 should be taken as ‘‘zero’’.

As expressed in the above equation, for calculating the LSI of any water sample, the total dissolved solid (TDS), the temperature (T), pH, the Calcium hardness and the total alkalinity of the water sample is very important to know.

3.4 Methodology used in formulating the conceptual design factors for educational leaflets

The comprehensive literature review was conducted to list out the fundamental concepts in recycled water to be dealt in educational leaflets. Practices adopted in the design of educational leaflets in medical field were also cited for more authentic discussion. A small community consultation program was carried out to identify the information required about recycled water in educational leaflets which could help them to be more comfortable and confident when using recycled water for non-potable purposes.

3.4.1 Community Consultation

A preliminary educational leaflet was developed that incorporated basic information on recycled water. A questionnaire was developed based on the design of the educational leaflet with the aim of exploring people's expectations of the information they are willing to find in educational leaflets. A community consultation was carried out with local residents in several suburbs of Sydney, such as Campsie, Granville, Merrylands, Campbelltown, Ashfield, and Newington. The study population included adults above the age of 18 years from different cultural and socio-demographic backgrounds. Interviews were conducted with the parents of children at local primary schools or in community parks near their homes, or in their home. The objective of the group discussions was to elicit people's opinions of the content of the educational leaflet, its layout and format, and their views on what additional information they would require to make them comfortable and confident about using recycled water. Participants were informed about the objective of the group discussion. All interviews were conducted by interviewers trained for this study and demographic data were collected. Participants were given the educational leaflets to read, with no specified time limit. The time taken to read the leaflets was covertly recorded. Questions were asked to assess the participants' understanding of the content and to obtain an overview regarding the design of the leaflet. The acceptability of the leaflet was evaluated by asking for opinions about leaflet shape and size, attraction factors, readability, legibility, layout, misunderstood words and pictures. General comments or suggestions for improvement were encouraged. The Statistical Package for the Social Sciences (SPSS) one way ANOVA test was used for data analysis. The one-way analysis of variance (ANOVA) is used to determine whether there are any significant differences between the means of two or more independent (unrelated) groups. It is important to realise that the one-way ANOVA is an omnibus test statistic and depict two significantly different groups.

3.5 Methodology used for community attitude survey

3.5.1 Survey plan design and execution

A comprehensive literature review was carried out and a survey plan was designed. The computation of the sample size, the development of a questionnaire, the determination of sampling techniques and study area were all addressed in the survey design. Basically, the surveys were divided into three main categories, each dealing with a different situation. This study incorporated all three categories.

- The first category (Non-user of recycled water) consists of studies that attempt to investigate the attitude of the general public towards the water reuse schemes to establish a general idea. The study was carried out in few suburbs (Dunbogan and Laurieton) of Port Macquarie where there may be but yet no robust plan of recycled water supply to the community.

- The second category (Perspective user of recycled water) seeks public opinion on actual, forthcoming water reuse projects. This study was carried out in few suburbs (Manor Lake and Wyndham Vale) of Melbourne where the communities are already equipped with the dual reticulation system and are expecting to receive recycled water supply very soon.

- The third category (Current user of recycled water) examines public attitude in places where reuse schemes have already been put forward in place. This study was carried out in Newington of Sydney where the communities have already been supplied with recycled water.

3.5.2 Questionnaire survey and data analysis

A questionnaire was developed based upon the literature review and the feedbacks from the previous study (Pham et al. 2011). The study population included adults above the age of 18 from different cultural backgrounds and different socio-demographic backgrounds. Interviews were conducted at different public areas such as shopping centres, parks, swimming pools, outside public schools, stations and door to door at their residences.

The statistical package for social science (SPSS) was used for the data analysis. Descriptive statistics were employed to illustrate the respondents' characteristics, their responses, as well as possible differences between sites or groups of people. Wilcoxon Signed Ranks Test was employed to rank the most important factor according to the general community. Chi-square tests (χ^2 = Chi-square; df = degree of freedom) were carried out to provide significance levels for the observed differences whenever needed. The relationship between the various variables was investigated using cross-tabs thereby analysing the Pearson correlation coefficients as well as chi-square tests. Public concern of the use of recycled water was compared using a Chi-square test of a contingency table and a post-hoc multiple comparison test analogous to the Tukey's test (Zar, 2010).

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CHAPTER 4

INVESTIGATIONS WITH SYTHETIC WATER FOR DETERMINATION OF MAXIMUM ALLOWABLE VALUES OF HEAVY METALS IN RECYCLED WATER

4.1 Introduction

Water recycling as an alternative source has been recognised all around the world and has become a priority for the future sustainability and therefore is propagating worldwide. Dual reticulation systems have already been introduced in many cities in the world including Australia and this is likely to expand to many other cities in the future (Mainali et al., 2011a). Considerable amount of fresh water conservation has been achieved because of the use of recycled water in urban communities (Tillman et al., 1999; Ogoshi et al., 2001; Janasava et al., 2005 and Willis et al., 2011). For instance, the dual reticulation scheme at the Rouse Hill Development Area (RHDA) and Sydney Olympic Park Authority (SOPA) traditionally provide recycled water for outdoor garden use, toilet flushing and car washing at a total saving of approximately 35% of potable water use. Developed and proposed dual reticulation schemes in urban areas demand the substantial replacement of tap water with recycled water to ensure system optimisation and the sustainability of water supplies via more conservation of fresh water. Large amount of fresh water from urban household and urban laundry industry can be conserved provided washing machine as a new end use of recycled water (Miler, 2005; Mainali et al., 2011a). Pakula and Stamminger (2010) on the basis of their world wide survey advocate that the volume of water used for laundry washing significantly influences the total water consumption of households in most of the countries in the world. According to statistics in the NSW State of the Environment Report on typical water usage in Sydney metropolitan households, laundry use consumes up to 20% of total water demand (Ngo et al., 2009, Pham et al., 2011). A significant reduction in household drinking water demand could therefore be achieved if the drinking quality water for clothes washing was replaced with recycled water. Therefore, washing machine as a new end use of recycled water in dual reticulation systems in urban cities has a great potential for sustainable urban water management (Dixone et al., 1999; Henderson et al., 2009). However, the laundry use of recycled water has not been sufficiently investigated and researched in the past and hence until today there is no sufficient evidence and supporting quality guidelines for this particular use (O'Toole et al., 2008; Pham et al., 2011; Mainali et al., 2011). There has been no information of this new end use of recycled water in the Australian guidelines for the use of recycled water (Hurlimann and McKay, 2006; Mainali et al., 2011). Moreover, the effects of various heavy metals present in recycled water on clothes and washing machines have not been reported to a required extent (Ngo et al., 2009). This study, therefore, aimed to inform future recycled water quality guidelines to support the use of recycled water in washing machines.

Recycled water sources range over a broad spectrum of chemical quality depending upon the source of the recycled water and the degree of treatment (Radcliffe, 2004). Such water may contain slightly higher concentrations of heavy metals compared to the potable water depending upon the source. The water with higher concentrations of heavy metals may be corrosive or aggressive in nature. As a consequence, the cloth durability may not sustain its usual life span and perhaps more importantly, neither does the washing machine. The aesthetic appearance of the cloth may be affected as well. Probable aesthetics and discolouration of laundry due to the use of recycled water was one of the most important concerns raised by the participants in many community surveys commissioned by researchers (Dolnicar and Saunders, 2006; Hurlimann et al., 2007; Roseth, 2008; Ngo et al., 2009; Pham et al., 2011; Mainali et al., 2013 b). DeKoning et al (2008) advocate that for using recycled water for cloth washing, there should be no deterioration of washing results which makes demands on hardness and concentrations of heavy metals. For that reason, to come up with the clear and concise results to develop the sense of belief among the general public, this study was carried out for predicting the long term effects on the tensile and tearing strengths of cloth samples, for predicting the long term effects like scaling or corrosion of washing machines and for analysing the long term effects on the aesthetic appearance of the cloth samples due to the higher concentrations of heavy metals which may be present in recycled water.

Fabric utility parameters most often depend on its mechanical properties. Tensile strength and tearing strength both are the most important strength parameters of cloth fibres exhibiting the durability of the cloth material (Witkowska and Frydrych, 2005). The lifespan of a textile product is directly related to the number of wash cycles it can endure. Therefore, tensile and tearing strength tests of cloth samples washed in tap water and various concentrations of aqueous solutions after various wash cycles have been carried out and a comparative study was done. MINITAB 16 as a statistical tool was used and ANOVA One way test was applied for the significance analysis (Tukey's test $p<0.05$). One-Way ANOVA is used to compare the means of three or more groups to determine whether they differ significantly from one another. Similarly, Langelier Saturation Index (LSI) method has been used by many researchers (Gacem et al., 2012) for prognosticating the corrosive and scale forming tendency of the aqueous solutions. Thus, to conclude the maximum allowable value of the heavy metals in terms of washing machine durability, LSI has been employed.

The colour of textile material is often one of its most important features and colour is a subjective perception (individual/personal) (Fabiano and Leonardo, 2012). The washed cloth samples were therefore subjected to test in Spectrometer Perkin Elmer LAMBDA 950 to compare the change in colour of the cloth samples washed in tap water and various aqueous solutions. In addition to this, Scanning Electronic microscope (SEM) images of the washed coth samples were developed to analyse the change in surface morphology of the cloth sample.

According to the Australian guidelines for drinking water (ADWG, 1996), staining of sanitary ware and laundry is more likely to occur at Cu concentrations above 1 mg/L, Mn concentrations above 0.1mg/L, Fe concentrations above 0.3mg/L and Zn concentrations above 3mg/L. In addition to this, Fe, Mn and Zn are the heavy metals which have minor contributions on total hardness of water (WHO, 2011). Therefore the heavy metals Iron (Fe), Zinc (Zn), Lead (Pb), Copper (Cu) and Manganese (Mn) are selected as the first targeted study elements for this research. The study aims to determine the maximum allowable values (MAVs) of the heavy metals Iron (Fe), Zinc (Zn), Lead (Pb), Copper (Cu) and Manganese (Mn) in recycled water for washing clothes in washing machines without any bad impacts. Robust guidelines presenting the MAVs of heavy metals in recycled water for washing clothes will not only ensure fewer problems with clothes washing but also develop a sense of belief among the recycled water users. This will encourage beneficial and sustainable use of more recycled water by maximising the reuse of recycled water through minimising and managing any risks associated with its use. This study, therefore, aimed to inform future recycled water quality guidelines to support the use of recycled water in washing machines.

4.2 Methodology

The maximum allowable values of the five targeted study heavy metals (Cu, Fe, Mn, Pb and Zn) in recycled water for using recycled water in washing machines were analysed. Aqueous solutions of varying concentration of the targeted study elements were prepared in the lab. The representative cloth materials polyester (Po), satin (S), polycotton (PoC), denim (De) and cotton (C) were used for washing in thus prepared aqueous solutions of heavy metals and tap water. The comparative studies in terms of tensile/tearing strengths of cloth samples, change in surface morphology, and change in cloth colour using spectrometer were carried out. The visual inspection of cloth and washing machines were also conducted. The details regarding the methodology are summarised in Section 3.2, Chapter 3.

4.3 Results and discussion

4.3.1 Tensile and tearing strength

To investigate the effects on cloth durability, it is important to analyse the change in the tensile and tearing strengths of the cloth samples. The cloth samples were washed in normal tap water for number of cycles. Similarly, the cloth samples were washed in aqueous solutions of various concentrations of heavy metals Fe, Zn, Pb, Cu and Mn for same number of wash cycles. The tensile and tearing strength tests were then employed and comparative study of the tensile and tearing strengths of cloth samples washed in tap water and in various concentrations of heavy metals at same number of wash cycles were carried out.

The comparative study of tensile and tearing strengths of the cloth samples (De, S, Po, Co, PoC) washed in tap water at different wash cycles (1^{st}, 5^{th}, 10^{th}, 20^{th}, 30^{th} and 50^{th}) and the cloth samples washed in various concentration of Cu, Fe, Mn, Pb and Zn at respective number of wash cycles were conducted. No significant variation of tensile strength was observed in the first few cycles of washing. The percentage change in tensile/tearing strengths of the cloth samples after 10^{th} washing was therefore considered for the analysis. Denim and Satin seem to be the strongest cloth fibres (Tensile strength > 500N) in terms of tensile strength test followed by Polycotton, Polyester and Cotton (Tensile strength < 200N) (Table 4.1). In terms of tearing strength () Denim is the strongest cloth type (> 60N) while Polyester and Satin seem to have similar tearing strengths (≈ 40N). Polycotton which holds its position as third strongest cloth type in terms of tensile strength was observed to hold fourth position in terms of tearing strength (≈25N). Cotton was found to have the lowest tearing strength (< 15N).

A. Tensile strength

The results of mean values of tensile strengths of cloth samples washed in various concentrations of aqueous solutions (Cu, Fe, Mn, Pb and Zn) at 10^{th} wash cycles are summarized in Table 4.1.

Table 4.1 Tensile strengths with Cu, Fe, Mn, Pb and Zn washings at 10^{th} wash cycle

Heavy metals	Cloth / Conc. (mg/L)	De	Po	PoC	S	C
	TW	531^{A}±9.5	315^{A}±3.9	398^{ABC}±10.5	551^{A}±6.3	151^{A}±6.3
Cu	1	520^{A}±13.5	321^{A}±19.6	392^{ABC}±15.3	549^{A}±17.1	141^{ABC}±11.5
	2	521^{A}±14.3	283^{BC}±17.8	412^{A}±19.2	553^{A}±11.7	138^{ABC}±10.8
	5	513^{A}±14.3	279^{BC}±17.3	402^{AB}±13.9	560^{A}±11.5	151^{AB}±13.7
	10	448^{B}±18.5	274^{BC}±22.3	390^{BC}±17.2	510^{B}±20.8	144^{ABC}±11.8
	15	450^{B}±31.5	259^{BC}±15.6	378^{CD}±18.8	459^{C}±20.8	137^{BC}±11.8
	20	446^{B}±20.9	297^{B}±25.4	369^{D}±14.8	462^{C}±11.9	133^{C}±10.1

	TW	531^{A}±9.5	315^{A}±3.9	398^{ABC}±10.5	551^{A}±6.3	151^{A}±6.3
Fe	0.1	530^{C}±10.1	308^{ABC}±7.2	392^{D}±5.4	550^{C}±6.1	152^{A}±4.3
	0.3	538^{BC}±7.3	307^{ABC}±6.2	402^{C}±8.8	545^{C}±5.0	157^{A}±4.6
	1	541^{B}±7.8	311^{AB}±5.3	399^{CD}±4.1	560^{B}±5.5	156^{A}±6.2
	3	557^{A}±4.4	300^{CD}±4.2	411^{B}±7.2	569^{A}±2.5	150^{A}±4.3
	4	554^{A}±4.9	299^{D}±10.8	431^{A}±4.7	565^{AB}±4.4	141^{B}±4.1
	5	551^{A}±3.9	304^{BCD}±5.1	434^{A}±2.7	566^{AB}±3.5	145^{B}±4.2
	TW	531^{C}±9.5	315^{A}±3.9	398^{CD}±10.5	551^{C}±6.3	151^{A}±6.3
Mn	0.01	530^{AB}±7.1	316^{A}±9.9	401^{A}±5.5	549^{B}±6.4	151^{A}±6.4
	0.05	531^{AB}±7.2	313^{A}±6.6	400^{A}±6.6	551^{AB}±8.3	148^{AB}±7.6
	0.1	527^{B}±6.7	319^{A}±6.2	402^{A}±6.3	557^{A}±6.3	151^{A}±6.4
	0.5	538^{A}±6.3	305^{B}±6.5	395^{AB}±7.4	547^{B}±4.0	147^{AB}±7.3
	1	530^{AB}±6.8	303^{B}±6.4	389^{BC}±5.5	498^{C}±6.8	147^{AB}±7.0
	2	516^{C}±4.4	303^{B}±6.0	381^{C}±5.3	490^{C}±9.7	139^{B}±8.3
	TW	531^{A}±9.5	315^{AB}±3.9	398^{AB}±10.5	551^{A}±6.3	151^{AB}±6.3
Pb	0.01	524^{AB}±18.3	309^{B}±11.8	388^{BC}±11.2	548^{A}±9.7	154^{A}±7.5
	0.05	522^{AB}±15.6	309^{B}±13.6	409^{A}±11.4	540^{AB}±14.8	150^{AB}±6.5
	0.5	520^{ABC}±17.6	305^{B}±13.4	388^{BC}±10.4	533^{BC}±6.9	144^{B}±7.3
	1	511^{BC}±14.6	308^{B}±12.7	385^{C}±8.0	529^{C}±6.3	145^{AB}±9.6

	2	503^{C}±12.5	297^{A}±15.8	379^{C}±9.4	528^{C}±7.5	146^{AB}±8.5
	TW	531^{AB}±9.5	315^{AB}±3.9	398^{A}±10.5	551^{A}±6.3	151^{A}±6.3
Zn	1	535^{A}±13.3	305^{B}±13.4	396^{A}±15.3	540^{AB}±11.5	149^{A}±9.7
	3	542^{AB}±11.8	301^{B}±13.8	388^{A}±23.0	555^{A}±16.5	144^{A}±10.9
	6	533^{AB}±12.5	304^{B}±14.3	387^{A}±15.9	557^{A}±10.2	145^{A}±11.1
	10	529^{AB}±9.0	319^{AB}±16.6	395^{A}±10.6	554^{A}±9.5	148^{A}±9.5
	30	519^{BC}±17.3	328^{A}±16.9	396^{A}±12.4	539^{AB}±19.7	145^{A}±9.1
	60	505^{C}±20.7	310^{AB}±15.9	392^{A}±16.4	527^{B}±20.1	147^{A}±9.2

Note: A, B, C, D represents the group according to ANOVA-One way analysis (Tukey's test $p < 0.05$, $n = 11$). The values sharing the same alphabets represent no significant difference in tensile strength. (± values are the standard deviations)

Cu Tensile:

Table 4.1 showed that for almost all cloth types (except Po) washed for 10 wash cycles in (≤ 5 mg/L) Cu solution, there was less than 5% (in an average) reduction in tensile strength of cloth samples washed in tap water. For more reliable results, ANOVA- One way test ($p < 0.05$) was employed to test the significance difference of the tensile strengths of the cloth samples washed in tap water and in various aqueous solutions of Cu. No significance difference in the tensile strengths of cloth samples De, PoC, S and C washed in Tap water (TW), 1 mg/L, 2 mg/L and 5 mg/L of Cu solutions was observed. However, cloth sample Polyester did not show any significant change in tensile strength compared to that of TW only up to 1 mg/L (≤ 1 mg/L) of Cu concentration (Tukey's test $p < 0.05$). For cloth sample Cotton, up to 10 mg/L (≤ 10 mg/L) of Cu solution there still exhibited no significant reduction of strength. Hence, accordingly with almost 80% of cloth samples resulting to be safe in terms of their tensile strength in Cu concentration up to 5 mg/L, it is summarised that (≤ 5 mg/L) of Cu solutions, there is no negative impacts on the tensile strengths of cloth samples compared to that of TW.

Fe Tensile:

Table 4.1 further indicated that that most of cloth types for 10 wash cycles in all six concentrations of Fe, there was less than 5% (in an average) reduction in tensile strength of cloth samples washed in tap water. They were observed to have almost the same tensile strength as that of the cloth samples washed in tap water or even more. The results from ANOVA- One way test ($p < 0.05$) revealed no significance difference in the tensile strengths of all cloth samples washed in Tap water (TW), 0.1 mg/L and 0.3 mg/L of Fe solution. Cloth samples Po and PoC did not show any significant change in tensile strength compared to that of TW up to 1 mg/L (≤ 1 mg/L) of Fe concentration (Tukey's test $p < 0.05$). For cloth sample C, up to 3mg/L of Fe solution there still exhibited no significant reduction of strength. For De and S, at Fe concentration of 1 mg/L or above (≥ 1 mg/L), there was significant change in the tensile strengths compared to the same washed in tap water. However, these cloth samples were found to have increased tensile strength but no reduction. Hence, from this analysis, it is summarised that up to 1 mg/L of Fe solutions, there is no negative impacts on the tensile strengths of cloth samples compared to that of TW. The samples washed in higher concentrations of Fe (≥ 0.3 mg/L) however were observed to turn as brownish yellow in appearance, suggesting the impact on aesthetic appearance of cloth samples.

Mn Tensile:

Table 4.1 further indicated that there was not much change in tensile strength of the cloth samples washed in various Mn concentrations compared to cloth samples washed in tap water. In terms of percentage it was only about 3% in an average. However, analysing with ANOVA- One way test ($p < 0.05$), significance difference is observed in tensile strengths of almost all cloth samples except (De and C) washed in 1mg/L and above concentration of Mn solutions compared to the same cloth samples washed in tap water for 10 wash cycles. No significant reduction in tensile strength for almost all cloths (except Polyester) was observed at 0.5 mg/L of Mn (≤ 0.5 mg/L). Hence, summarizing 0.5 mg/L of Mn is recommended safe in terms of tensile strength.

Pb Tensile:

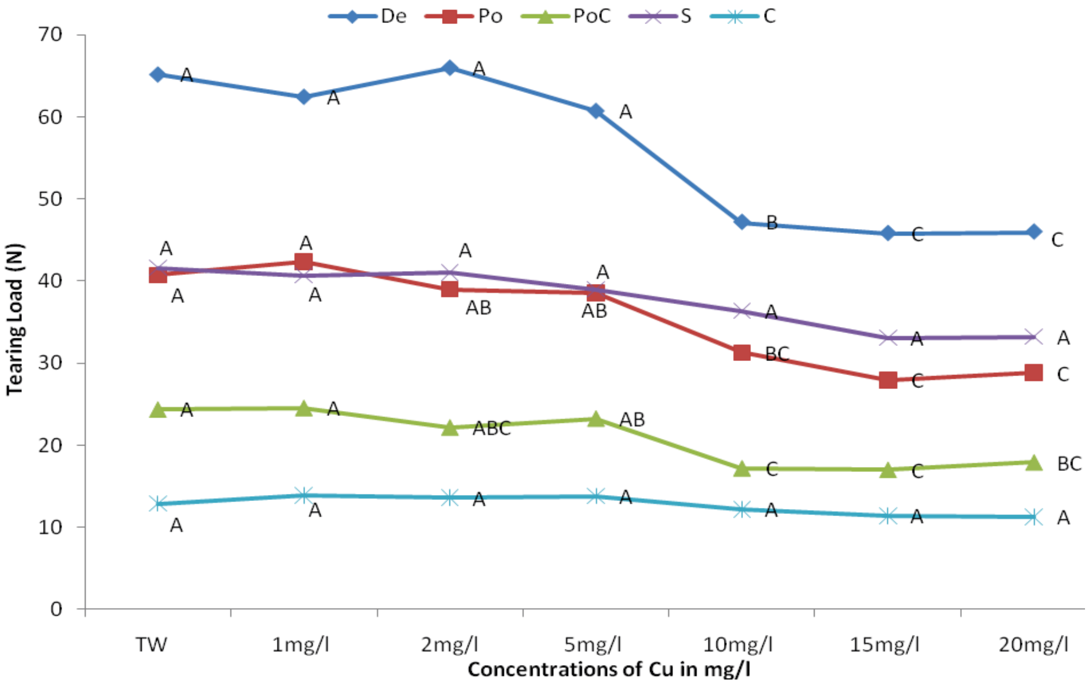
Table 4.1 further showed that all cloth samples washed in Pb solutions showed a trend of reduced tensile strengths with the increase in concentration of Pb. From the significance analysis ($p < 0.05$), no significant reduction in tensile strength for cloth Satin was observed at 0.5 mg/L of Pb (≤ 0.5 mg/L). 1 mg/L of Pb (≤ 1 mg/L) was found to be safe for the cloth sample PoC and De. Up to 2 mg/L of Pb (≤ 2 mg/L), there was no significance difference in tensile strength of cloth samples Polyester and Cotton compared to that of TW. Hence, summarizing 1 mg/L of Pb is recommended safe in terms of tensile strength.

Zn Tensile:

The change in tensile strengths of cloth samples Denim and Satin were significant at Zn concentration above 30 mg/L. However, all other cloth samples Polyester, Polycotton and Cotton washed in tap water and in various concentrations of Zn solutions up to the 10^{th} wash cycle showed no significant reduction in tensile strengths (Tukey's method $p < 0.05$). Therefore, 60 mg/L of Zn is safe in terms of tensile strength test up to 10 wash cycles.

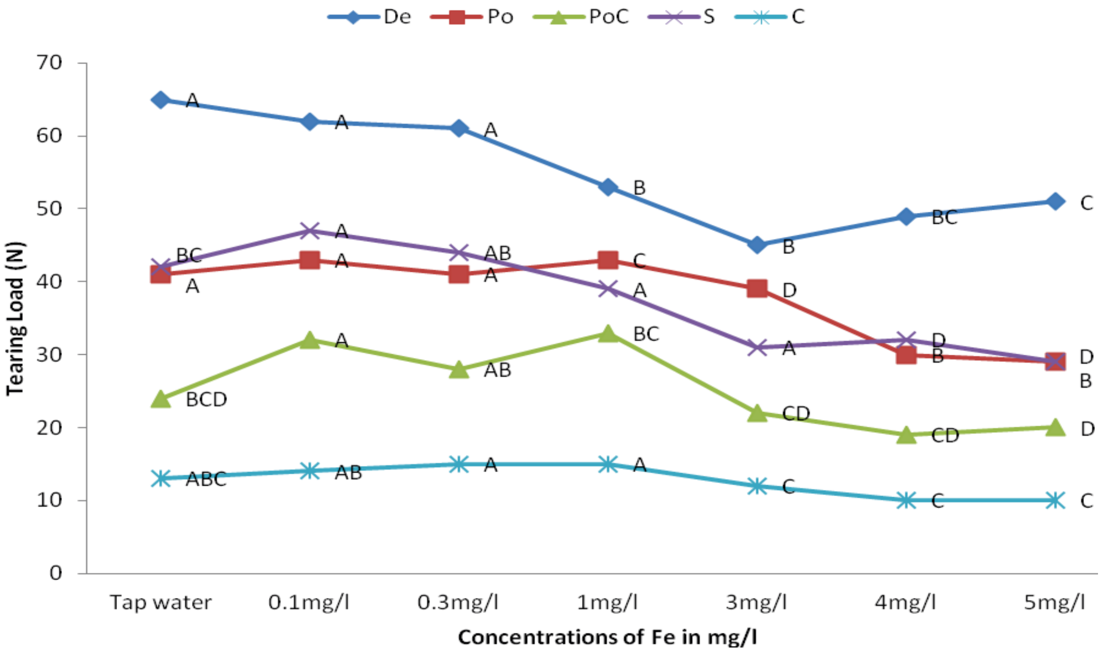
A. Tearing strength

The results of mean values of tearing strengths of cloth samples washed in various concentrations of aqueous solutions (Cu, Fe, Mn, Pb and Zn) at 10^{th} wash cycles are summarized in Figure 4.1 (a), (b), (c), (d) and (e) respectively.



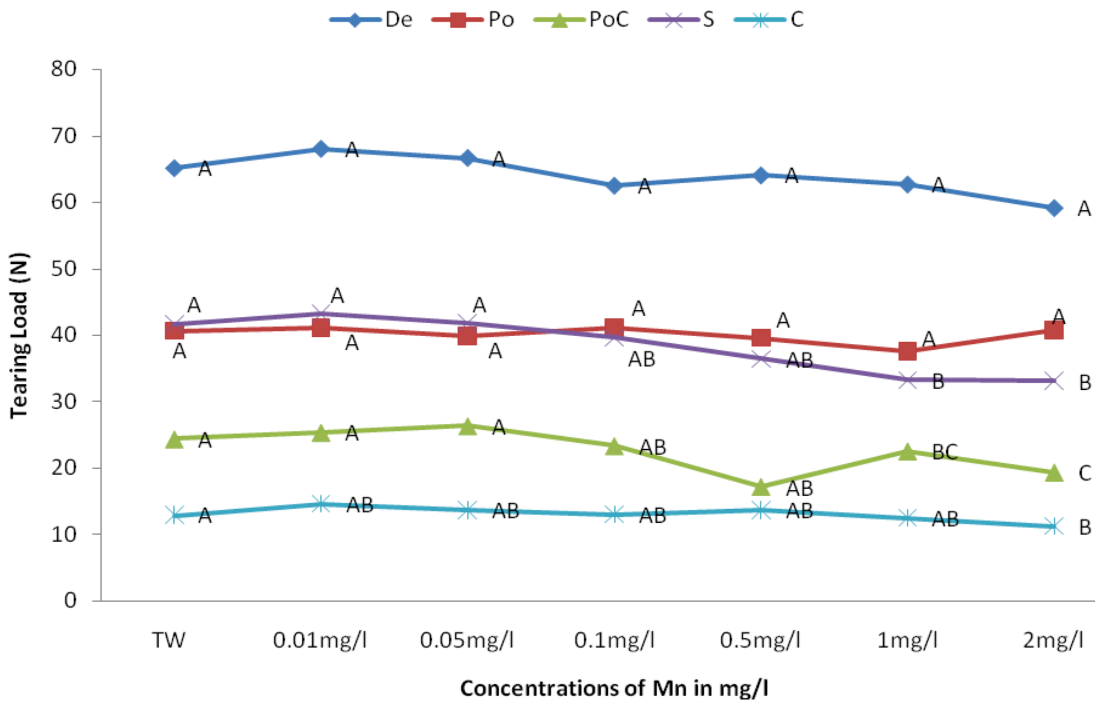
De
Po
PoC
S
C
Tearing Load (N)
Concentrations of Cu in mg/l
TW
1mg/l
2mg/l
5mg/l
10mg/l
15mg/l
20mg/l

(a)

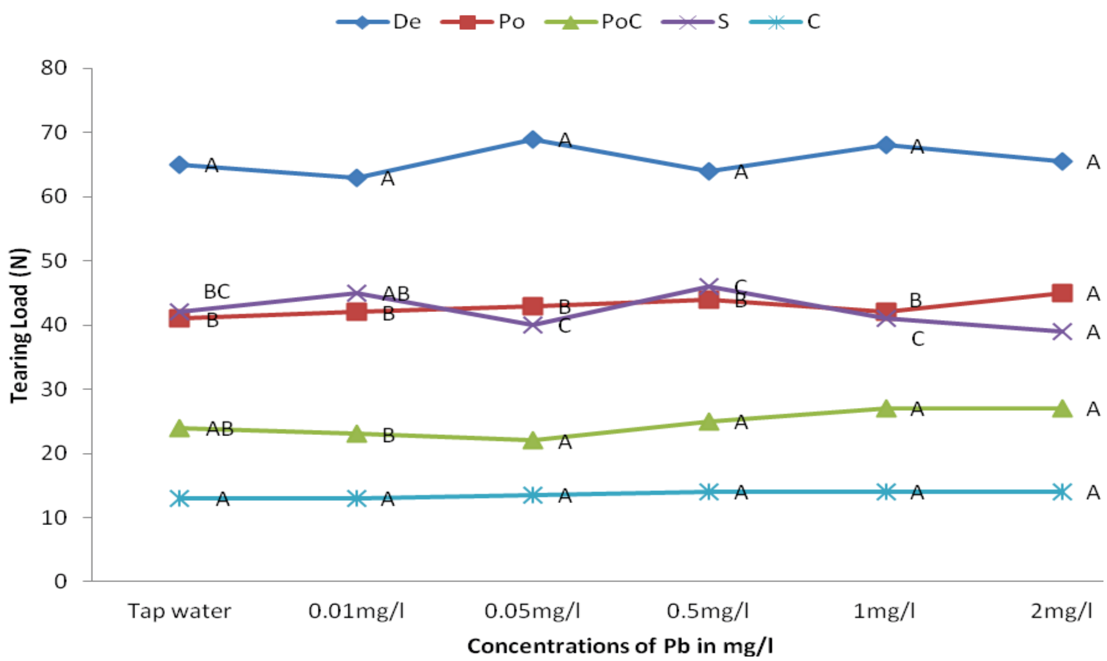


De
Po
PoC
S
C
Tearing Load (N)
Concentrations of Fe in mg/l
Tap water
0.1mg/l
0.3mg/l
1mg/l
3mg/l
4mg/l
5mg/l

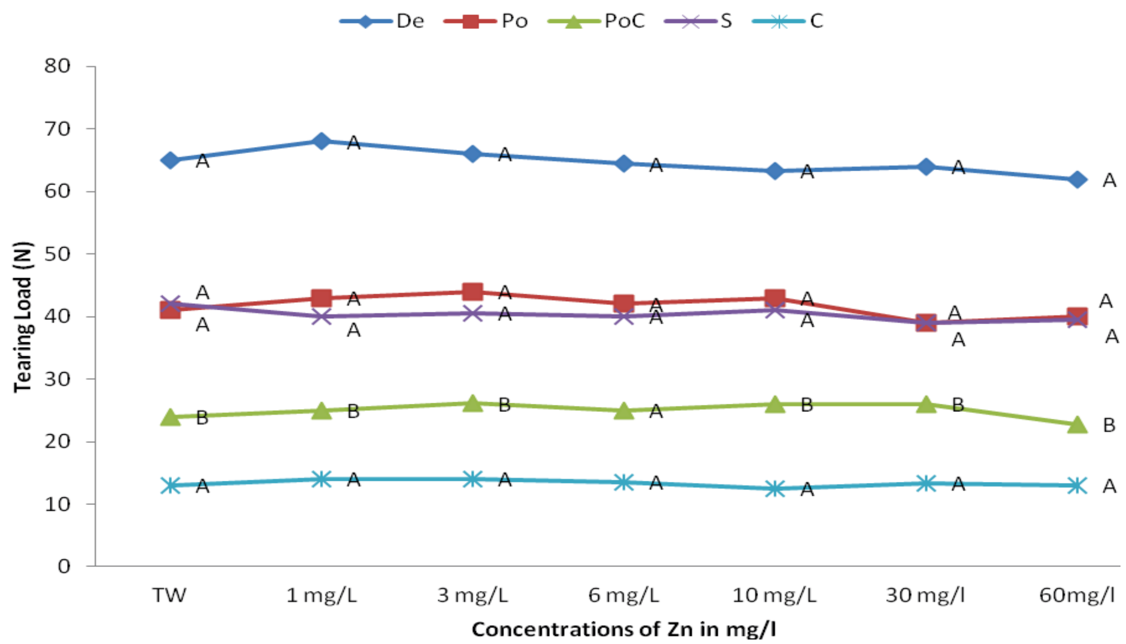
(b)


De
Po
PoC
S
C
Tearing Load (N)
0
10
20
30
40
50
60
70
80
TW
0.01mg/l
0.05mg/l
0.1mg/l
0.5mg/l
1mg/l
2mg/l
Concentrations of Mn in mg/l

(c)


De
Po
PoC
S
C
Tearing Load (N)
0
10
20
30
40
50
60
70
80
Tap water
0.01mg/l
0.05mg/l
0.5mg/l
1mg/l
2mg/l
Concentrations of Pb in mg/l

(d)



(e)

Figure 4.1 Tearing strength of cloth samples washed in various concentration of Cu, Fe, Mn, Pb and Zn solutions and tap water.

Note: A, B, C, D represents the group according to ANOVA-One way analysis (Tukey's test $p < 0.05$). The points sharing the same alphabets represent no significant difference in tearing strength.

The results from ANOVA One way test ($p < 0.05$) as shown in Figure 4.1 (b) revealed that there was no significant difference in tearing strength of the all cloth samples washed in Fe concentrations 0.01 mg/L, 0.03 mg/L and 1 mg/L compared to the same cloth samples washed in tap water. Cloth samples Polycotton and Cotton washed in all six concentrations of Fe had no significant reduction in tearing strengths when compared to that of TW. Similarly, no significant difference in tearing strengths of cloth samples (Denim washed in Fe 0.3 mg/L, Satin washed in Fe 1 mg/L and Polyester washed in Fe 3 mg/L respectively) was observed when compared with those of TW. At 1 mg/L of Fe, all cloth samples have no significant reduction in tearing strengths except De, however at higher concentration (above 1 mg/L) of Fe, there were found significant reduction in tearing strength. Therefore, 1 mg/L of Fe concentration in terms of tearing strength of cloth samples is recommendable.

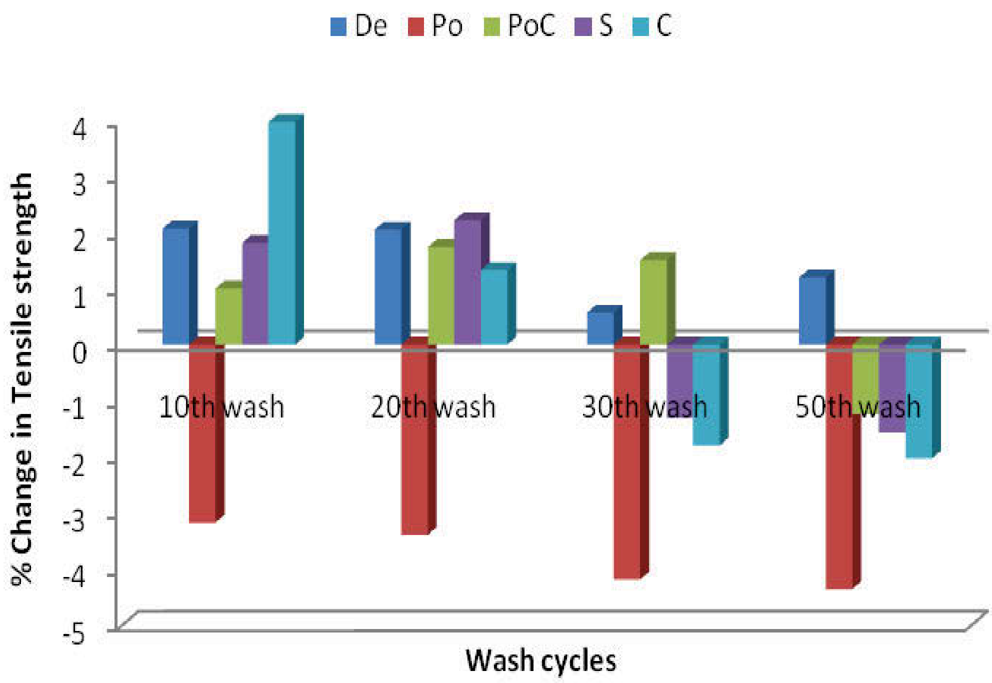
Results from tearing strength analysis (Figure 4.1 d) showed that no significant reduction in the tearing strength of cloth samples Cotton, Polycotton and Denim washed in various concentration of Pb (up to 2 mg/L) compared to the tearing strengths of cloth samples washed in tap water. For cloth samples Satin and Polyester, no significant difference was observed up to 1mg/L of Pb. Therefore, in terms of tearing strength of cloth samples, 1 mg/L of Pb is recommended.

As can be observed from Figure 4.1 (e), all cloth samples at all concentrations did not show significant difference (Tukey's test $p < 0.05$) in the strength at 10^{th} wash cycles, giving the idea that 60 mg/L of Zn is safe to use in washing machine for washing clothes in terms of cloth durability.

A. Long wash cycle tests

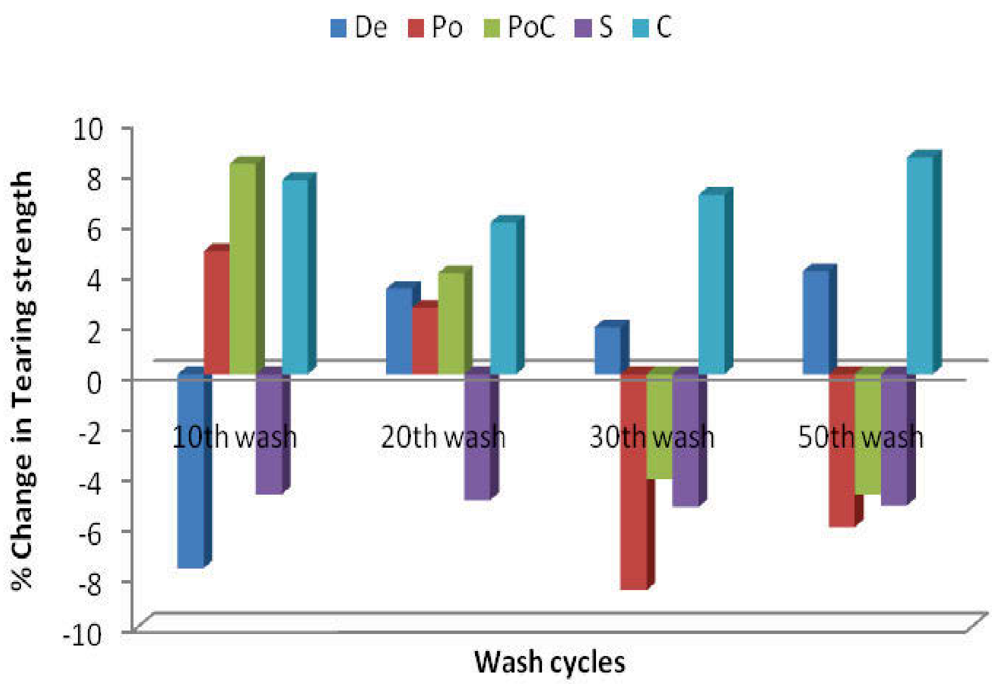
For further assurance, the comparative study of tearing and tensile strengths of cloth samples washed in tap water at 20^{th}, 30^{th} and 50th wash cycles and cloth samples washed in recommended values of Cu (5 mg/L), Fe (1 mg/L), Mn (0.5 mg/L), Pb (1 mg/L) and Zn (60 mg/L) as above were carried out. The average mean value of change in % of tensile and tearing strengths of cloth samples washed in 1 mg/L of Fe solution compared to the tensile and tearing strengths of cloth samples washed in tap water at various wash cycles is presented in Figure 4.2 (a and b) respectively. The change in % on the positive side of graphs revealed that the cloth samples were observed to have better tensile and tearing strengths compared to the tensile and tearing strengths of cloth samples washed in tap water for same number of wash cycles.

There was no significant reduction of tearing and tensile strengths of all cloth samples at 1 mg/L of Fe for all cycles of washings (Tukey's test $p < 0.05$). The analysis further revealed that with the increasing number of wash cycles, the difference of the tensile strength and tearing strength was significant for the concentration of Fe above 1 mg/L. Therefore, 1 mg/L of Fe is recommended to be the maximum allowable concentration in terms of tensile and tearing strength.



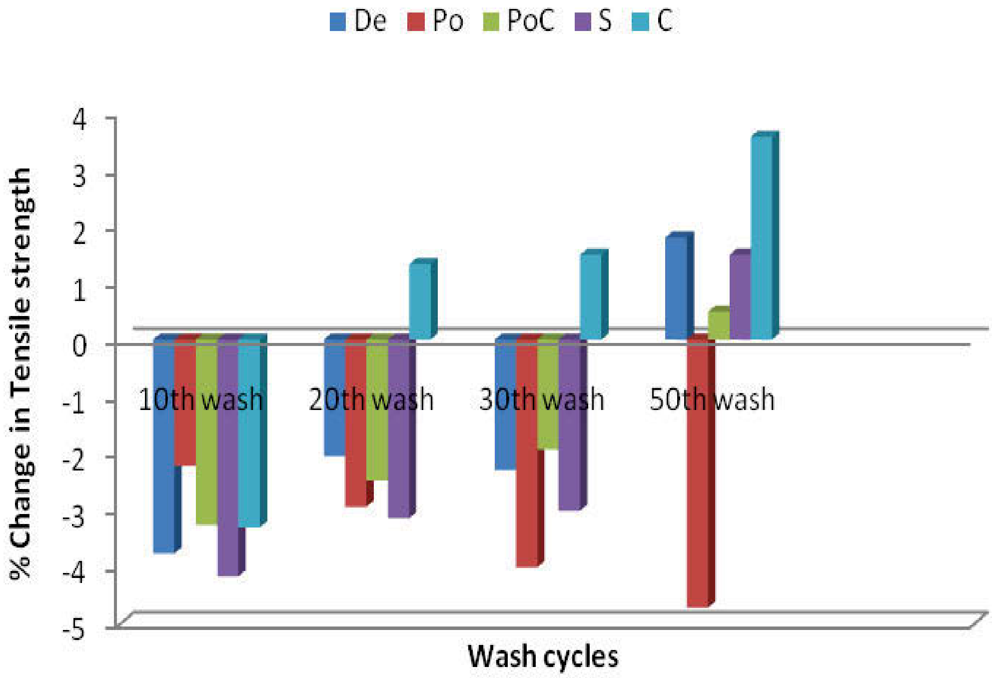
De Po PoC S C
% Change in Tensile strength
4
3
2
1
0
-1
-2
-3
-4
-5
10th wash
20th wash
30th wash
50th wash
Wash cycles

(a)



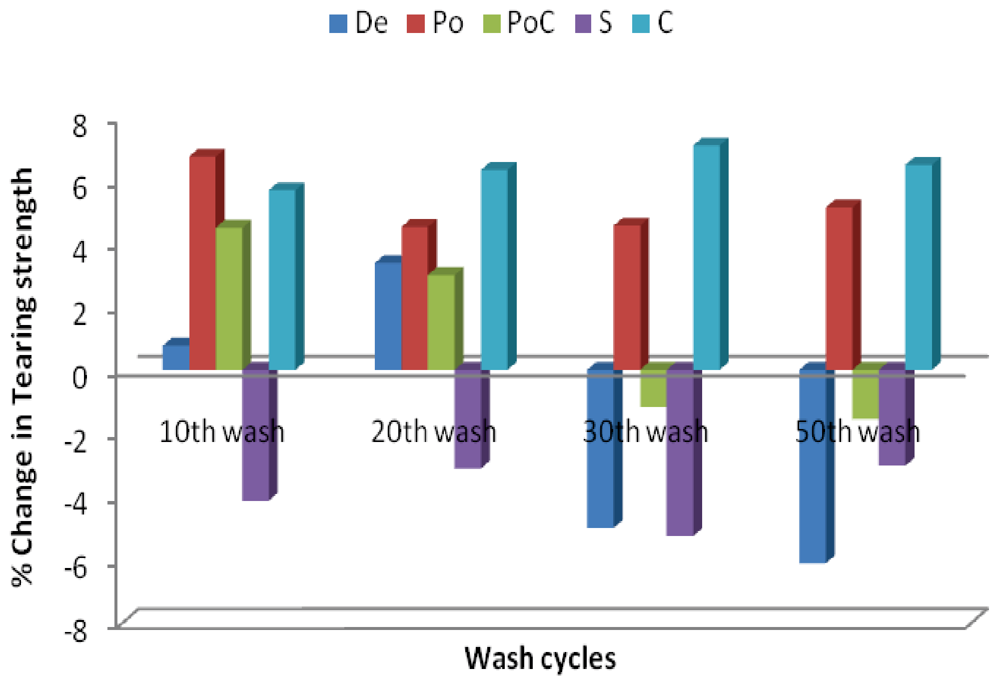
De Po PoC S C
% Change in Tearing strength
10
8
6
4
2
0
-2
-4
-6
-8
-10
10th wash
20th wash
30th wash
50th wash
Wash cycles

(b)



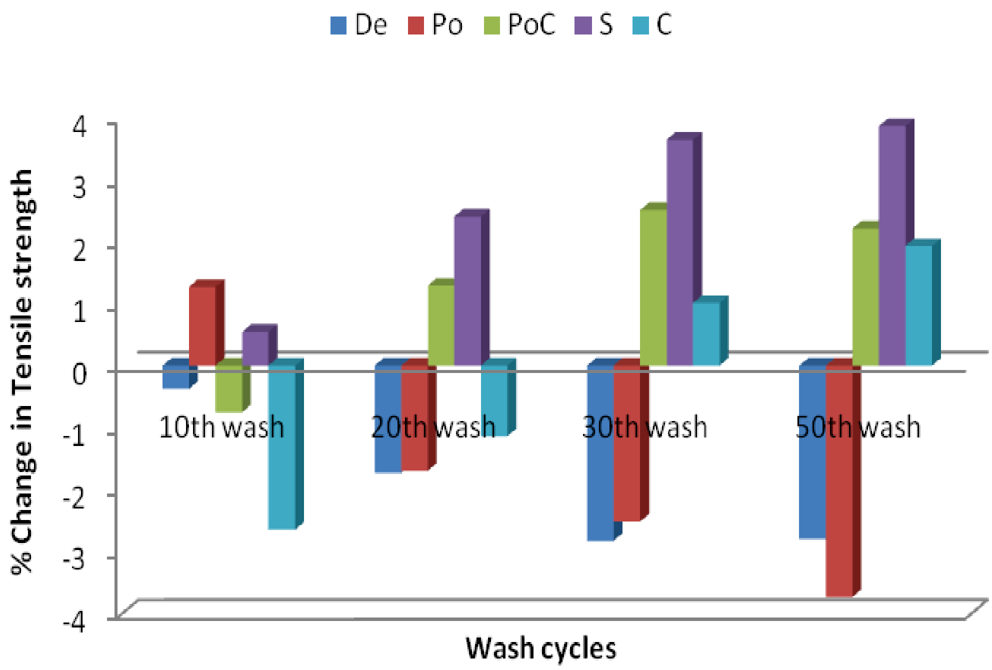
De Po PoC S C
4
3
2
1
0
-1
-2
-3
-4
-5
% Change in Tensile strength
10th wash
20th wash
30th wash
50th wash
Wash cycles

(c)

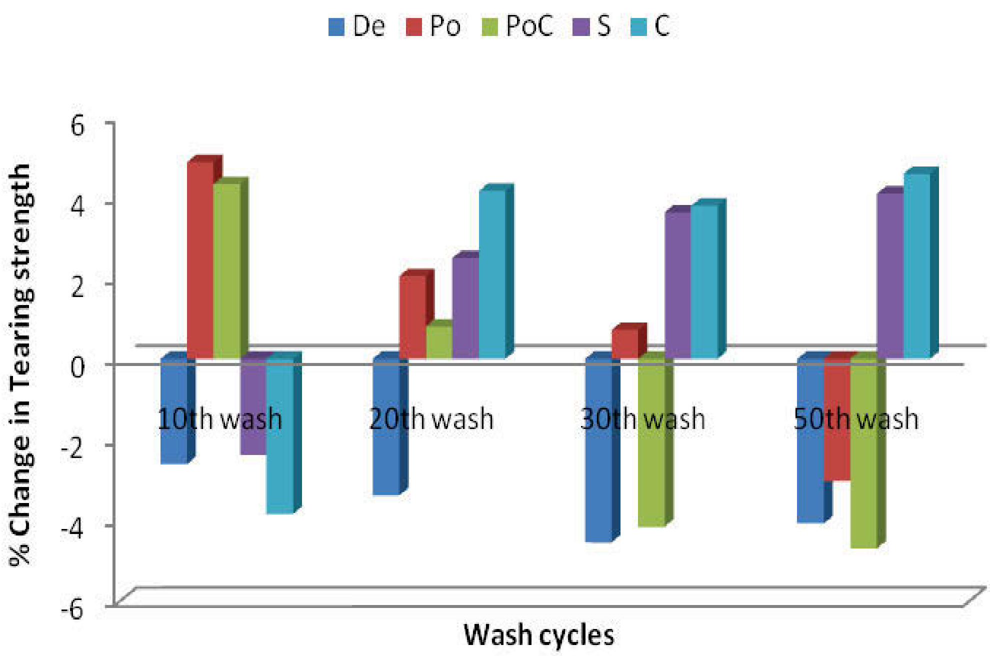


De Po PoC S C
8
6
4
2
0
-2
-4
-6
-8
% Change in Tearing strength
10th wash
20th wash
30th wash
50th wash
Wash cycles

(d)


De Po PoC S C
% Change in Tensile strength
4
3
2
1
0
-1
-2
-3
-4
10th wash
20th wash
30th wash
50th wash
Wash cycles

(e)


De Po PoC S C
% Change in Tearing strength
6
4
2
0
-2
-4
-6
10th wash
20th wash
30th wash
50th wash
Wash cycles

(f)

Figure 4.2 Comparative study of tensile and tearing strengths of cloth samples washed in tap water , 1 mg/L of Fe (a, b), 1 mg/L of Pb (c, d) and 10 mg/L of Zn (e, f) solutions at 10^{th}, 20^{th}, 30^{th} and 50^{th} wash cycles respectively.

Similarly, to assure 1 mg/L of Pb is safe without harsh impacts on the cloth's strengths, comparative study of tensile and tearing strength between the cloth samples washed in tap water at different wash cycles (10^{th}, 20^{th}, 30^{th} and 50^{th}) and the cloth samples washed in aqueous solution of 1mg/L of Pb was carried out. No significant reduction (Tukey's test $p < 0.05$) of tensile or tearing strengths of all cloth samples at 1 mg/L of Pb for all cycles of washings was observed (Figure 4.2 b and c). Therefore, 1 mg/L of Pb is recommended to be the maximum allowable concentration in terms of tensile and tearing strength.

For further confirmation that 60 mg/L of Zn is safe without harsh impacts on the cloth's strengths, comparative study of tensile and tearing strength between the cloth samples washed in tap water at different wash cycles (10^{th}, 20^{th}, 30^{th} and 50^{th}) and the cloth samples washed in aqueous solution of various concentrations of Zn was also conducted. The analysis revealed that with the increasing no of wash cycles, at 30 mg/L and 60 mg/L of Zn, the reduction in tearing and tensile strength of cloth samples were significant. Only up to 10 mg/L of Zn (≤ 10 mg/L Zn), even at 50^{th} wash cycle, there was still no significant reduction of tensile or tearing strengths of all cloth samples compared with the cloth samples washed in tap water for same number of wash cycles. Therefore, 10 mg/L of Zn is recommended to be the maximum allowable concentration in terms of tensile and tearing strength.

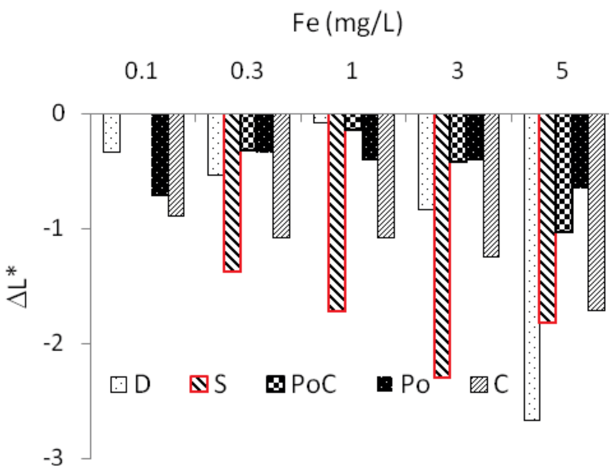
The similar analysis was carried out for the heavy metals Cu and Mn and the results indicated that MAV for Cu and Mn in terms of tensile and tearing strength is 5 mg/L and 1 mg/L respectively (Mainali et al., 2012).

4.3.2 Colour difference

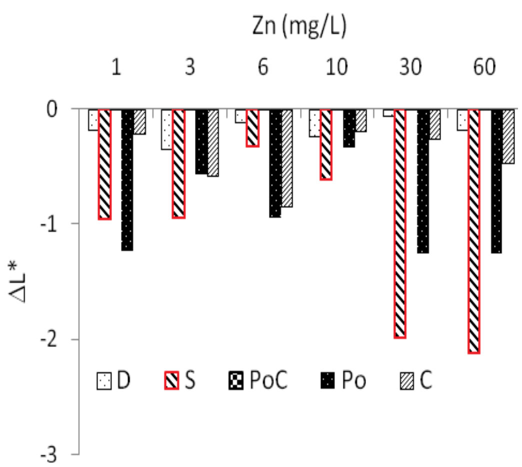
The spectrometry analysis of the cloth samples washed in various aqueous solutions and tap water (after 10^{th} and 50^{th} wash cycles) including the unwashed original cloth samples was performed. Figure 4.3 and Figure 4.4 showed the difference in delta L*, a*, b* and C* of 5 kinds of cloth samples washed in tap water and heavy metal solutions after 10 washing cycles. The figures exhibited that the change in colour depends upon the cloth material and type and concentration of heavy metals solutions.

A. Delta L (ΔL*)

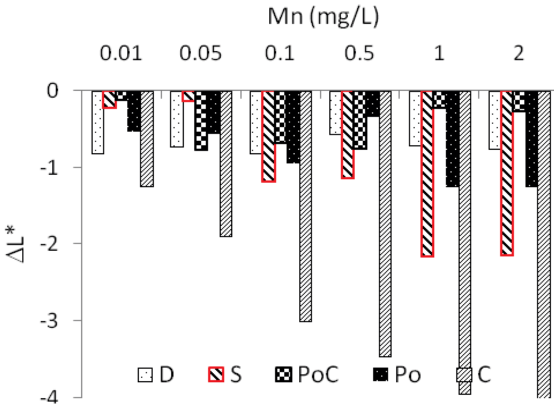
Figure 4.3 shows the change in colour of cloth samples in terms of ΔL*, difference in brightness (delta L* positive) and darkness (delta L* negative). In general, the change in colour after being washed in heavy metals solutions was observed. The cloth samples became darker with increasing concentration of heavy metals (delta L* negative). All cloth samples were observed to be darker after washing in Fe, Zn and Pb solutions, especially at concentrations higher than 1 mg/L, 30mg/L and 0.05mg/L respectively. Moreover, denim becomes slightly darker in Zn, Mn and Pb solutions but much darker at high concentration of Fe and Cu (> 5 mg/L and 20 mg/L respectively). Satin was darker at high concentration of all heavy metals tested excluding Cu. However, cotton was lighter in Mn and Cu solution (delta L* positive, Figure 4.3 c, d).



(a)



(b)



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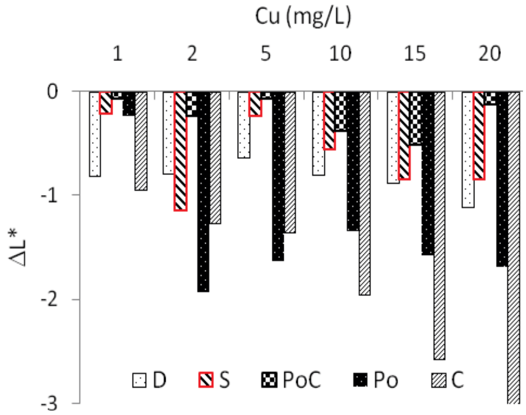
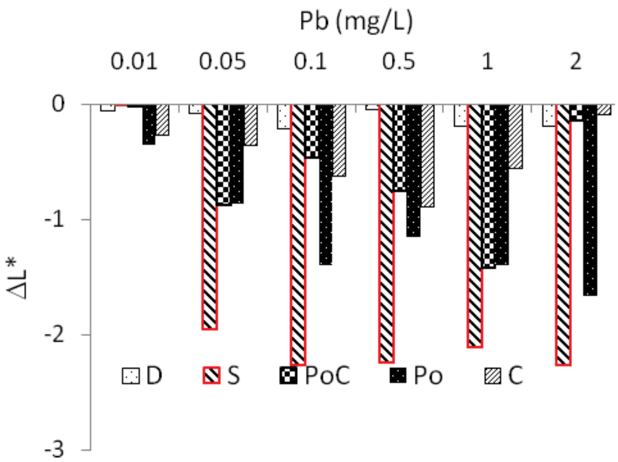


(d)



(e)

Figure 4.3 The change in colour of cloth samples in terms of ΔL*.

Note: ΔL = difference in lightness / darkness ; value + = lighter, value – = darker*

B. Delta a (Δa*)

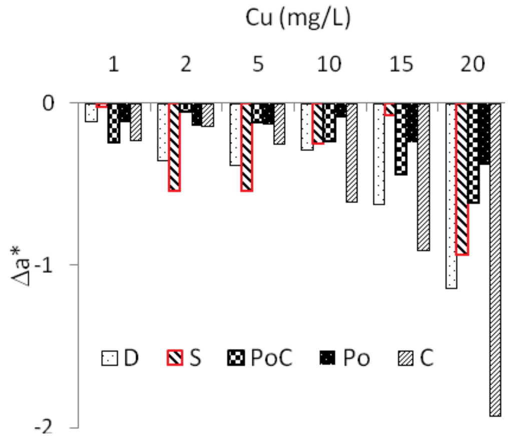
Results reveal that only with the copper solution especially at 20 mg/L, cloth samples were observed to be greener than in tap water when compared after 10 wash cycles (delta a* negative, Figure 4.4 a).

C. Delta b (Δb*)

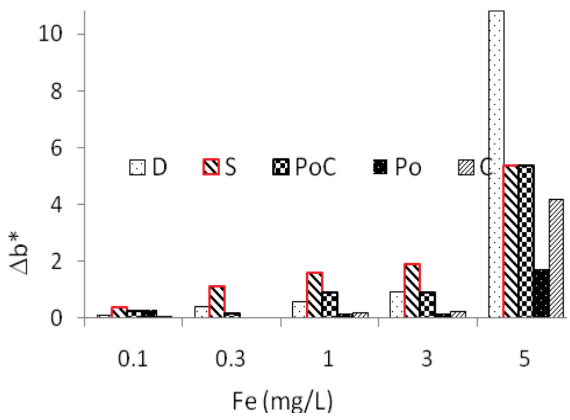
Figure 4.4 b indicates that most of cloth samples washed in Fe solution are more yellowish. Levels of yellowness depends on concentration of Fe in solutions, especially at higher 0.3mg/L conventions of Fe (delta b* positive). Satin were yellowish after being washed in Fe solutions (>0.3mg/L). However, Cu, Zn and Pb solutions made cloth samples become bluer, especially satin and denim (delta b* negative, Figure 4.4 b). From 2mg/L of Cu, 0.05 mg/L of Pb and 30mg/L of Zn satin cloth was observed more bluer compared to the one washed with tap water at the same number of wash cycles.

D. Delta C (ΔC*)

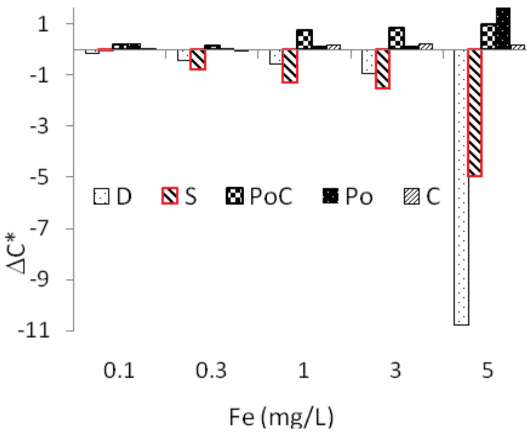
The cloth samples were duller at high concentration of Cu, Fe (delta C* negative, Figure 4.4 c, d). Stain started becoming duller after washing at their low concentration (delta C* negative and <-1). At high concentration of Fe (>5mg/L) and higher than 15mg/L of Cu, denim became bluer.



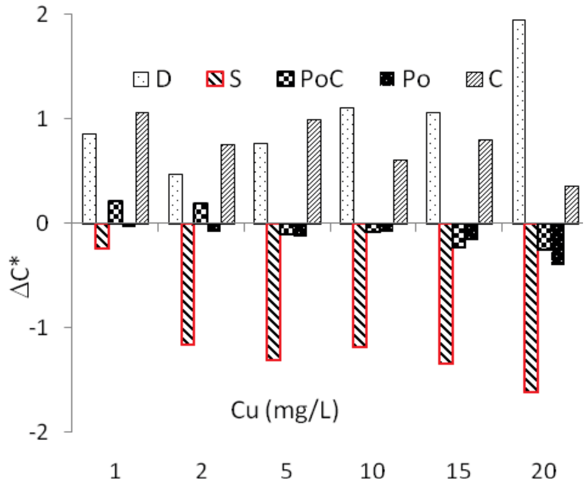
(a)



b



(c)



(d)

Figure 4.4 The changing colour of cloth samples in Δa*, Δb* and ΔC*.

Note: Δa = difference on red/green axis, + = redder, – = greener*

Δb = difference on yellow/blue axis, + = yellower, – = bluer*

ΔC = difference in chroma, value + = brighter – = duller*

E. Delta E (ΔE*):

Table 4.2 and Table 4.3 showed the difference in colour of cloth samples at different heavy metals concentrations. The change in colour of cloth samples was observed after being washed in most heavy metals. The levels of change of colour depend on cloths material and heavy metals concentrations. From 0.05 mg/L of Pb, 0.3mg/L of Fe, 1mg/L of Mn, 2 mg/L of Cu and 30 mg/L of Zn, satin was observed to change the colour (delta E* > 2). Cotton, denim, satin were sensitive with all 5 heavy metals solutions in comparison with other cloths. Polycotton and polyester were not much changed in colour when washed in heavy metals solutions. These cloth samples were observed to have no change in colour even after 10 and 50 wash cycles in heavy metals solutions and in tap water when compared with the original one (delta E* < 1).

Satin has one of the most noticeable changes in colour when washed with Fe solutions. The change in colour of satin was observed when washed in 1 mg/L of Fe solution while other cloths normally change colour only at or above 5 mg/L of Fe after 10 wash cycles (delta E*>2).There was no change in colour when washed with different concentrations of Pb and Zn after 10 and 50 wash cycles in comparison with one washed in tap water. Delta E was lower than 1 for all 6 concentrations (Table 4.3). However, denim exhibits colour change when washed with 3mg/L, 2mg/L and 2 mg/L of Fe, Mn and Cu respectively. Delta E* was higher than 2 at high concentration of heavy metals in water. Denim washed in 3mg/L concentration of Fe in water was yellowish than the one washed in tap water.

In conclusion, heavy metals concentration in water at lower than 0.1mg/L of Mn, 0.5mg/L of Pb, 1mg/L of Fe, 2mg/L of Cu and 30mg/L of Zn are considered safe for cloth in terms of change in colour of fabrics.

Table 4.2 The change of colour in delta E* calculated by various formulas at different concentration of heavy metals in water in comparison with tap water after 10 wash cycles

	Con.	Denim			Satin			Polycotton			Polyester			Cotton		
	(mg/L)	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000
Fe	0.1	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.8	0.5	0.6	0.9	0.5	0.7
	0.3	0.7	0.5	0.5	1.8	1.4	1.5	0.4	0.3	0.3	0.3	0.2	0.3	1.1	0.5	0.8
	1	0.6	0.5	0.5	2.4	1.9	2.1	1.0	0.9	1.0	0.4	0.3	0.4	1.1	0.6	0.8
	3	1.3	0.9	1.0	3.0	2.2	2.4	1.0	0.9	1.0	0.4	0.3	0.4	1.3	0.7	0.9
	5	11.2	9.5	8.2	5.7	5.4	5.0	5.5	5.4	5.3	1.8	1.6	1.7	1.5	1.6	1.1
Zn	1	0.2	0.1	0.1	1.0	0.6	0.7	0.7	0.4	0.5	1.2	0.6	1.0	0.2	0.1	0.2
	3	0.4	0.2	0.2	1.4	1.2	1.2	0.4	0.3	0.4	0.6	0.3	0.5	0.6	0.3	0.4
	6	0.2	0.2	0.2	0.8	0.7	0.7	0.4	0.3	0.4	1.0	0.6	0.8	0.9	0.4	0.6
	10	0.3	0.2	0.2	0.7	0.5	0.5	0.7	0.4	0.5	0.4	0.2	0.3	0.2	0.1	0.2
	30	0.4	0.4	0.4	2.7	2.1	2.3	0.5	0.4	0.5	1.3	0.6	1.0	0.3	0.1	0.2
	60	0.2	0.2	0.2	2.7	2.0	2.2	0.2	0.2	0.2	1.3	0.6	1.0	0.5	0.2	0.3
Pb	0.01	0.3	0.3	0.4	0.3	0.3	0.3	0.1	0.2	0.2	0.4	0.2	0.3	0.3	0.1	0.2
	0.05	0.3	0.3	0.3	1.4	1.0	1.2	0.9	0.6	0.8	0.9	0.5	0.7	0.4	0.2	0.3
	0.1	0.6	0.5	0.5	1.9	1.1	1.4	0.6	0.4	0.5	1.4	0.7	1.1	0.6	0.3	0.5
	0.5	0.1	0.1	0.1	1.3	1.3	1.7	0.8	0.5	0.7	1.2	0.6	0.9	0.9	0.4	0.6
	1	0.3	0.2	0.3	2.7	1.9	2.2	1.5	0.8	1.1	1.4	0.7	1.1	0.6	0.3	0.4
	2	0.2	0.1	0.1	2.9	2.2	2.4	0.2	0.2	0.2	1.7	0.8	1.3	0.1	0.1	0.1

	Con.	Denim			Satin			Polycotton			Polyester			Organic cotton		
	(mg/L)	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000
Cu	1	1.2	1.0	1.0	1.2	1.4	1.2	0.3	0.3	0.4	0.3	0.2	0.3	1.1	1.1	0.8
	2	1.1	0.8	0.9	1.9	1.8	1.9	0.3	0.2	0.3	1.9	1.0	1.5	1.3	1.0	0.9
	5	1.2	1.0	1.1	1.9	1.8	1.9	0.2	0.2	0.2	1.6	0.8	1.3	1.4	1.2	1.1
	10	1.5	1.3	1.4	1.8	1.8	1.8	0.4	0.3	0.4	1.3	0.7	1.1	1.1	1.2	1.1
	15	1.8	1.6	1.7	2.1	2.0	2.0	0.7	0.5	0.7	1.6	0.8	1.3	2.7	2.2	2.2
	20	2.4	2.2	2.5	2.3	2.2	2.3	0.6	0.6	0.9	1.8	1.0	1.5	5.4	5.9	4.3
Mn	0.01	1.8	1.4	1.6	0.5	0.4	0.5	0.4	0.4	0.4	0.6	0.3	0.5	1.2	0.8	0.9
	0.05	1.7	1.4	1.6	0.6	0.6	0.6	0.8	0.5	0.6	0.6	0.3	0.5	1.9	1.2	1.3
	0.1	1.8	1.4	1.6	1.2	0.8	0.8	0.7	0.4	0.5	1.0	0.5	0.7	2.0	1.6	1.9
	0.5	1.5	1.2	1.3	1.2	0.7	0.9	0.8	0.4	0.6	0.4	0.3	0.4	2.5	1.9	2.4
	1	1.3	1.0	1.1	2.2	1.1	1.5	0.3	0.2	0.2	1.3	0.7	1.0	3.0	2.3	2.8
	2	1.8	1.4	1.2	2.2	1.1	1.5	0.4	0.4	0.4	1.3	0.7	1.1	3.7	2.6	3.3

Note:

ΔE76: CIELAB76, ΔE94: CIE94, ΔE2000: CIEDE2000

ΔE* = total colour difference value

ΔE meaning:

0 - 1: meaning a normally invisible difference

1 - 2: very small invisible difference, only obvious to a trained eye

2 - 3.5: medium difference, also obvious to an untrained eye

3.5 - 5: an obvious difference

> 6: a very obvious difference

Table 4.3 The change of colour in delta E* calculated by various formula at different concentration of heavy metals in water in comparison with tap water after 50 wash cycles

Heavy metals	Con. (mg/L)	Denim			Satin			Polycotton			Polyester			Cotton		
		ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000
Fe	5	7.8	6.6	6.0	6.3	4.6	4.9	4.4	4.4	4.3	3.2	3.0	3.1	2.3	2.2	2.3
Zn	60	1.1	0.9	0.9	5.4	2.9	3.7	2.6	1.5	2.0	1.1	0.6	0.9	0.6	0.4	0.5
Pb	2	0.6	0.6	0.7	2.5	2.2	2.4	0.3	0.3	0.3	1.1	0.6	0.9	0.3	0.2	0.3
Cu	20	6.7	5.6	6.8	3.2	2.6	2.1	1.1	0.8	1.2	2.1	2.3	2.6	6.2	3.3	3.2
Mn	2	1.4	1.1	1.3	3.2	1.6	2.1	1.4	0.9	1.1	1.4	0.7	1.1	4.9	3.0	2.8

Note:

ΔE76: CIELAB76, ΔE94: CIE94, ΔE2000: CIEDE2000

ΔE* = total colour difference value

ΔE meaning:

0 - 1: meaning a normally invisible difference

1 - 2: very small invisible difference, only obvious to a trained eye

2 - 3.5: medium difference, also obvious to an untrained eye

3.5 - 5: an obvious difference

> 6: a very obvious difference.

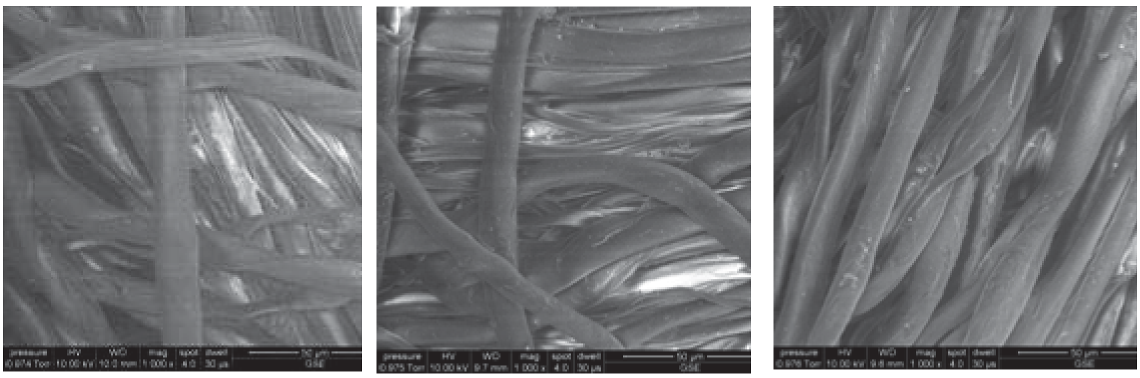
4.3.3 Change in surface structure characteristic of fabric sample

The scanning electron microscope (SEM) was used to investigate the surface changes of fabric after being washed in different concentration of heavy metals. The images of various cloth samples washed in different aqueous solution of varying concentrations of heavy metals are obtained and observed.

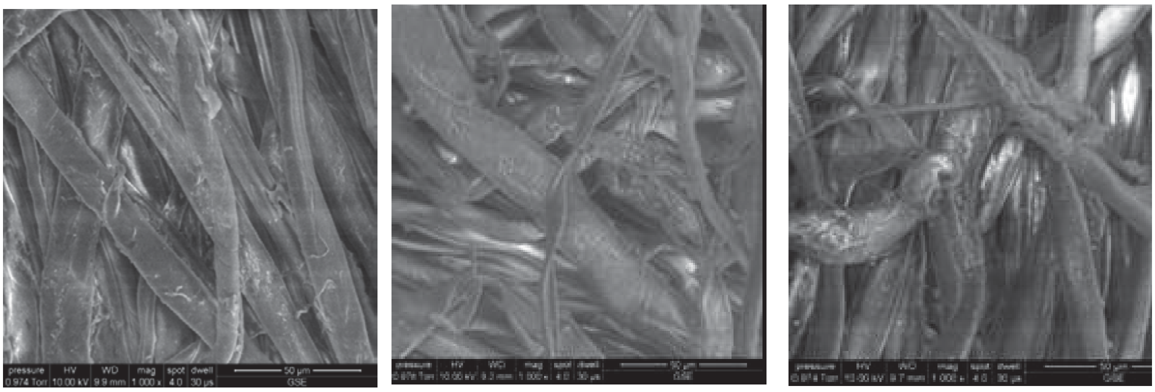
Cu:

Figure 4.5 represents the SEM images of denim cloth washed for 10 wash cycles in tap water (Figure 4.5 a) and the images of denim after 10 wash cycles in various concentrations (2, 5, 10, 15, 20) mg/L of Cu (Figure 4.5 b, c, d, e, f respectively). The observation revealed that the cloth after being washed only with tap water for 10 wash cycles (Figure 4.5 a) had not distinct surface and structure damages, as was expected. The cloth samples washed with high concentrations of heavy metals are observed to have some damages indicating that high concentration of heavy metals could be the cause of damage since all other washing conditions are identical.

From the images, it can be explained that the cloth surface structure was not much changed up to 5 mg/L of Cu concentration. However, at 10 mg/L, 15 mg/L and 20 mg/L concentrations of Cu, the internal structure of the cloths seems to be damaged.



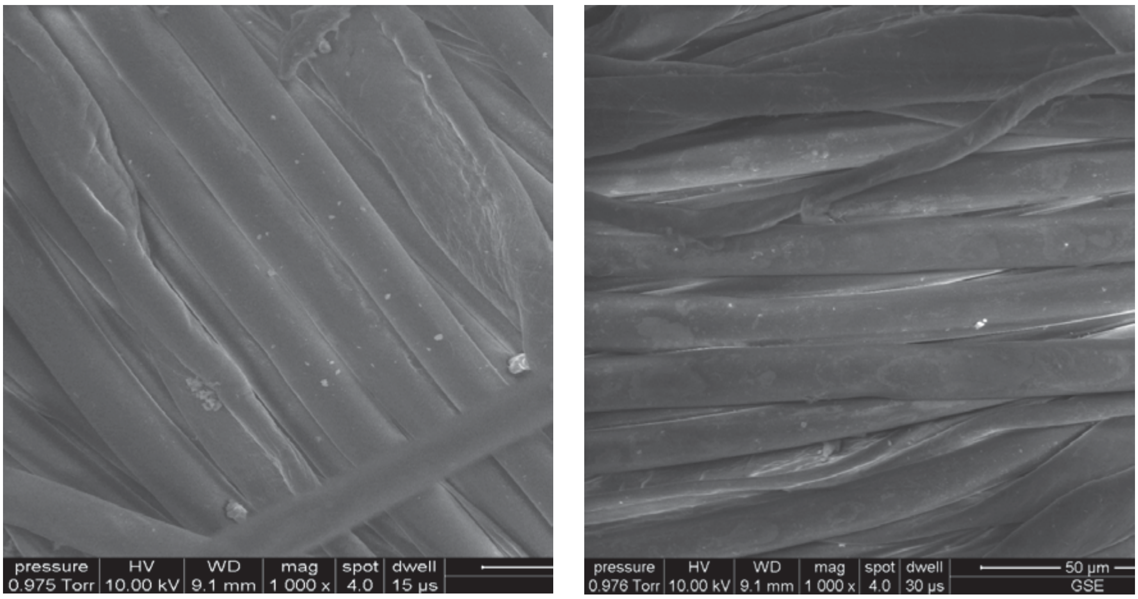
(a) **(b)** **(c)**



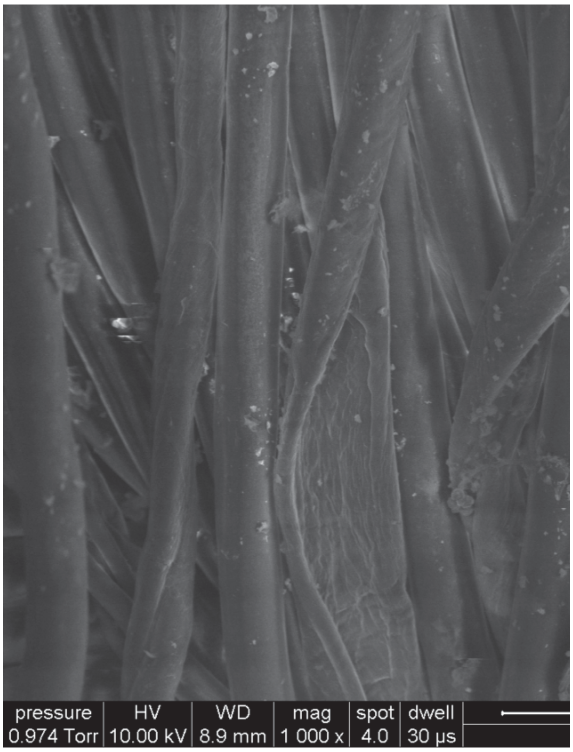
(d) **(e)** **(f)**

Figure 4.5 Denim (1000x) after 10 wash cycles in tap water and Cu concentration at 2, 5, 10, 15, 20 mg/L.

Similarly, Figure 4.6 presents the SEM images of PoC cloth washed for 10 cycles in tap water and different concentrations of the Copper (Cu). Comparing the images, no such changes have been observed in the cloth fibre structure up to 2 mg/L of Cu concentration. However, at 5 mg/L and beyond concentrations (≥ 5mg/L) of Cu, the internal structures of the clothes seem to be damaged. The damage can be seen more clearly in De cloth compared to PoC which can be because the single fibre of PoC was more smooth and homogeneous than that of De in the original stage.

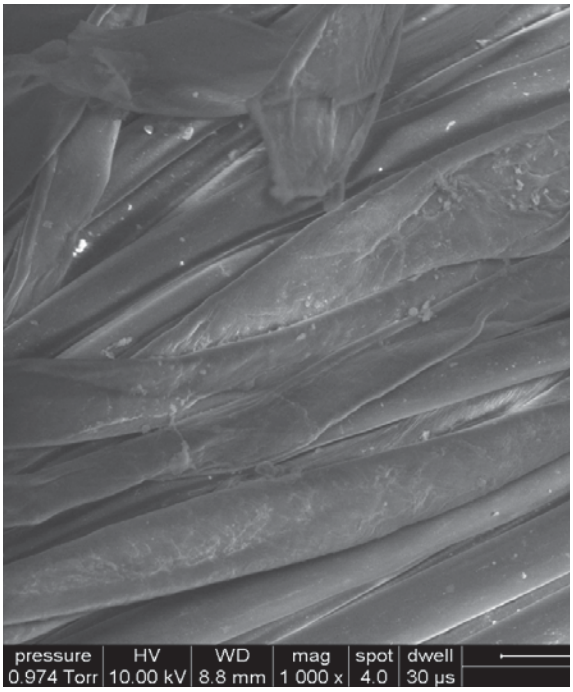


(a) **(b)**

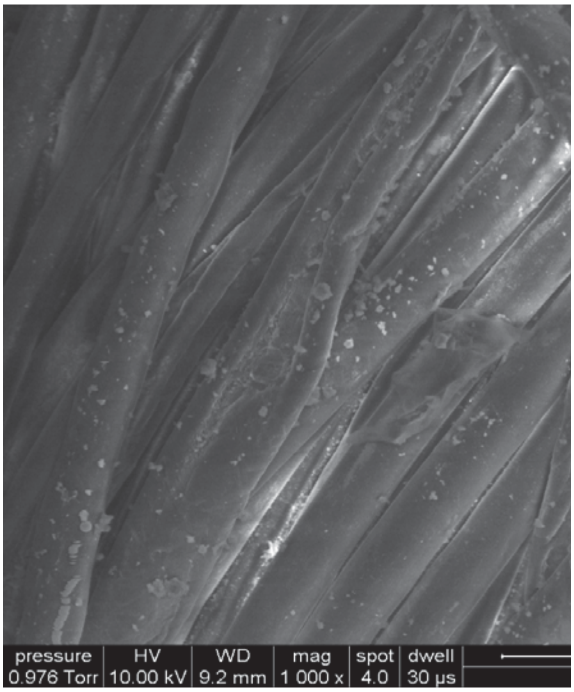


(c)

(d)



(e)



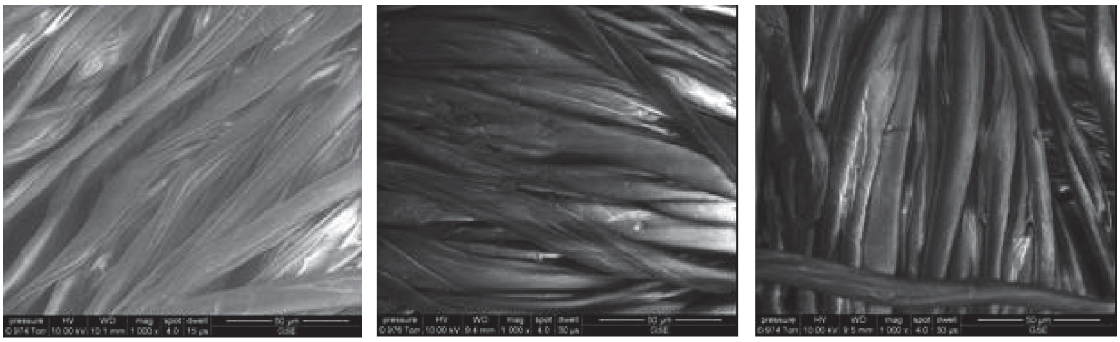
(f)

Figure 4.6 Polycotton (1000x) after 10 wash cycles in tap water (a) and Cu concentration at 2, 5, 10, 15, 20 mg/L (b, c, d, e, f).

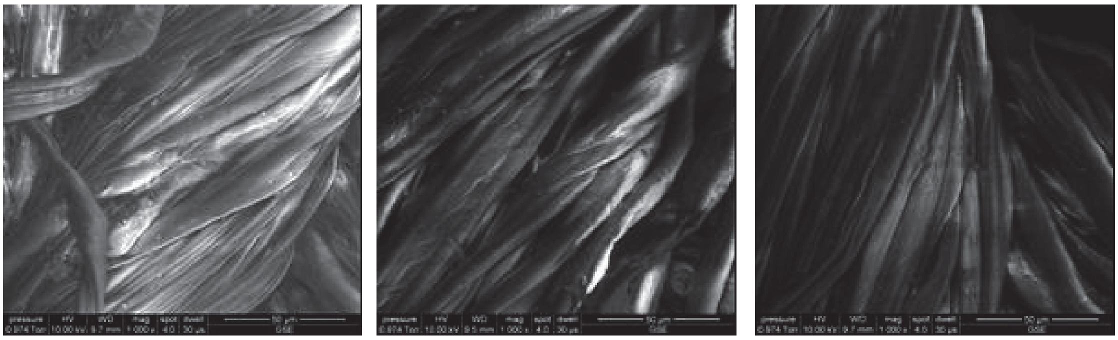
In the contrary to the above results, the images of S revealed that there was not much change in the structure of the cloth material in all concentrations of the copper solutions. The reason could be defined as that the S fibre are more smooth and homogeneous in appearance in the original stage than in PoC and De. Similarly, comparison of the images of Po and C are carried out and finally concluded that (≤ 2 mg/L) of Cu are safe for washing cloth in terms of surface structure of fabrics.

Fe:

All 5 cloth samples after 10 wash cycles in different concentration of Fe are compared by SEM images to find out the change in surface structure of fabric. The cloth samples washed in tap water and Fe concentration ≥ 1 mg/L, are observed to have similar surface morphology however at higher concentration of Fe, the cloth samples were observed to have changed surface morphology. As can be observed in Figure 4.7 (d, e, f) cotton cloth samples washed with Fe solution concentration >1 mg/L are observed to have some change in morphological structure. Similar changes are observed with almost all cloth types washed for 10 wash cycles in all six concentrations of Fe. However, with cloth samples Po and S, no significant change can be observed for clothes washed in all concentrations of Fe solutions. Therefore, it is summarised that up to (≤ 1 mg/L) of Fe solution, there is no negative impacts on the surface structure of fabric.



(a) **b** **c**

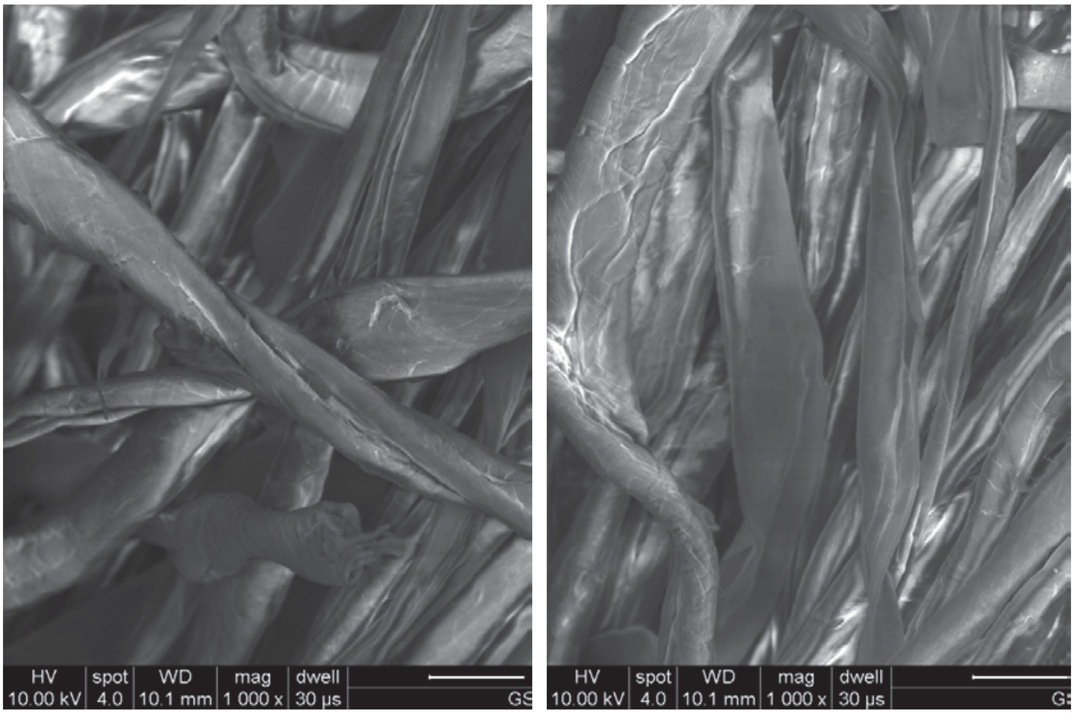


d e f

Figure 4.7 Cotton (1000x) after 10 wash cycles in tap water and Fe concentration at 0.1, 0.3, 1, 3, 5 mg/L.

Pb:

The images (Figure 4.8) of cloth samples De resulted from SEM revealed that at all concentrations of Pb after 10 wash cycles, they exhibit no change in surface structure of fabric. All cloth samples washed in Pb solutions up to 2 mg/L concentration do not revealed any distinct change in surface morphology. It gives the idea that Pb has no effect on cloth's surface structure and up to 2 mg/L of Pb is safe to use in washing machine for washing clothes in terms of surface structural characteristic.

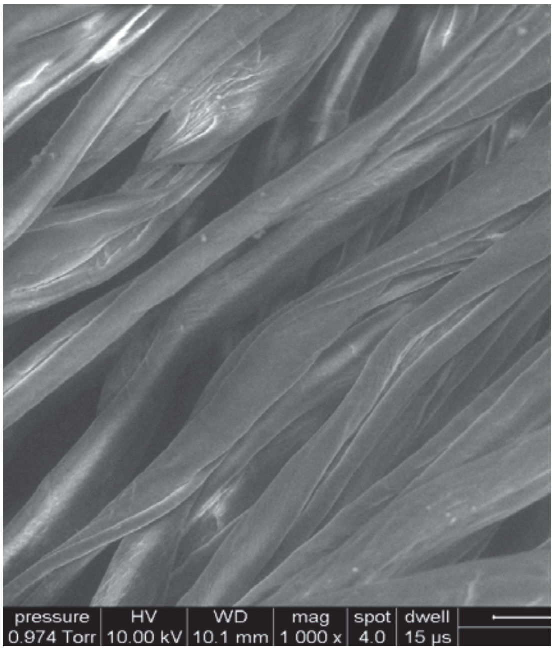


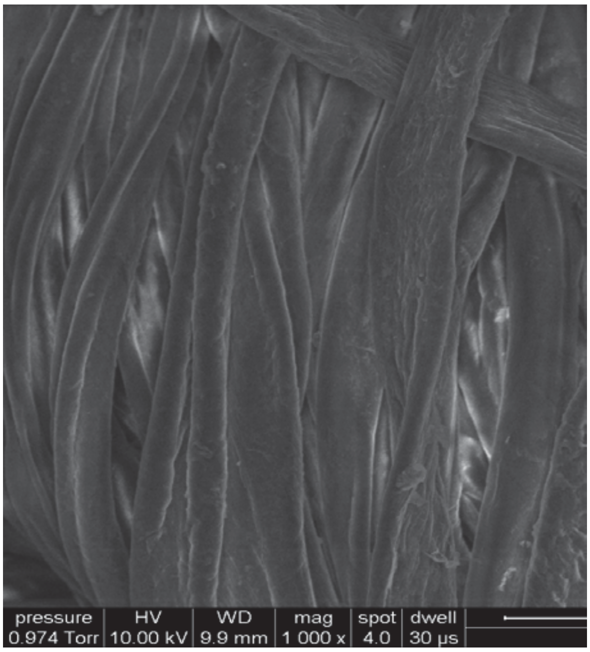
a b

Figure 4.8 Denim (1000x) after 10 wash cycles in tap water and Pb concentration at 0.5 and 2 mg/L.

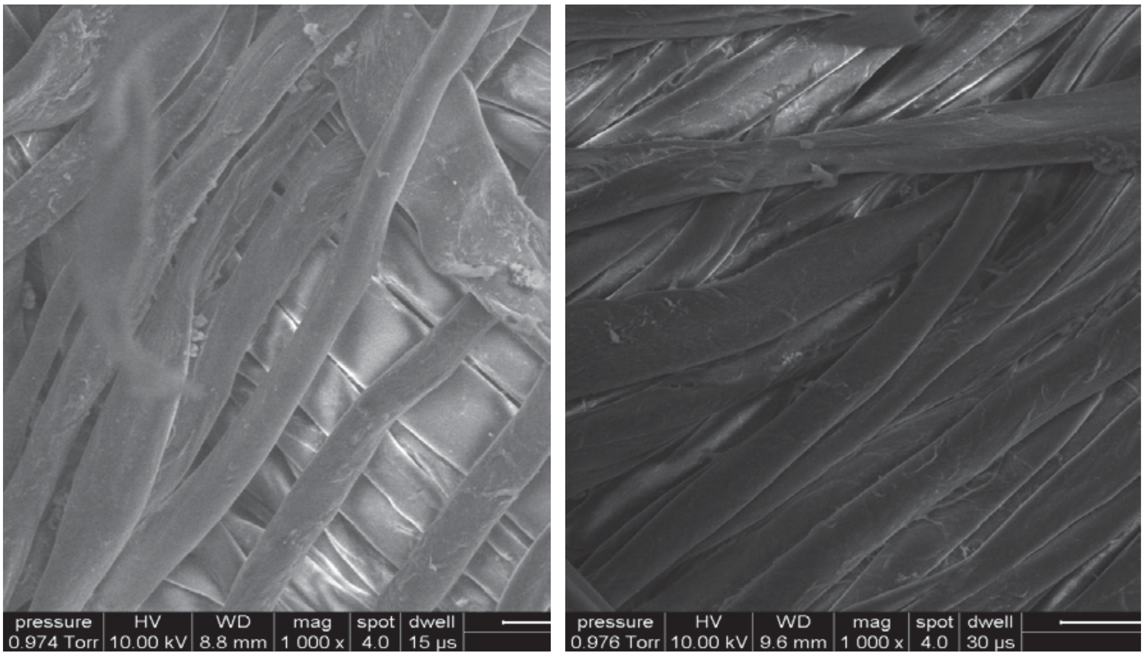
Mn, Zn:

Similarly, SEM images of cloth samples washed in various concentrations of Mn and Zn for 10 wash cycles were observed and compared with the images of cloth samples washed in tap water for 10 wash cycles. It was revealed that distinct damages in internal structure of the denim and cotton cloth fibres were observed in 10th wash cycles of 2 mg/L of Mn whereas for the rest of the cloth fibres not much change was observed. Other concentrations of Mn do not reveal any change in the internal structure of almost all cloth fibres. Similarly, no specific changes in the surface and internal structure of all cloth samples washed for 10 wash cycles in various concentration of Zn are observed. Only few changes are observed in the cloth samples washed in various concentration of Zn for 10 wash cycles when compared to the original unwashed cloth samples. However, those changes are similar as observed in the cloth samples washed in tap water for 10 wash cycles. Figure 4.9 presents the SEM images of cloth samples cotton and denim washed for 10 wash cycles in 30 mg/L of Zn.





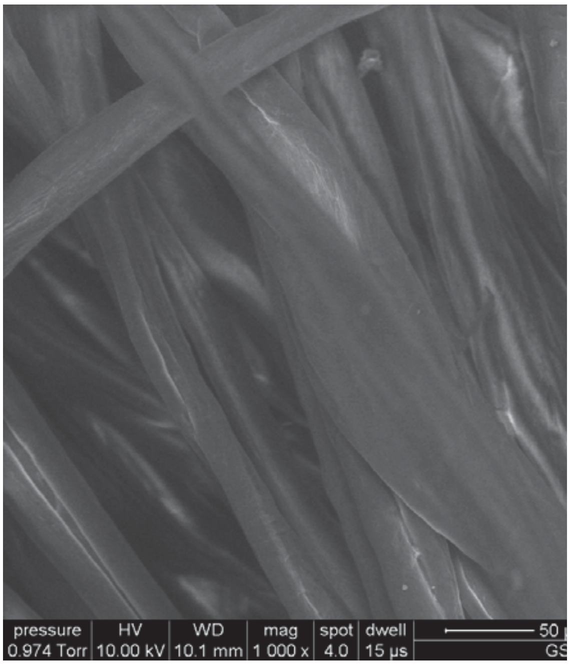
(a) **(b)**



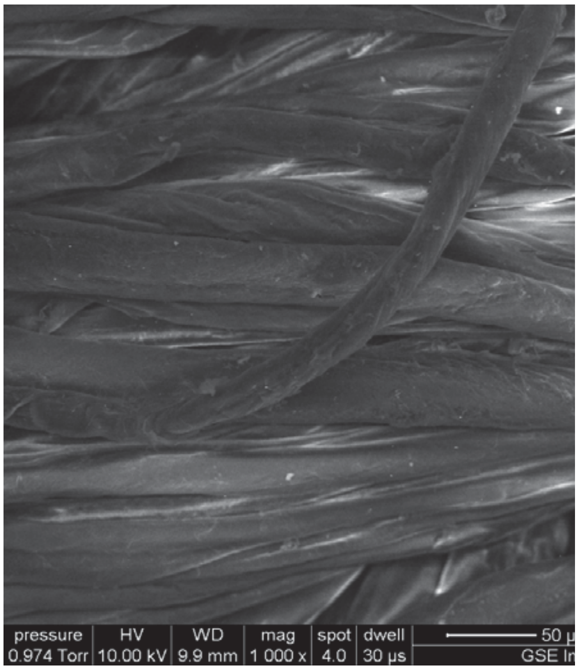
(c) **(d)**

Figure 4.9 Cotton (a,b) and Denim (c,d) (1000x) washed in tap water and 30 mg/L of Zn.

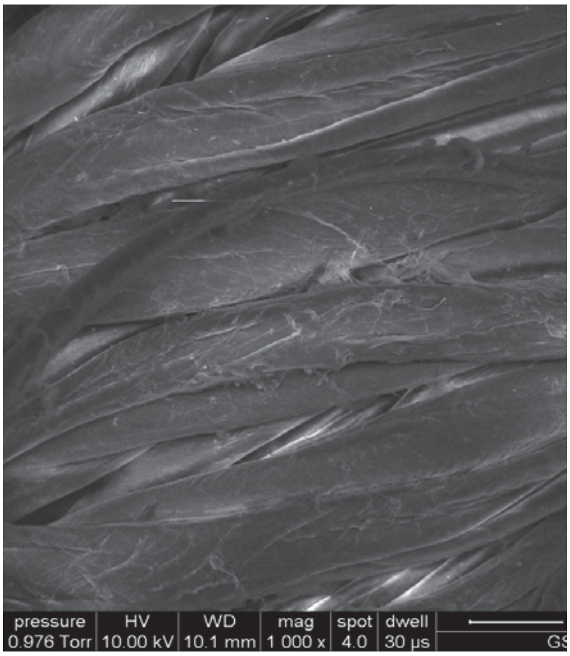
For further confirmation that 2 mg/L of Cu, 1 mg/L of Fe, 2 mg/L of Mn, 2 mg/L of Pb and 60 mg/L of Zn are safe without harsh impacts on the surface morphology of cloth, images of cloth samples washed in tap water at 50^{th} wash cycles and the cloth samples washed in aqueous solution of various concentration of heavy metals were also conducted. The images of cotton and denim (Figure 4.10 and Figure 4.11) washed in 2mg/L of Mn, 2mg/L of Pb and 60 mg/L of Zn were observed to have some drastic change in their surface structure when compared to the ones washed in tap water for 50 number of wash cycles. However, the results were normal at 1 mg/L of Mn, 1 mg/L of Pb and 30 mg/L of Zn even after 50 wash cycles. All other cloth samples were observed to have not much difference in their surface structure for all recommended concentrations of the heavy metals. Therefore, it has been summarised that under 2 mg/L of Cu, 1 mg/L of Fe, 1 mg/L of Mn, 1 mg/L of Pb and 30 mg/L of Zn are safe in terms of surface structure of fabric.



(a)



(b)



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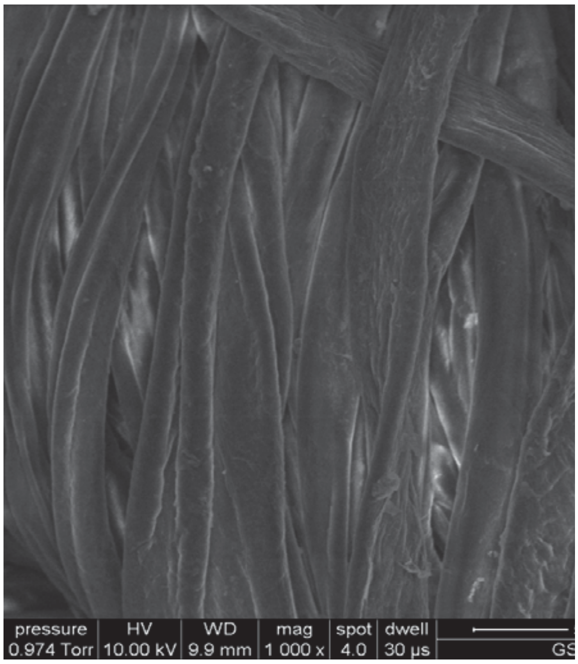


(d)

Figure 4.10 Organic cotton (1000x) after 50 wash cycles in tap water (a), in 2mg/L of Mn (b), 2mg/L of Pb (c) and 60mg/L of Zn (d).

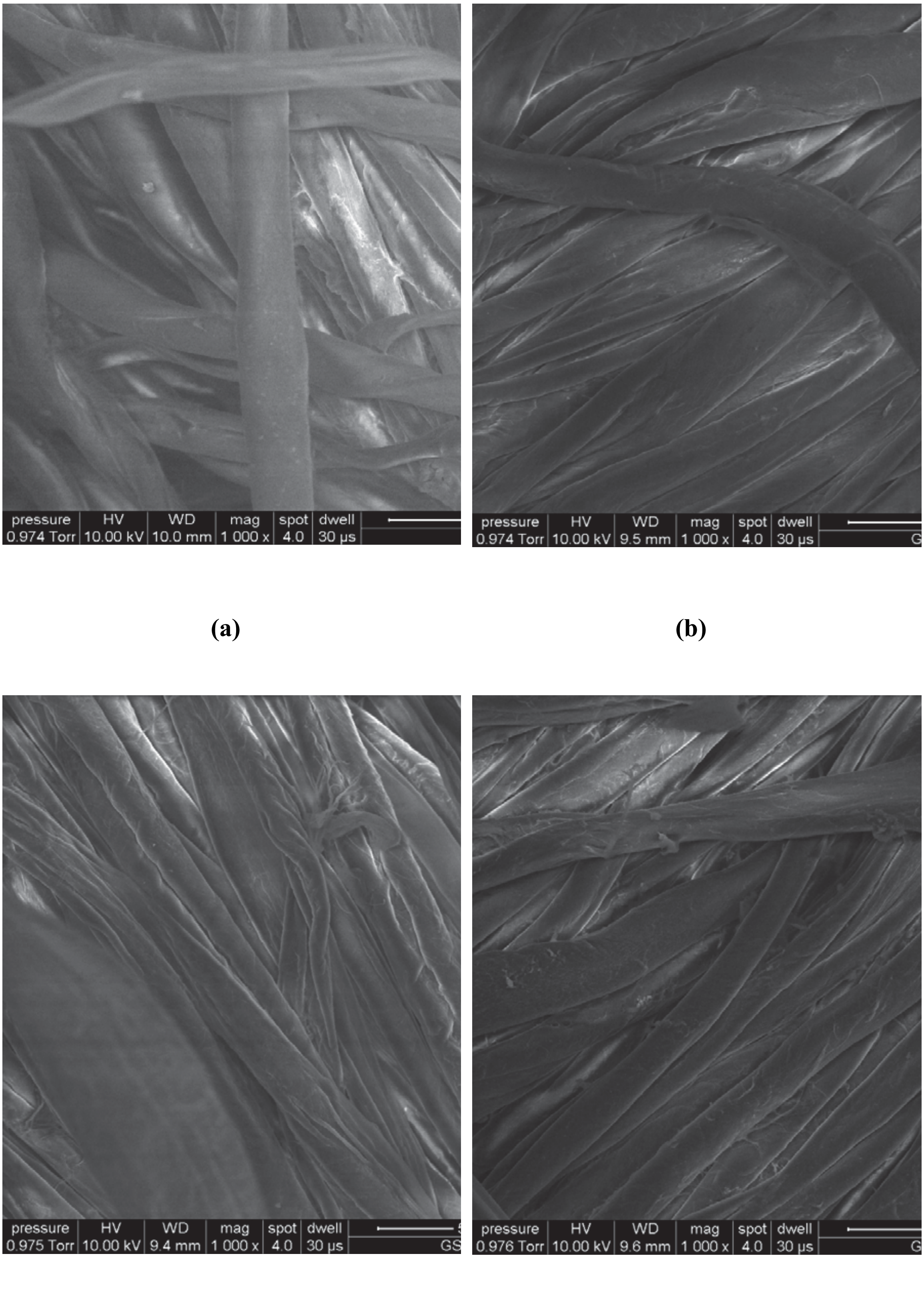
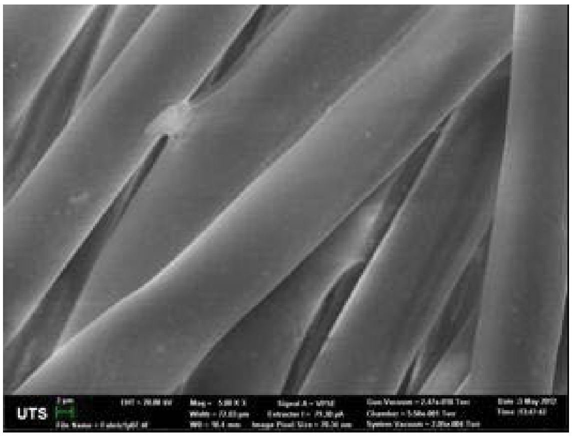
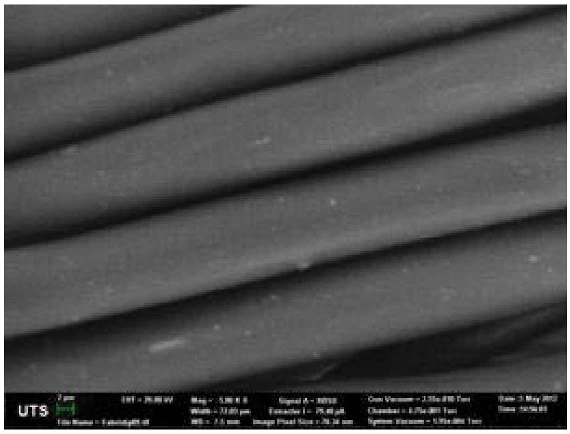


Figure 4.11 Denim (1000x) after 50 wash cycles in tap water (a), in 2mg/L of Mn (b), 2mg/L of Pb (c) and 60mg/L of Zn (d).

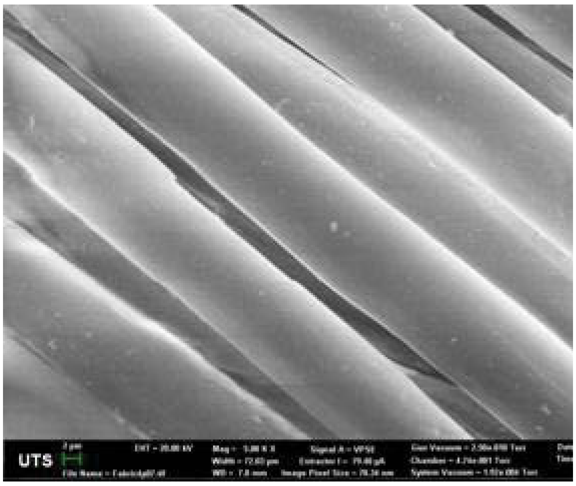
For further assurance, the images of cloth samples washed in recommended values of 1 mg/L of Pb, and 1 mg/L of Mn, 1mg/L of Fe, 2 mg/L of Cu and 30 mg/L of Zn were taken in SEM at 3000x. The images (Figure 4.12) show that there was no change in the surface structures of the fabric compared with ones washed with tap water. Therefore, those doses are safe for fabric in terms of surface structural characteristics.



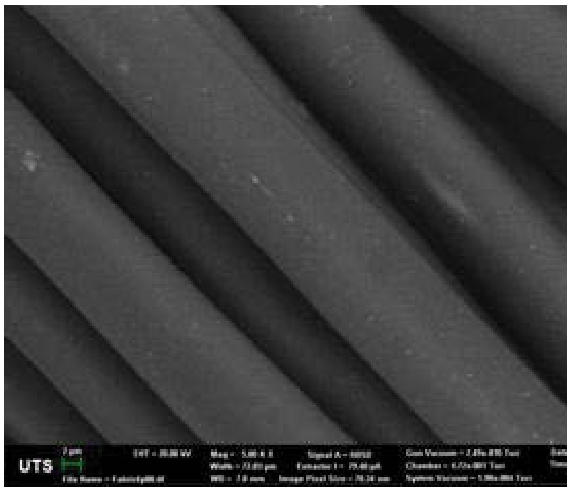
(a)



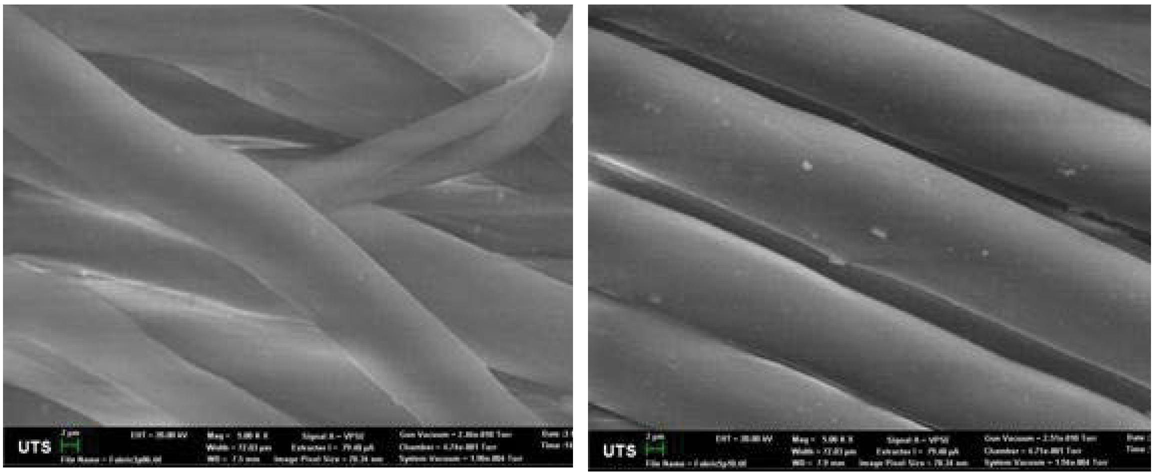
(b)



(c)



(d)



(e) (f)

Figure 4.12 Polycotton (3000x) after 10 wash cycles of tap water (a), 1 mg/L of Pb, Fe and Mn (b, c, d), 10 mg/L of Cu (e) and 30 mg/L of Zn (f).

4.4 Conclusions

To establish the guidelines for the new use of recycled water for household laundry, the effects of heavy metals (Fe, Pb, Zn, Cu, Mn) in terms of cloth quality and washing machine durability are one of the essential investigations. MAVs of heavy metals in recycled water safe for household laundry were determined by the investigation of long term effects of washing with various concentrations of heavy metals on the cloth durability, aesthetic appearance of the cloth and effects on washing machine. The specific findings are as follows:

- 1 mg/L of Fe, 1 mg/L of Pb, 10 mg/L of Zn, 2 mg/L of Cu and 1 mg/L of Mn are the MAVs in recycled water for using in washing machine in terms of tensile and tearing strengths.
- No signs of corrosion on washing machine throughout the washing of cloth samples up to 50 cycles with varying concentrations of Fe, Pb, Zn, Cu and Mn indicated that even at higher concentrations of these heavy metals, there is no impact on the machine's aesthetic appearance and functional system.
- In terms of aesthetic appearance of cloths, on the basis of SEM analysis, the MAVs of heavy metals in recycled water for laundry were found to be 2 mg/L of

Cu, 1 mg/L of Fe, 1 mg/L of Mn, 1 mg/L of Pb and 10 mg/L of Zn respectively and on the basis of spectrometer analysis, the MAVs of heavy metals in recycled water for laundry were found to be 2 mg/L of Cu, 1 mg/L of Fe, 0.1 mg/L of Mn, 0.5 mg/L of Pb and 10 mg/L of Zn respectively.

Conclusively, considering the lowest concentration limits on the basis of whole analysis, the MAVs of heavy metals in recycled water for laundry were recommended to be 2 mg/L of Cu, 0.3 mg/L of Fe, 0.5 mg/L of Mn, 0.5 mg/L of Pb and 10 mg/L of Zn. It is important to note that these MAVs of heavy metals have been suggested only considering their effects on cloth durability, aesthetic aspects of cloth quality and durability of washing machine.

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CHAPTER 5

INVESTIGATIONS OF THE FEASIBILITY OF RECYCLED WATER FOR HOUSE HOLD LAUNDARY

5.1 Introduction

Numerous initiatives have been embraced Australia-wide to increase the availability of less-climate dependent water sources. Dual reticulation systems are one of the integral parts of such initiatives. Many cities in Australia are already equipped with dual reticulation system and this is likely to expand in many other cities in the future due to the persisting and increasing water stress (Radcliffe, 2004; Hurlimann, 2008; Mainali et al., 2011). The existing dual reticulation schemes in Australia include Rouse Hill (Sydney), Newington (Sydney), Mawson Lakes (Adelaide), New Haven Village (Adelaide), Aurora (Melbourne), Marriott Waters (Melbourne) and Pimpama Coomera (Gold Coast) (Radcliffe, 2004; Hurlimann, 2008; Willis et al., 2010; Mainali et al., 2013). All the schemes provide class A recycled water for non-potable uses. Those uses include toilet flushing, garden irrigation and car washing. Considerable amount of fresh water conservation has been achieved due to the use of recycled water in urban communities (Tillman et al., 1999; Ogoshi et al., 2001; Janasava et al., 2005; Anderson, 2006; Corwin and Bradford, 2008; O'Connor, 2008; Willis et al., 2011). The significant savings of potable water have been already evidenced (about 35-50%) in Rouse Hill and New Haven Village and (32%) in Pimpama Coomera (Sydney Water, 2008, Fearnley et al., 2004; Willis et al., 2011).

There are many proposed and under construction dual reticulation system in many states of Australia. According to Lazarova et al. (2013), class A recycled water will be supplied to 14000 new homes and the industrial developments in areas including Edmondson Park, Middleton Grange, Ingleburn Gardens, Panorama Estate and Yarrunga Industrial Area in Sydney. In addition to these, Ropes Creek and Pitt Town in Sydney, new residential developments in Gillieston Heights, North Cooranbong and Thornton North in Newcastle area will also be supplied with recycled water. In Melbourne, 100,000 homes in Yarra valley area, new residential developments in City of Wyndham, Armstrong Creek residential developments of Geelong, 1200 new homes in Hunt club estate in Cranbourne East, 24000 new homes in Toolern which is one of the lowest- rainfall area of Victoria and fastest growing urban areas of Australia, will be supplied with recycled water via dual reticulation system for residential non-potable purposes (Lazarova et al., 2013; City West Water, 2011; Western Water, 2010). Similarly, 8000 new homes in southern part of Adelaide and 1000 homes in Brighton which is a northern suburb in Perth will be receiving recycled water via dual reticulation system (Lazarova et al., 2013). Further addition of end uses of the recycled water in the existing and perspective dual reticulation schemes in urban areas would be of great benefit for such schemes.

Many researchers (Radcliffe, 2004; Anderson, 2006; O'Toole et al., 2008; Storey, 2009; Ngo et al., 2009; Mainali et al., 2011) foresee washing machine for washing clothes as a potential new end use of the recycled water. Washing machine involves significant amount of household water (almost 20%) in most of the countries of the world including Australia (Ngo et al., 2009; Pakula and Stamminger, 2010). Therefore, considerable amount of tap water can be conserved if washing clothes in washing machine is added as a new end use of recycled water. According to Lazarova et al (2013), recycled water is approved for the laundry use in Yarra valley area in Melbourne and the washing machines are being connected with recycled water in new developments. This is a very positive beginning however, sufficient investigation and study in regards to the laundry use of recycled water is not observed to the required extent and hence until today there is not much evidence of use of recycled water in washing machine.

Few studies on the use of recycled water for washing machines (O'Toole et al., 2008; Storey, 2009; Mainali et al., 2011a; Chen et al., 2012) have been carried out. O'Toole et al. (2008) and Storey (2009) concluded from their studies that class A recycled water, as used in dual reticulation systems, for washing machine use will not lead to the transmission of micro-organisms at concentrations likely to cause enteric diseases. Mainali et al., (2011) carried out the descriptive feasibility study of recycled water use for washing machines in terms of strengths, weaknesses, opportunities and threats (SWOT) analysis and concluded it to be the potential new end use of recycled water. Chen et al., (2012) proposed an assessment framework and methodology for detailed evaluation of recycled water use over washing machines and concluded that the Micro filtration and Granular activated carbon treated recycled water coupled with existing washing machines were preferred options. All these studies are hence with positive results supporting the use of fit for purpose recycled water for washing machine and have made suggestions on further technical investigations.

Community surveys commissioned by many researchers (Dolnicar and Saunders, 2006; Roseth, 2008; Pham et al., 2011; Mainali et al., 2013b) shows support for the concept of using recycled water in washing machines. However, amongst the concerns raised by the participants were the effects of recycled water on public health, aesthetics and discolouration of laundry, cloth as well as machine durability. The results from the study of O'Toole et al. (2008) and Storey (2009) addressed one of the important concerns "health issues" raised by the community. However, these are very few studies addressing this issue and in addition to this, as revealed from community attitude surveys, general public are equally concerned about the durability and aesthetic appearances of cloth and washing machine (Mainali et al., 2013b). So far the authors are concerned, no study has been found carried out incorporating these issues. To encourage the use of recycled water in washing machine for washing clothes, the general community should be given the assurance that the recycled water will not have negative impacts on public health, cloth aesthetic appearance, cloth durability and machine durability. For that reason, to come up with the clear and concise results to develop the sense of belief among the general public, the study was carried out for analysing the long term effects on the durability of the cloth samples and aesthetic appearance of cloth samples due to the use of recycled water, for predicting the long term effects like scaling or corrosion of washing machines due to the use of recycled water and to analyse the microbiological contamination of cloth samples due to the recycled water.

Washing cloth with recycled water is expected to be accepted as long as no deterioration compared to washing clothes with drinking water occurs. Therefore, a comparative study of tensile and tearing strength tests of cloth samples washed in tap water and recycled water have been carried out to analyse the effects on cloth durability. MINITAB 16 as a statistical tool was used and ANOVA One way test was applied for the significance analysis (Tukey's test $p < 0.05$). Similarly, Spectrometer Perkin Elmer LAMBDA 950 was employed to compare the change in colour of the cloth samples washed in tap water and the recycled water for same number of wash cycles. In addition to this, Scanning Electronic Microscope (SEM) is used to observe the surface morphology change of the cloth fabrics. The microbiological analysis of the recycled water and the cloths washed in recycled water has been carried out for further assurance in terms of microbiological contamination of cloth samples. Langelier Saturation Index (LSI) method has been used by many researchers (Gacem et al., 2012) for prognosticating the corrosive and scale forming tendency of the aqueous solutions.

Thus, LSI analysis has been employed to conclude whether the recycled water does have corrosive/scale forming tendency or not.

This comprehensive study presenting the experimental verifications to address the community's basic concerns in regards to the use of recycled water for washing clothes will not only ensure fewer problems with clothes washing but also develop a sense of belief among the recycled water users. This will encourage beneficial and sustainable use of more recycled water by maximising the reuse of recycled water through minimising and managing any risks associated with its use.

5.2 Methodology

The Port Macquarie Reclaimed Water Plant (PMRWP) in Port Macquarie, City West Water (CWW) in Melbourne and Sydney Olympic Park Authority (SOPA) in Sydney were the three providers of recycled water for the experimentations. The representative cloth fibers (polyester (Po), satin (S), polycotton (PoC), denim (De) and cotton (C) were washed in recycled water from the three providers and in tap water at identical conditions. The comparative studies in terms of the tensile/tearing strengths of the cloth fibers, surface morphology of the cloth fibers, change in colour using Spectrometer, visual analysis and microbiological analysis were carried out. Langelier saturation index analysis of recycled water from three providers followed by visual inspection of washing machine was carried out for predicting the scale forming or corrosive potential of recycled water. The detail of the methodology has been presented in section 3.3 of chapter 3.

5.3 Results and discussion

5.3.1 Providers of recycled water for experimentation

The Port Macquarie Reclaimed Water Plant (PMRWP) in Port Macquarie, City West Water (CWW) in Melbourne and Sydney Olympic Park Authority (SOPA) in Sydney were the three providers of recycled water for the experimentations. PMWRP is an integral part of the Port Macquarie Hasting Council in order to ensure a more sustainable water supply for the future. According to the council's authorities and websites, a multiple barrier treatment process is used producing thereby the highest quality (six star) water which is more purer than tap water. However, there have been no developments of infrastructure for the supplying recycled water to the community via dual pipe system. The use of the recycled water has been reported for Landscape irrigation (especially Golf courses) only.

CWW is one of Melbourne's three retail water businesses which supplies recycled water produced from its own plants and Western treatment plant. West Werribee Dual Water Supply Project in Melbourne is managed and looked after by CWW. 1500 houses in this area (Manor lakes, Blue stone etc) have been already connected with dual pipe system and supply of recycled water is due very soon (early 2014 as suggested by the CWW website and concerned authorities).

Table 5.1 General characteristics of the recycled water from three providers

Parameters	Quality Criteria*	PMRWP	CWW	SOPA
Turbidity	<2 NTU	1.6	1.8	0.2
BOD_5	<20 mg/L		<2	<2
pH	6.5 to 8.0	7.5	7.6	7.5
Total Phosphorus	≤1mg/L	<1	7.2	0.6
Total Nitrogen	≤12mg/L	<2	14.5	1.5
TDS	Mean 500 mgL	810	590	400
Hardness ($CaCO_3$) (mg/l)	-	121	155	115
Alkalinity ($CaCO_3$)(mg/l)	-	89	117	84
TOC	-	5.8	5.2	3.0

*Note: * Criteria derived from*

NSW Guidelines for Urban and Residential Use of Reclaimed Water

Australian Drinking Water Guidelines, 1996,

NHMRC•-NSW Health Department

(Reference- Listowski, 2009)

SOPA is providing class A recycled water to the residents of Newington via dual reticulation system. The Water Reclamation and Management Scheme (WRAMS) at Sydney Olympic Park produce recycled water using advanced biological treatment and membrane filtration technologies. The general characteristics of the recycled water from the three providers are presented in Table 5.1. All physical, chemical and biological characteristics of the recycled water from all three providers are well maintained within the permissible quality criteria of recycled water for non-potable household activities. However, the TDS of the recycled water provided by PMRWP in Port Macquarie and CWW in Melbourne is higher than the suggested permissible value.

5.3.2 Tensile and tearing strength

The comparative study of tensile and tearing strengths of the cloth samples (De, S, Po, Co, PoC) washed in tap water at different wash cycles (1st, 5th, 10th, 20th, 30th and 50th) and the cloth samples washed in recycled water at respective number of wash cycles were conducted. As stated in Mainali et al. (2013a), among the test cloth samples, denim and satin seem to be the strongest cloth fibres (Tensile strength > 500N) in terms of tensile strength test followed by polycotton, polyester and cotton (Tensile strength < 200N) (Table 2). In terms of tearing strength denim is the strongest cloth type (> 60N) while polyester and satin seem to have similar tearing strengths (≈ 40N). Polycotton which holds its position as third strongest cloth type in terms of tensile strength was observed to hold fourth position in terms of tearing strength (≈25N). Cotton was found to have the lowest tearing strength (<15N).

A. Tensile strength

The results of mean values of tensile strengths of cloth samples washed in tap water and recycled water from three different providers at 10th wash cycles are summarized in Figure 5.1. The figure showed that for all cloth types washed for 10 wash cycles in recycled water from all three providers, there was less than 5 % reduction in tensile strength of cloth samples compared to the tensile strength of cloth samples washed in tap water. For more reliable results, ANOVA- One way test ($p < 0.05$) was employed to test the significance difference of the tensile strengths of the cloth samples washed in tap water and in recycled water from three different providers. All tensile strengths of particular cloth samples (D, PoC, Po, S and C) washed in recycled water and tap water were represented in a same group sharing a common alphabet A exhibiting no significance difference in the tensile strengths.

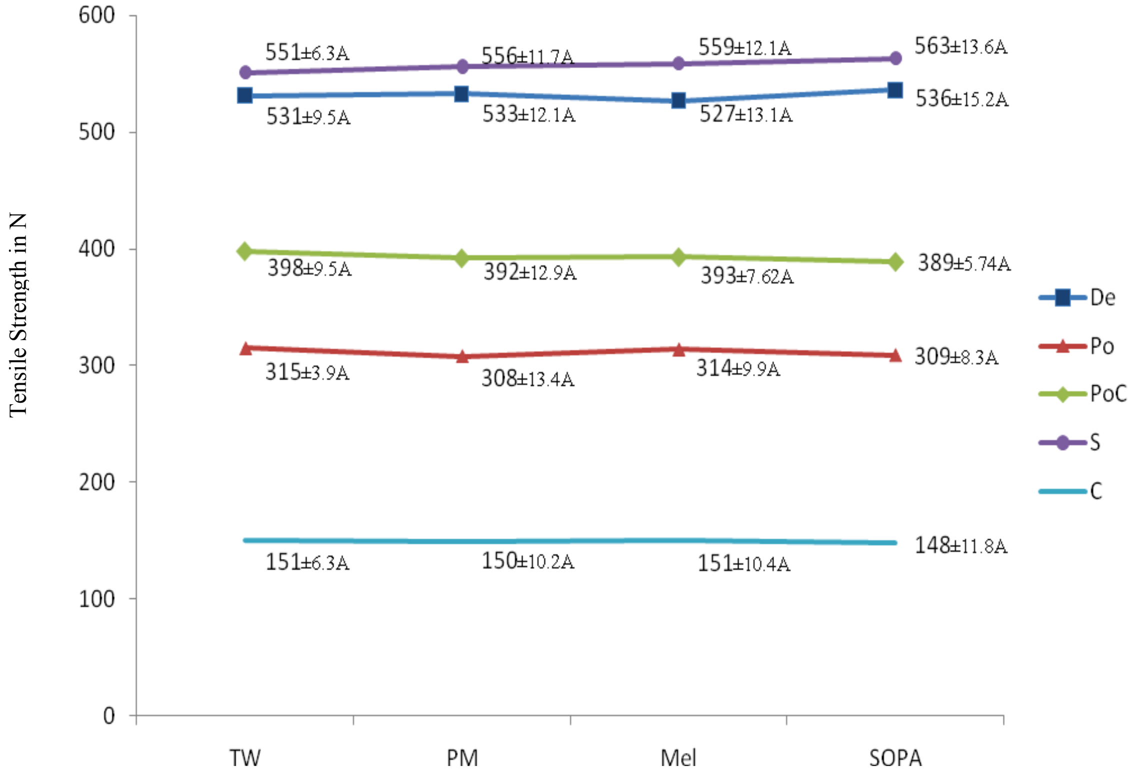


Figure 5.1 Tensile strengths of cloth samples washed in Tap water (TW) and recycled water from Port Macquarie (PM), Melbourne (Mel) and Sydney (SOPA) at 10th wash cycle.

Note: Alphabet A represents the group according to ANOVA-One way analysis (Tukey's test $p<0.05$, $n=11$). The values sharing the same alphabets represent no significant difference in tensile strength. (±values are the standard deviations)

B. Tearing strength

The results of mean values of tearing strengths of cloth samples washed in tap water and recycled water from three different providers at 10th wash cycles are summarized in Figure 5.2.

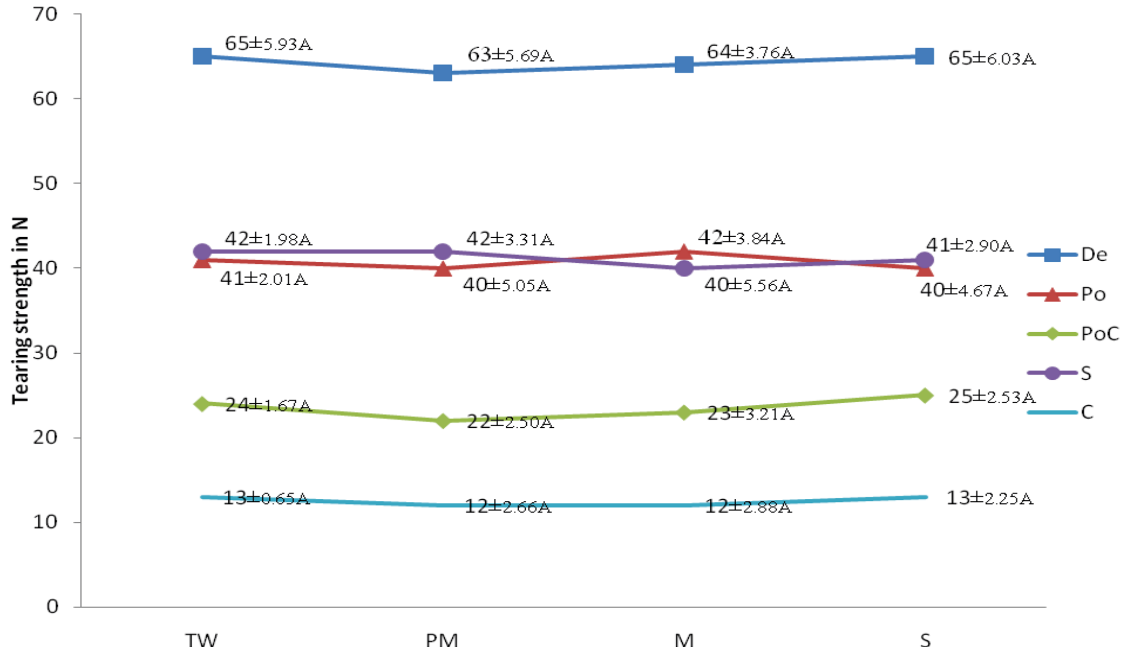


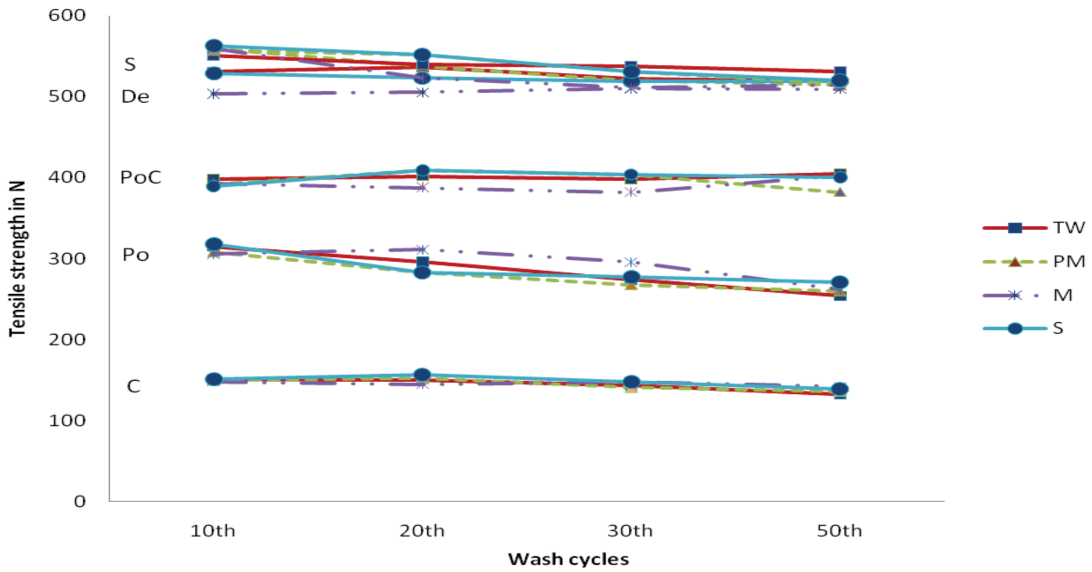
Figure 5.2 Tearing strength of cloth samples washed in tap water and recycled water from three providers.

Note: A represents the group according to ANOVA-One way analysis (Tukey's test $p < 0.05$). The points sharing the same alphabets represent no significant difference in tearing strength.

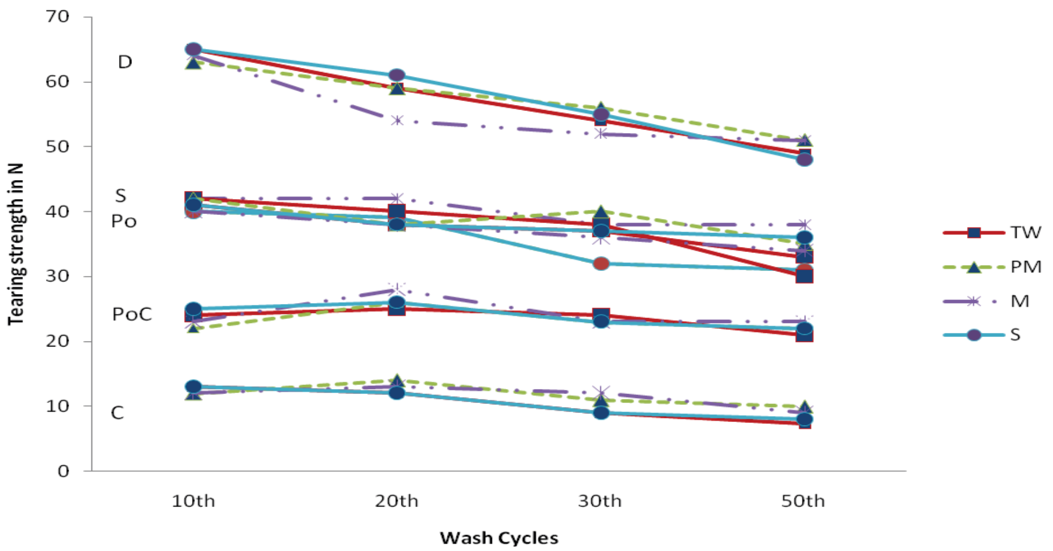
The results from ANOVA One way test ($p < 0.05$) as shown in Figure 5.2 revealed that there was no significant difference in tearing strength of the all cloth samples washed in recycled water from three different providers compared to the same cloth samples washed in tap water.

C. Long wash cycle tests

For further assurance, the comparative study of tearing and tensile strengths of cloth samples washed in tap water at 20th, 30th and 50th wash cycles and cloth samples washed in recycled water from three providers were carried out at same wash cycles. The average mean value of tensile and tearing strengths of cloth samples washed in recycled water compared to the tensile and tearing strengths of cloth samples washed in tap water at various wash cycles is presented in Figure 5.3 (a and b) respectively. There was no significant reduction of tearing and tensile strengths of all cloth samples washed in recycled water from all three providers for all cycles of washings (Tukey's test $p<0.05$) compared to the tensile and tearing strengths of cloth samples washed in tap water at same number of wash cycles. Also, further observation revealed that almost all cloths have not shown much change in tensile and tearing strengths when compared with first wash and fiftieth wash except denim cloth which showed slight change in first and fiftieth wash which was slightly remarkable than other cloths. However, the trend for cloths washed in recycled water and tap water is exactly same.



(a)



(b)

Figure 5.3 Comparative study of tensile and tearing strengths of cloth samples washed in tap water (TW), and recycled water from Port Macquarie (PM), Melbourne (M) and Sydney (S) 10th, 20th, 30th and 50th wash cycles respectively.

5.3.3 Colour difference

The colour of fabric is the first attribute attracting a person/user to select it. The aesthetic appearance of the cloth or fabric is highly influenced by its colour. The perception and interpretation of colour are highly subjective and is dependent of the factors like age, eye fatigue and many other physiological factors (X-Rite, 2000). The change in aesthetic appearance of the cloth materials and the degree of dullness of the cloth material with the increased number of washing cycles in tap water and recycled water is measured by the colour difference. It is obvious that some change in colour is brought about due to the (numbers of) washing/s of cloth. However, to conclude that the recycled water is safe to wash clothes, the change brought about by washing the cloth in recycled water and tap water should have no significant difference.

The spectrometry analysis of the cloth samples washed in recycled water from three providers and tap water (after 10^{th} and 50^{th} wash cycles) was carried out. The CIELAB space is a uniform three dimensional space defined by the colorimetric coordinates L*, a* and b* - L* (lightness, ranging from 0 to 100 with higher numbers being brighter), a* (green–red coordinate), b* (blue–yellow coordinate) (C.I.E., 1986). All L* values of cloth samples washed in tap water and recycled water were close to 100, revealing the brightness of the cloth samples. Denim has the highest L* value claiming to be the brightest of all followed by sation, polycotton, cotton and polyester. There was no significant change in lightness (ΔL) of the cloth samples washed in recycled water compared to the lightness of the cloth samples washed in drinking water. Also, There is no significant change in the values of a* (Δa) and b* (Δb) of the cloth samples washed in recycled water from all three providers compared to the cloths washed in drinking water (Table 5.2).

Table 5.3 presents the change in colour of cloth samples in terms of ΔE. In general, all ΔE values for all cloth samples washed in recycled water from all three providers at 10 wash cycles lies in the range of 0-1 confirming thereby no visible difference between the colours of the clothes washed in recycled water compared to the clothes washed in tap water at identical conditions. Similarly ΔE values for almost all cloth samples washed in recycled water from all three providers at 50 wash cycles lies in the range of 0-1 except for denim washed in the recycled water from Melbourne. The ΔE value for denim washed in recycled water from Melbourne for 50 wash cycles compared to the denim washed in tap water for 50 wash cycles is 2, 1.8 and 1.8 resulted from CIELAB76 (ΔE76); CIE94 (ΔE94) and CIEDE2000 (ΔE2000) respectively. Hence, only in the denim cloth washed in recycled water from Melbourne there is small change in colour which is visible to the trained eyes.

Table 5.2 The difference in L*, a* and b* of cloths washed in recycled water from three different providers in comparison with cloths washed in tap water after 10 and 50 wash cycles respectively, expressed as ΔL, Δa and Δb respectively

	Denim			Satin			Polycotton			Polyester			Cotton		
	ΔL	Δa	Δb	ΔL	Δa	Δb	ΔL	Δa	Δb	ΔL	Δa	Δb	ΔL	Δa	Δb
PM_10	-0.5	-0.1	0.1	0.7	0.0	0.2	-0.1	0.0	0.0	0.5	-0.1	1.2	-0.7	-0.0	-0.0
M_10	0.3	0.1	0.1	0.1	0.1	0.2	-0.1	0.1	-0.0	0.9	-0.1	1.4	-0.0	-0.0	-0.1
S_10	0.3	0.0	-0.4	0.1	0.0	0.0	-0.1	-0.2	-1.7	0.8	0.0	1.1	-2.0	0.2	0.8
PM_50	0.7	-0.0	-0.5	0.5	0.0	-0.4	-2.0	0.0	-0.2	0.6	-0.0	-0.2	-0.6	-0.1	0.4
M_50	1.4	0.3	-1.8	0.8	0.1	-0.5	-0.3	0.0	-0.1	0.1	0.0	-0.3	-0.3	-0.0	0.5
S_50	-0.0	0.0	0.4	0.2	0.01	-0.3	-0.2	-0.2	-1.8	0.1	-0.0	0.1	0.2	0.2	0.6

Table 5.3 The change of colour of cloths washed in recycled water from three different providers in comparison with cloths washed in tap water after 10 and 50 wash cycles respectively, expressed as ΔE* calculated by various formulas

	Denim			Satin			Polycotton			Polyester			Cotton		
	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000	ΔE76	ΔE94	ΔE2000
PM_10	0.5	0.3	0.4	0.6	0.5	0.5	0.2	0.1	0.1	0.2	0.1	0.2	0.7	0.3	0.4
M_10	0.8	0.7	0.7	0.5	0.3	0.4	0.1	0.1	0.2	0.3	0.2	0.3	0.1	0.1	0.5
S_10	0.6	0.5	0.5	0.3	0.2	0.3	0.4	0.3	0.3	0.2	0.1	0.2	1.0	0.5	0.1
PM_50	0.9	0.6	0.6	0.7	0.5	0.5	0.1	0.8	0.5	0.7	0.4	0.5	0.8	0.5	0.6
M_50	2.0	1.8	1.8	0.9	0.6	0.6	0.1	0.6	0.3	0.3	0.3	0.3	0.7	0.6	0.6
S_50	0.5	0.4	0.4	0.3	0.2	0.3	0.3	0.7	0.6	0.1	0.1	0.1	0.7	0.7	0.7

Note: ΔE76: CIELAB76, ΔE94: CIE94, ΔE2000: CIEDE2000

ΔE* = total colour difference value

ΔE meaning:

0-1 Normally an invisible difference

1-2: very small visible difference, only obvious to a trained eye

2-3.5: medium difference, also obvious to an untrained eye

3.5-5: an obvious difference

>6: a very obvious difference

5.3.4 Change in surface morphology of fabric sample

The scanning electron microscope (SEM) was used to investigate if there is noticeable change in the surface morphology of the fabrics washed in recycled water compared to the fabrics washed in tap water at identical conditions. The images of all cloth samples washed in recycled water and tap water are developed and observed. Figure 5.4 represents the SEM images of denim cloth washed for 10 wash cycles in tap water and the images of denim after 10 wash cycles in recycled water from Port Macquarie (PM), Melbourne (M) and Sydney (S) respectively. The observation revealed that there is no such distinct change in surface morphology of the cloth samples.

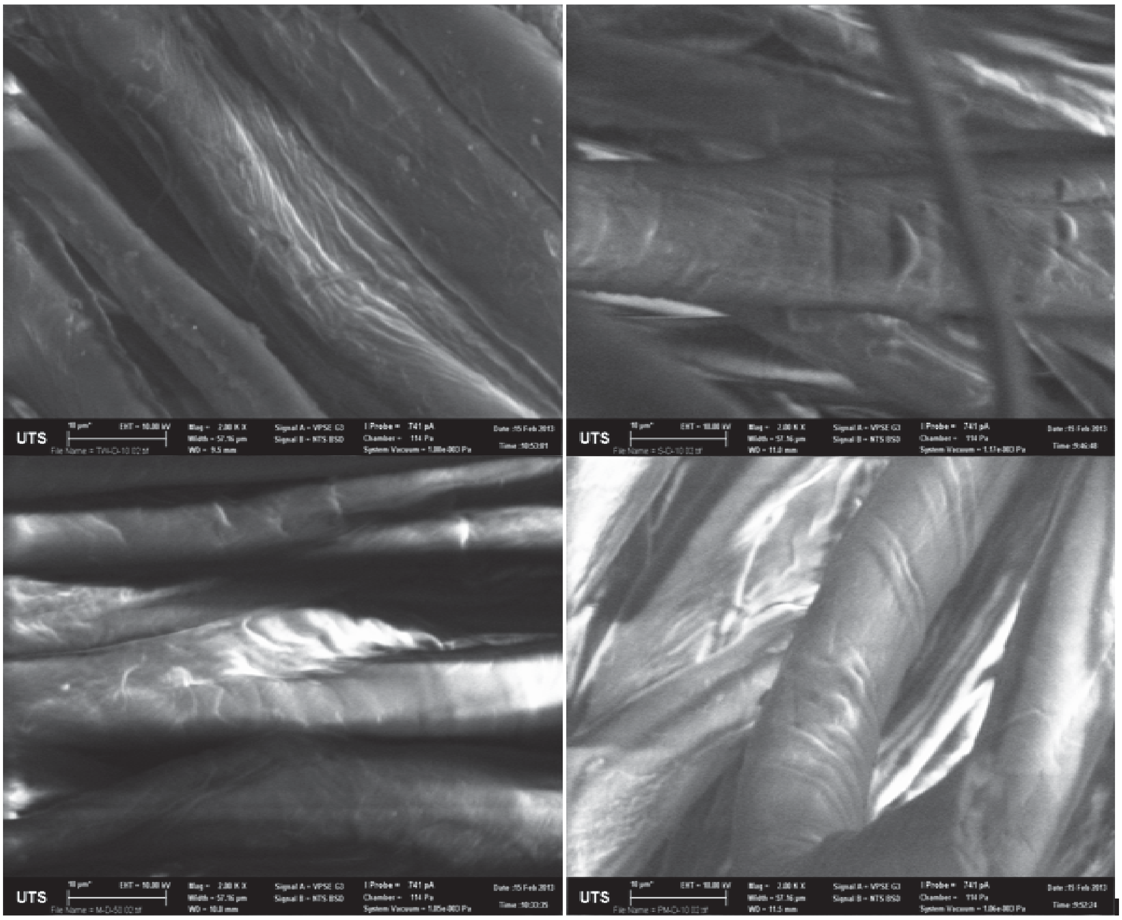


Figure 5.4 Denim (2000x) after 10 wash cycles in tap water and recycled water from PM, M and S respectively.

Similarly, Figure 5.5 presents the SEM images of cotton cloth washed for 10 cycles in tap water and recycled water for 10 wash cycles. No change in surface morphology is observed in cloth samples.

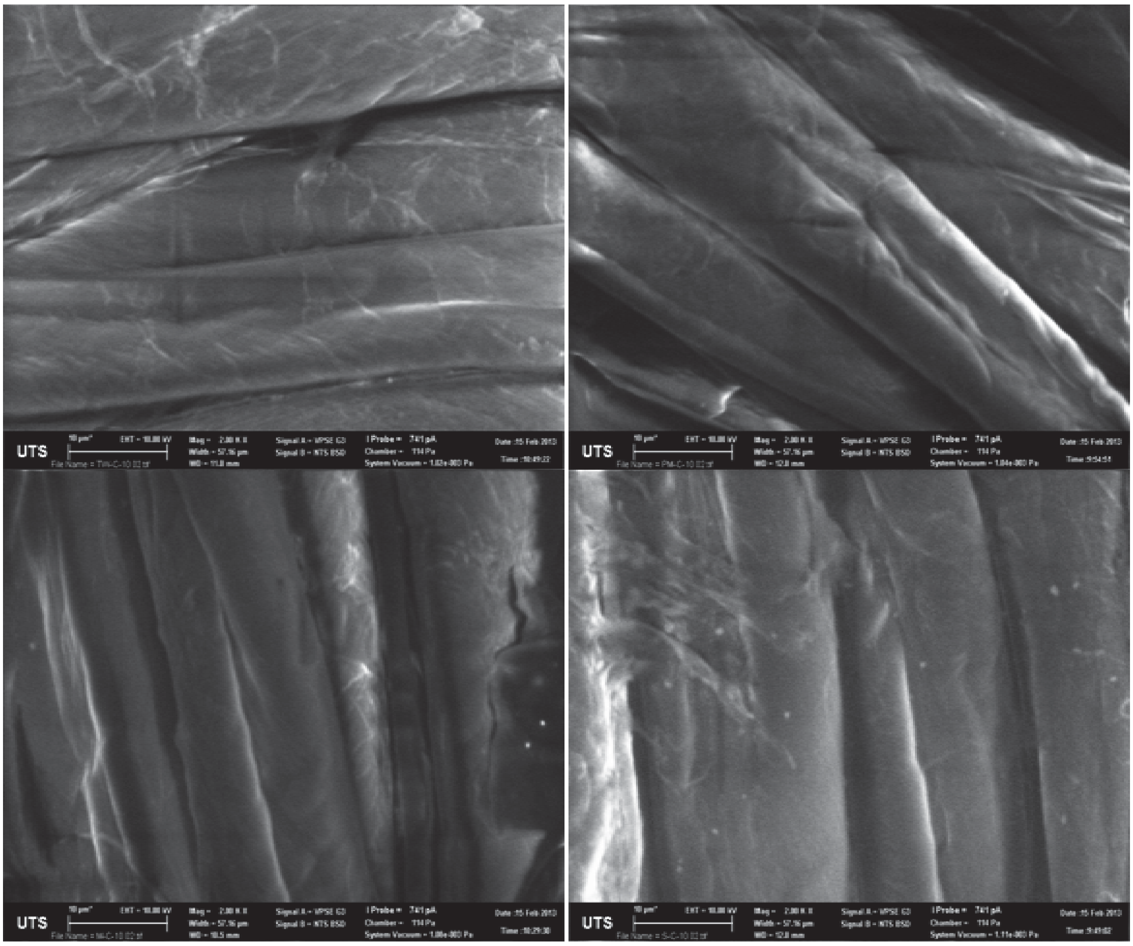


Figure 5.5 Cotton (2000x) after 10 wash cycles in tap water and recycled water from PM, M and S respectively**.**

Denim has been observed as the strongest in terms of tensile strength and cotton has been observed as the weakest. Therefore, SEM images of these two cloth samples are presented here. However, all cloth samples do not show any distinct change in their surface morphology. For, analysing the long term effect, images of cloth samples washed in tap water and the recycled water from three providers at 50 wash cycles is observed. No distinct change in the surface morphology of the cloth samples was observed.

5.3.5 Microbiological analysis

Public perception of potential health risk associated with contact with recycled water during laundry activities has the potential to restrict such use. Already there exist many planned recycling water schemes and with advancement in the treatment technology, scientists have reported no negative health effects even from drinking high quality treated reclaimed water (Khan and Gerrard, 2006). However the acceptance of recycled water is always associated with many problems. Class A recycled water which is subjected to advance treatment technology, is supplied in dual reticulation systems and therefore is of very high quality. However, as far as authors are concerned, there has been very few investigations reported which investigates the microbiological contamination of cloth samples washed in recycled water. O'Toole et al. (2008) presented a detail investigation which investigated the degree to which pathogens could be transferred from recycled water to hands, sample fabrics, nearby surfaces and the air during a typical household laundry cycle. They concluded that the class A recycled water, as used in Sydney's current recycled water schemes, was unlikely to pose a health hazard when given the inadvertent ingestion volume of 0.01 ml. Their major objective was to determine the minimum microbiological quality of recycled water that can be safely supplied for domestic machine washing of clothes. Comparative study of microbiological load of clothes washed in recycled greywater and clothes washed in drinking water was carried out in a German research study (Nolde, 2005). The cloth samples were dried in machine and in an indoor room. The results concluded that no difference was found from a hygienic-microbiological aspect between those samples washed and rinsed with recycled greywater and those washed with drinking water. The hygienic microbiological quality of samples was assessed using heterotrophic plate counts and not enteric indicator micro-organisms.

Therefore, in this study, the microbiological study of cloth samples washed in recycled water was carried out to improve the data base regarding the same and also to cover some of those bacteria which are more related with skin diseases. The microbiological study is represented in terms of faecal Coliform, E.coli count, S.aureus count and Pseudomonas count. The coliform bacterial should not be detected in the treated water and if found indicates the inappropriate treatment or the post contamination and therefore can be used as an indicator (WHO, 2004). E Coli is found in large numbers in the faeces of humans and of nearly all warm- blooded animals; as such it serves as a acceptable index of faecal contamination (WHO, 2004). Staphylococcus aureus and Pseudomonas are opportunistic pathogens. Staphylococcus aureus is a bacterium that is frequently found in the human respiratory tract and on the skin (Goodwin et al., 2012). Similarly, Pseudomonas aeruginosa has been associated with cases of folliculitis and dermatitis (Gross et al., 2007). All of them have been considered by many researchers (Wilkoff et al., 1969; Neely et al., 2000; Fijan et al., 2007; Oller et al., 2009; Kasuga et al., 2011) to see the contamination in cloth fabrics. Therefore, they are used in our study (Table 5.4).

Table 5.4 Microbiological analysis of cloth samples washed in recycled water

	Sample Description	Faecal Coliform TMW 141 CFU/item	S.aureus count TMPC 102 CFU/item	Pseudomonas aeruginosa count TMW 220 CFU/item	Ecoli Count TMW 141 CFU/item
Tap water	TW	<1	<1	<1	<1
Recycled water	RW	<1	<1	<1	<1
	OC	<1	<1	<1	<1
Cotton 1st wash	TW $C_{1\ Wet}$	<1	<1	<1	<1
	TW $C_{1\ A\ Dry}$	<1	<1	<1	<1
	TW $C_{1M\ Dry}$	<1	<1	<1	<1
	RW $C_{1\ Wet}$	<1	<1	<1	<1
	RW $C_{1\ A\ Dry}$	<1	<1	<1	<1
	RW $C_{1M\ Dry}$	<1	<1	<1	<1
Cotton 10th wash	TW $C_{10\ Wet}$	<1	<1	<1	<1
	TW $C_{10A\ Dry}$	<1	<1	<1	<1
	TW $C_{10M\ Dry}$	<1	<1	<1	<1
	RW $C_{10\ Wet}$	<1	<1	<1	<1
	RW $C_{10A\ Dry}$	<1	<1	<1	<1
	RW $C_{10M\ Dry}$	<1	<1	<1	<1
Cotton 30th wash	TW $C_{30\ Wet}$	<1	<1	<1	<1
	TW $C_{30\ A\ Dry}$	<1	<1	<1	<1

	RW C $_{\text{30 Wet}}$	<1	<1	<1	<1
	RW C $_{\text{30A Dry}}$	<1	<1	<1	<1
	ODe	<1	<1	<1	<1
	TW D $_{\text{1 A Dry}}$	<1	<1	<1	<1
	TW D $_{\text{1 Wet}}$	<1	<1	<1	<1
Denim 1st wash	TW D $_{\text{1M Dry}}$	<1	<1	<1	<1
	RW De $_{\text{1 Wet}}$	<1	<1	<1	<1
	RWDe $_{\text{1 A Dry}}$	<1	<1	<1	<1
	RW De $_{\text{1M Dry}}$	<1	<1	<1	<1
	TW D $_{\text{10 Wet}}$	<1	<1	<1	<1
	TW De $_{\text{10A Dry}}$	<1	<1	<1	<1
Denim 10th wash	TW De $_{\text{10M Dry}}$	<1	<1	<1	<1
	RW De $_{\text{10 Wet}}$	<1	<1	<1	<1
	RW De $_{\text{10A Dry}}$	<1	<1	<1	<1
	RW De $_{\text{10M Dry}}$	<1	<1	<1	<1
	TW De $_{\text{30 Wet}}$	<1	<1	<1	<1
	TW De $_{\text{30 A Dry}}$	<1	<1	<1	<1
Denim 30th wash	RW De $_{\text{30 Wet}}$	<1	<1	<1	<1
	RW De $_{\text{30A Dry}}$	<1	<1	<1	<1
	RW SOPA	<1	<1	<1	<1

Note:

O-Original

C-Cotton

De- Denim
1- First wash
10- Tenth wash
30- Thirtieth wash
A- Air dry
M- Machine dry

The tap water (TW) and recycled water from SOPA (RW SOPA) were subjected to the microbiological test. Both the tap water and recycled water are found to have less than 1 (< 1) CFU/ items of all indicators suggesting no microbiological contamination. The unwashed cloth samples, cloth samples washed in tap water and the cloth samples washed in recycled water at various wash cycles and varying wet, machine dry and air dry conditions were subjected to the microbiological analysis. The results revealed that all cloth samples are found to have less than 1 (< 1) CFU/ items of all indicators suggesting no microbiological contamination of cloth samples washed in both the tap water and in recycled water.

5.3.6 LSI calculations

LSI is employed to prognose the scale forming or corrosive index of the recycled water from the three providers. According to Langelier, If the LSI < 0 (negative value), the water causes corrosion of steel. If the LSI = 0, the water is neutral and stable and does not cause corrosion or scaling. When the LSI > 0 (positive value), the water can cause scaling on the surfaces of pipelines, heat-exchangers, and other technological equipment.

Table 5.5 LSI of aqueous solutions of various concentrations of various heavy metals

Water	Ca hardness $CaCO_3$(mg/l)	Total Alkalinity (mg/l)	pH	TDS	Temp. (˚C)	LSI
PM	121	89	7.5	645	24	-0.40
M	190	120	7.4	682	24	-0.21
S	115	88	7.6	400	24	-0.36

The LSI analysis of the recycled waters from all three providers was carried out. LSI index for the recycled water from PMWRP, CWW and SOPA are -0.40, -0.21 and -0.36 respectively (Table 5.5). Since the LSI is rather a qualitative than a quantitative characteristic, its being equal to zero should not be taken too literally. Besides, no one could avoid the possibility of instrumental errors and errors of approximation (calculation by conventional equations). Therefore, the values of the LSI in the range of -0.5 to +0.5 should be taken as ‘‘zero’’ (Prisyazhniuk, 2007). The values of the LSI for the recycled water from all three providers are in the range of -0.5 to +0.5 and hence should be taken as ‘‘zero” revealing the water to be stable with no corrosive or scale forming tendency. However, TDS and salinity of the recycled water has been observed as to be comparatively higher than that of drinking water. The concerned authorities are giving due consideration to these problems and are in process to get a solution for the same.

5.4 Conclusions

To assess the feasibility of use of recycled water for household laundry, the long term washing effects on the cloth durability, aesthetic appearance of the cloth and effects on washing machine were analysed. The specific findings are as follows:

- No significant change in the tensile and tearing strengths of cloth samples washed in recycled water (from all three providers) compared to the cloth samples washed in tap water at identical conditions were revealed. Hence, recycled water is safe and has no impacts on cloth durability.

- In terms of aesthetic appearance of cloths, on the basis of SEM analysis and Spectrometer analysis, no change in surface morphology and colour of the cloth samples were revealed concluding thereby no negative impacts of recycled water on cloth aesthetic appearance.

- No microbiological contamination has been detected in cloth samples washed in recycled water.

- No signs of corrosion or scaling on washing machine throughout the washing of cloth samples up to 50 cycles with recycled water from three different providers was revealed, there is no impact on the machine's aesthetic appearance and functional system.

- As indicated by LSI test, recycled water from all three providers is stable and has no tendency of corrosion or scaling.

Conclusively, the use of recycled water in washing machine is feasible in all aspects and therefore, introduction of this new end use should be made to all existing and proposed dual reticulation systems.

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CHAPTER 6

EDUCTIONAL LEAFLETS

6.1 Background

Despite its acknowledged potential and evident benefits, water recycling makes only a small contribution to water supplies (Russell and Hampton, 2006). Public attitudes against recycled water are seen to be a major hindrance to its use (Baumann, 1983). Dishman et al. (1989) concluded that technical aspects of potable water reuse can be resolved, but the resistance from the public to accept could lead to the failure of the project. Simpson and Stratton (2011) pointed out that many research studies have focused on exploring the reasons for the lack of acceptance of recycled water, but much less work has been carried out to identify ways in which technical hitches may be conquered. The evidence of successful and controversial recycled water projects around the world suggest that community attitudes to the use of such projects are critical to their success (Mainali et al., 2011a). Many researchers (Po et al., 2003; Hartley, 2006; Hurliman, 2008, Roseth, 2008; Ngo et al., 2009, Mainali et al., 2011a) advocate that positive community attitude towards the water recycling projects is one of the most important factors for the success of those projects. Positive community attitude towards water recycling projects can be attained by providing adequate information and knowledge about recycled water quality, the treatment procedures, the importance of its use in today's world of water shortage, and its fit for purpose use, encompassing different standards of recycled water. In today's world, it is argued that the basic economic resource is no longer capital, natural resources, or labour but knowledge (Brown et al., 2002). Lohman and Milliken, in their 1985 study in Denver, Colorado, concluded that information plays an important role in the acceptance of reclaimed water. More recently, a number of authors have expressed the opinion that the knowledge of reuse projects does not play a major role Leviston et al., 2006; Nancarrow et al., 2007); however, many other researchers (Roseth, 2008; Hurlimann et al., 2008; Dolnicar et al., 2009; Dolnicar and Hurlimann, 2011) emphasise the importance of knowledge and information which influence the positive attitude of the community towards the use of recycled water. Other researchers (Hills et al., 2002; Jeffrey and Jefferson, 2003; Hurlimann, 2007; Simpson and Stratton, 2011) have advocated that knowledge/information about water augmentation schemes increases public acceptance. The study by Dolnicar et al. (2010) provided empirical proof for the positive effect of information on the acceptance levels of water from alternative sources like desalination and water recycling. Their study revealed that information about water from alternative sources increases public acceptance. Mainali et al. (2011 a) suggest that knowledge of existing water shortages together with the knowledge of water reuse schemes is a critical factor for the success of water reuse schemes. In a survey, less than 20% of respondents reported that they were 'very informed' about reclaimed water (OlgivyEarth, 2010). In 2009, research was conducted in San Jose in California, Denver in Colorado, Tampa in Florida, and Perth in Western Australia by the WateReuse Research Foundation which revealed that knowledge of water science in the community is not robust and that the provision of information improved the acceptance of water recycling (Simpson and Stratton, 2011).

It is always a big challenge to reach the targeted audience and motivate them to participate in a programme, particularly if it is brought to them unwanted. This is where a 'leaflet' or 'flier' has a major role to play. In the commercial world, a flier is referred to as a marketing leaflet which is used to disseminate information to promote a business, in the hope of achieving their full potential. However, in community based programs where such leaflets are used to provide information and knowledge on a particular project, scheme or product, they are referred as 'educational leaflets'. Commercial leaflets for the promotion of a new product in a market and an educational leaflet for the community for the acceptance of recycled water differ in many aspects. An educational leaflet not only arouses the community's interest in participating in a project or a scheme, it also brings the target community into a state of readiness to accept the product.

There are many research studies revealing that the use of educational leaflets noticeably increases the understanding of the subject matter in the community and increases acceptance of the product (Hesketh and Laidlaw, 1997; Roseth, 2008; Saeed et al., 2008; Dolnicar et al., 2010; Sawamura et al., 2010; Simpson and Stratton, 2011; Dowse et al., 2011). So far as the authors are concerned, there are very few studies (Roseth, 2008; Hurlimann, 2008; Dolnicar et al., 2010; Simpson and Stratton, 2011) who have considered the impact of educational leaflets on the use of recycled water. Consumer acceptance of a new health related product in a market is somehow related to the acceptance of recycled water by the community in terms of concerns about health-related effects on the general public. Therefore, some studies related to educational leaflets in the medical field have been cited here. Saeed et al. (2008) conducted a study to determine the impact of counselling and educational leaflets on the contraceptive practices of couples and drew the conclusion that there is a definite increase in contraceptive uptake in women provided with educational leaflets. According to Sawampura et al. (2010), intervention using an educational leaflet had a significant positive impact on patients' attitudes toward depression and antidepressant treatment. The authors conclude that the results indicate that the educational leaflet is an effective tool for delivering information. There are many other research studies (Coudeyre, 2002; Petti, 2007; Venmans, 2007; White, 2007) in the medical field that have reached the conclusion that educational leaflets increase the level of understanding and bring the community to a state of readiness to accept something new. There is no doubt that there are many options available to educate people about recycling water. Video presentations and direct communications are just two of the options available, both of which can have a good impact as far as educating people is concerned. However, in terms of time and money, one of the best means of educating people about recycled water is with educational leaflets. The community attitude survey commissioned by Mainali et al. (2013b) in Melbourne, Port Macquarie and Sydney revealed that, when given the option to choose the best method of getting information on recycled water, more than 50% of the general public chose educational leaflets, followed by websites and e-mails. To ensure the best output, it is essential to create educational leaflets with an effective format and design. Our extensive literature review revealed no specific study carried out for the good design of educational leaflets for recycled water. The need to focus on educating end users about recycled water have been put forward by many researchers but little emphasis on the design and distribution of appropriate educational leaflets has been observed. A key gap is observed in respect of appropriate design criteria for such educational leaflets for the same; guidelines for evaluating educational materials exist, but they do not relate specifically to educational leaflets. The prime focus in this chapter, therefore, is on the design of an educational leaflet about recycled water that will convince the general public to accept the use of recycled water for washing machines. The fundamental concept of recycled water for educational leaflets is covered in this chapter.

6.2 Fundamental concepts of recycled water for the educational leaflets

Education is an essential part of sustainable water management. It is observed that there is intense lack of knowledge in the community regarding recycled water. Simpson and Stratton (2011) developed eight criteria to evaluate the content and format of available booklets and web sites (34 in total) related to recycled water. The review was carried out in 2008-09. The authors focused on the content of the information on recycled water provided for the community. The eight criteria developed by Simpson and Stratton (2011) are:

- Does it provide information about wastewater, where it comes from and what is in it?
- Does it show how water becomes progressively cleaner as it is treated at the wastewater treatment plant and the reclamation plant?
- Does it emphasise that the water is treated to a quality that is safe and fit for the purpose of its intended use?
- Does it give examples of water that is already being recycled?
- Is it quick and easy to read and understand? i.e. it should have a Flesch readability score of 50 or over.
- Does it encourage the concept that water should be judged not by its history but by its quality?
- Does it promote confidence and trust in water utilities?
- Does it include a discussion of risk/safety—can we be sure?

By following the above eight criteria, analysing and following the listed websites and booklets, and accommodating the comments made by Simpson and Stratton (2011), the fundamental concepts necessary for educating people regarding recycled water have been presented. It is of great importance to understand the meanings and related terminologies of recycled water thoroughly and comprehensively to better understand the importance of recycled water and the need to use it, wastewater treatment methodologies, the specific end uses of recycled water and the associated water quality criteria of recycled water.

6.2.1 Definition of wastewater

The simplest definition of wastewater is that it is water that has been used and is no longer wanted, because no further benefit can be derived from it. Generally, it is defined as the liquid waste discharged from domestic households, municipal and commercial properties, industry, and agriculture. It often contains contaminants that result from mixing wastewater from different sources. The source of the wastewater influences the characteristics of the waste stream. Importantly, however, due consideration should be given to the fact that about 99 % of wastewater is water, and only 1% is solid wastes (Vigneswaran and Sundaravadivel, 2004). According to Jennifer Simpson in her educational booklet "From waste-d-water to purified water", wastewater is primarily composed of water — a 200-litre drum of it contains only about one tablespoon of dirt (Simpson, 2008). The dirt consists of organic molecules that contain carbon, inorganic molecules that do not contain carbon (except for carbonates), micro-organisms and fine particles that are suspended in the water rather than dissolved. The sources and potential pollutants of recycled water are summarised in Table 6.1.

Table 6.1 Sources of wastewater and potential pollutants

Sources of wastewater	Potential Pollutants
Domestic/Commercial properties	Organic matter (proteins, lipids, carbohydrates etc), phosphorous, solids, ammonium, pathogens.
Stormwater	Atmospheric depositions, heavy metals, sand, silt etc
Industry/ Agriculture	Chemicals, hydrocarbons / pesticides, fertilizers
Municipal water	

6.2.2 Organic Matter

Organic matter contains carbon atoms. A carbon atom has four bonds — it can attach itself to four other atoms at the same time; it has a strong affinity with hydrogen, oxygen, nitrogen and phosphorus and readily joins on to other carbon atoms (Figure 6.1). It is also very reactive, so there are millions of organic compounds. Some organic compounds are simple, whereas some are highly complex. Natural organic materials are food and animals, whereas synthetic materials are chemicals which include herbicides, insecticides, pharmaceuticals, food colouring and flavours, personal-care products, dyes and paints, adhesives, detergents, polymers and plastics.

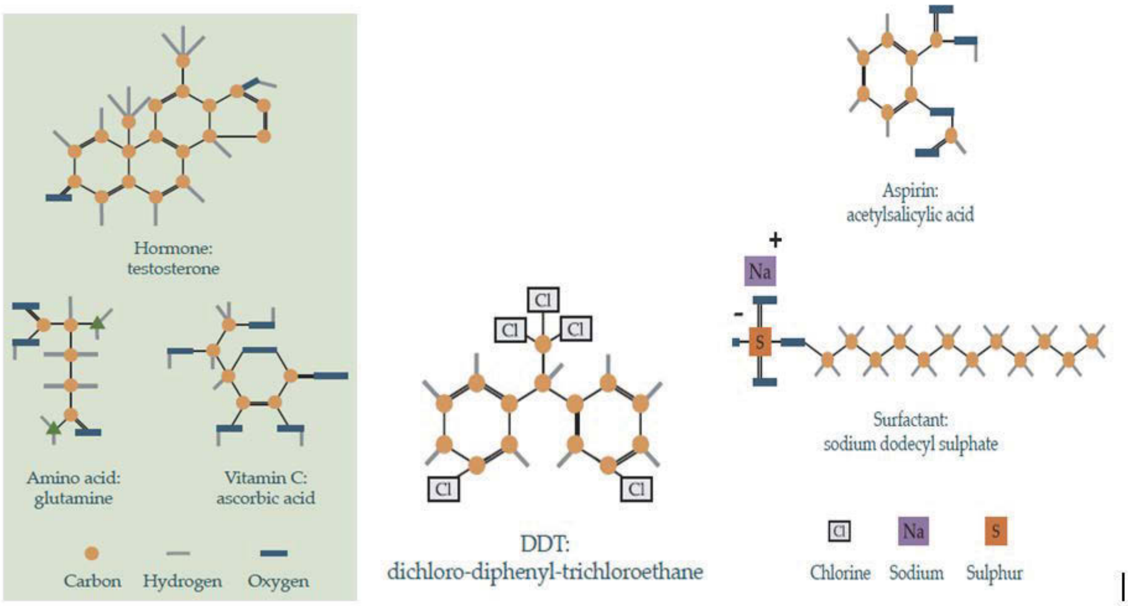

Figure 6.1 Natural and synthetic organic matter found in wastewater. (Adapted from Simpson, 2008.)

6.2.3 Inorganic matter

Inorganic matter contains no carbon. Inorganic mineral compounds in water are of little concern. Heavy metals and nutrients in water, by contrast, are of major concern. High levels of heavy metals in water can be a health hazard due to high toxicity, in addition to which, the presence of heavy metals such as iron and manganese to a high level may cause staining of clothes and appliances. There is also an increasing concern about emerging pollutants, including pharmaceuticals and steroids.

Both nitrogen (N) and phosphorus (P) are of environmental concern because they are nutrients, and if present in excess, they may cause eutrophication in the form of algal bloom, which seriously affects aquatic life. Nitrogen in the form of urea is a breakdown product of the proteins in plant and animal matter. Urine is the main source of urea, most of which reacts with water to form ammonia compounds. Phosphorus is also obtained from plant and animal matter, but the main source of phosphorus found in sewage is from the detergents we use.

6.2.4 Micro-organisms

Micro-organisms include bacteria, viruses, pathogens and some single-celled protozoa. Bacteria are of huge importance to humans in many aspects, such as fermentation, nitrogen fixation, and decay including water treatment. However, they can sometimes be a health hazard in the form of pathogens, e.g. Vibrio (cholera), Salmonella (typhoid), Mycobacterium (tuberculosis), Shigella (bacterial dysentery), Yersinia (plague), and Campylobacter (gastroenteritis). Viruses are highly microscopic organisms and are great source for infection. Viruses found in water include poliovirus, hepatitis A and E and norovirus.

6.2.5 Suspended Particles

Wastewater also contains particles that are suspended rather than dissolved. They include fine particles of silt, sand, paper fibre and other insoluble matter, and cause the water to appear cloudy and coloured.

6.2.6 Definition of recycled water

Many researchers in the past (Asano and Levine, 1996; Asano, 1998) defined water recycling as the reclamation of effluent generated by a given user for on-site use by the same user, such as industry where the recycling system is a closed loop. According to Radcliffe (2004), the process of treating wastewater to make it reusable for one or more applications is referred to as water reclamation; thus, produced water is reclaimed water. The beneficial use of reclaimed or treated water for specific purposes such as irrigation, industrial or environmental use is termed as water reuse. The California Water Code has recently proposed a more general definition of recycled water as “water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur" (California Water Plan, 2009). More recently, Asano and Bahri (2011) stated that the process of treating wastewater to make it reusable is water reclamation, whereas using treated wastewater in a variety of useful ways such as for agricultural, industrial or residential purposes is water recycling and reuse. In Australia, the term 'water recycling' is regarded as the preferred term for generic water reclamation and reuse. The term 'recycled water' can apply to a number of alternative definitions, but broadly refers to the treatment and reuse of wastewater which would otherwise be discharged for no productive use.

The use of recycled water can be 'Direct reuse' or 'Indirect reuse' according to the mode of reuse. The California Water Plan (2009) states that Direct reuse is the use of recycled water that has been transported from a wastewater treatment plant to a reuse site without passing through a natural body of either surface or groundwater. This is also called 'pipe-to-pipe' reuse where the recycled water is conveyed in a distribution system following treatment. The purposeful direct use of recycled water without relinquishing control over the water during its delivery is referred to as 'Planned reuse'. Direct reuse is always considered as planned because it involves delivery in a distribution system leading from the wastewater treatment plant to the point of reuse. Direct reuse can be either Direct Potable reuse (DPR) or Direct Non-potable reuse (DNPR). Growing urbanised populations and increasing constraints on the development of new water sources have encouraged a variety of measures to conserve and reuse water over the last two or three decades. As part of this worldwide trend, a small but increasing number of municipalities are augmenting or considering augmenting the general water supply (potable and nonpotable) with highly treated municipal wastewater, hence DPR is occurring in some areas. The first DPR was introduced at Windhoek, Namibia in 1968 (Po et al., 2003; Marks, 2006), and 25% of the municipality's drinking water supply now consists of treated wastewater (Law, 2005). In Singapore, recycled water constitutes approximately 3% of municipal supply (Seah et al., 2003). The DNPR of water has become a common practice with more than 3300 non-potable water reuse projects registered worldwide in 2005 (Bixio et al., 2005). It is defined as the use of fit for purpose reclaimed water treated for a range of uses that do not require water of drinking quality standard. DNPR is gaining popularity in Australia in industry and agriculture. In addition to this, many suburbs in various states of

Australia already receive, or are in the process of receiving, a supply of recycled water for non-potable reuse via a dual reticulation system (Mainali et al., 2013a).

Water for Indirect use is discharged from a wastewater treatment plant, and the recycled water is passed through a natural body of water before being made available for use. Indirect reuse can be either planned or unplanned. 'Unplanned' or 'incidental' reuse is the unplanned use of wastewater after disposal, such as when treated wastewater is discharged into a river or other water body and later drawn upon by communities for water use. Indirect reuse can be either Indirect Potable reuse (IPR) or Indirect Non-potable reuse (INPR). There are many existing, planned IPR systems in the world, and the term IPR simply describes the situation where recycled water replenishes the source of drinking water from either groundwater basins or surface water reservoirs (Dimitriadis, 2005). The IPR system began more than 40 years ago in California (the leading state with the highest number of IPR projects in the US). Other states with demonstration or full-scale IPR projects include Arizona in Colorado, the Fred Harvey Water Reclamation Facility located in El Paso, Texas, the Upper Occoquan Sewerage Authority Water Recycling Project in North Virginia, and Florida (Po et al., 2003). In California, Water Factory 21, in the Orange County Water District (OCWD), is the oldest project, with a production capacity of 19 megalitres per day (ML/day). Water Factory 21 was closed in 2004 and an upgraded groundwater replenishment system plant was completed in 2007. The indirect reuse of recycled water for potable purposes already takes place in some parts of Australia. For example, Penrith in NSW discharges treated wastewater into the Nepean River, and it is then used by the North Richmond water treatment plant which treats it and delivers it to the community in the Hawkesbury region. In Wulpen, Belgium IPR is carried out be recharging the groundwater basin with purified water (Rodriguez et al., 2009).

When wastewater is treated and discharged into a river or other water body and is later drawn upon by communities for potable supply , it is referred to as 'unplanned' because the history of the water is not acknowledged in treatment processes, and the communities involved are largely unaware of the source of their water. Unplanned potable recycled water use occurs in numerous parts of the world; other areas in Australia include the Murray and Hawkesbury Rivers in Australia, and the Thames River in southern England. Numerous cities in Europe rely on unplanned IPR for approximately 70% of their potable water source during dry conditions (Durham et al., 2005). In many developing countries, untreated sewage is directly discharged into rivers. According to the information provided by UNDP (2008), around 90% of sewage is discharged untreated to rivers in the developing world as a whole.

6.2.7 Sources of Recycled water

Sources of recycled water are wastewater effluents from previous uses, including greywater, blackwater, municipal wastewater or industry effluents. The stream of recycled water may be comprised of any or all of these waters (Radcliffe, 2004). The characteristics and constituents of recycled water depend exclusively upon the source of the recycled water and require different treatment levels. Thus, it is indispensable to understand all kinds of recycled water sources and their characteristics to be able to accept the recycled water as fit for purpose.

A. Stormwater

Stormwater is water that originates during precipitation events. According to Naylor et al. (2012), stormwater is defined as the runoff from pervious and impervious surfaces in predominantly urban environments. Impervious surfaces include roofs, driveways, pavements, footpaths, compacted soil and roads. The water that originates from melting snow and enters the stormwater system is also referred as stormwater (Burton and Pitt, 2002). The stormwater quantity and quality depend upon the topography of the area, rainfall/runoff pattern, climate and so on. Many studies (Burton and Pitt, 2002; Huang et al., 2010; Barbosa et al., 2012) observe that stormwater transports large quantities of contaminants to receiving waters and hence is the major contributor to the pollution of receiving waters in many countries (Lee et al., 2007). Stormwater is different to domestic sewage in its quality parameters. It is recognised as the most important source of heavy metals, unlike domestic wastewater which constitutes the main source of organic and nitrogenous pollution (Gasperi et al., 2010; Barbosa et al., 2012).

Stormwater is a relatively abundant, local source of water, available throughout an urban area. The average annual volume of urban stormwater runoff in Australian cities is almost equal to the average annual urban water usage, of which at least 50% is for non-potable use (Mitchell et al., 1999). As cited in Naylor et al. (2012), stormwater runoff from Australian capital cities has been found to be comparable to the amount of potable water consumed. According to Laurenson et al. (2010), approximately 10,300

ML of storm water is generated annually in Australia. The general public usually does not associate stormwater with the yuck factor and as such it has better public acceptance for utilisation. Biochemical Oxygen Demand (BOD), bacteria and nutrient concentrations are lower in stormwater than in raw sanitary wastewater (Burton and Pitt, 2002). All these factors make it a potentially valuable resource for water supply substitution, particularly for nonpotable water applications. In fact, the harvesting of storm water is likely to reduce the size of storm water pollution management facilities because it is an effective mechanism for reducing pollutant load (Henderson et al., 2007; Davis et al., 2009). Many researchers (Booth et al., 2003; Mitchell et al., 2007; Biggs et al., 2009) have claimed with substantial evidence that greywater reuse and stormwater harvesting systems can help to reduce reliance on conventional centralised water systems with many other benefits and are key features of Water Sensitive Urban Design (WSUD) (Wong, 2006).

A focal point of proposed national water conservation programs is the recycling of both treated wastewater and urban stormwater (Anderson, 1996). However, this is currently not widely practised in Australia, and stormwater is particularly neglected; within cities, only 4% of rainwater and stormwater is recycled, while less than 1% of reclaimed wastewater is reused within urban areas (Dillon, 2004).

B. Grey water

Grey water is defined as the wastewater generated from household kitchen sinks, dishwashers, showers, baths, hand basins and laundry but excludes any input from toilets (Dixon et al., 1999; Eriksson et al., 2002; Radcliffe 2004; NWQMS 2006; Li et al. 2009; Misra et al., 2010). Some researchers (Christova Boal et al., 1996; Casanova et al., 2001; Al Jayyousi, 2003; Wilderer, 2004) exclude kitchen wastewater in their definition of grey water. Casanova et al. (2001) states that including kitchen wastewater as grey water may pose an unacceptable risk from pathogen contamination because of the high probability it will contain high levels of food scraps and other undesirable particles and wastes. According to NWQMS (2006), some guidelines also exclude water from the kitchen as a source of grey water for the same reason. However, as a general definition, the term greywater is used when designating all the wastewater produced in a household except toilet wastewater. Generally, greywater is less polluted and low in contaminating pathogens, nitrogen, suspended solids and turbidity compared wto municipal and industrial wastewaters. Sullage and light wastewater are terms also used instead of greywater. Some experts define greywater as water that is lower in quality than potable water, but of higher quality than black water (Jamrah et al., 2006; Prathapar et al., 2006; Al Jayyousi, 2003; Ottoson and Stenstrom, 2003; Surani, 2003). Revitt et al. (2011) note that greywater generally has a lower organic pollutant and pathogen content than combined municipal wastewater which includes toilet waste. No incidences of illness linked to grey water reuse have been reported so far and the health risks appear to be low; however, studies on the health impacts of grey water reuse are continuing and are in greater demand. Greywater quality can be affected by the inappropriate disposal of domestic waste. The quality of greywater varies depending upon the size, living standard and behaviour of the residents as well as the volume of water and the chemicals used. According to NWQMS (2006), greywater may contain urine and faeces from nappy washing and showering, as well as kitchen scraps, soil, hair, detergents, cleaning products, personal-care products, sunscreens, fats and oils. Cleaning products discharged in greywater can contain boron and phosphates, and the water is often alkaline and saline — all of which pose potential risks to the receiving environment. According to Morel and Diener (2006), greywater contributes to half the total organic load and up to two thirds of the phosphorous load in domestic wastewater. In some cases, high BOD and Chemical Oxygen Demand (COD) concentrations might also be observed, caused by chemical and pharmaceutical pollutants from soaps, detergents and personal care products as well as food waste in kitchen sinks (Morel and Diener, 2006).

In their cost-benefit analysis on reusing greywater for toilet flushing and irrigating food crops in residential schools in Madhya Pradesh, India, Godfrey et al. (2009) found that the benefits of greywater reuse were substantially higher than the related costs. Apart from toilet flushing, which is the most common application of greywater, other uses such as the irrigation of gardens, parks, school yards, cemeteries and golf courses, vehicle washing, fire protection and air conditioning are also found (Pidou et al., 2008). Greywater treatment and reuse schemes have already been piloted in many countries around the world and are becoming increasingly commonplace in water stressed areas such as Australia and Mediterranean countries (Friedler and Gilboa, 2010; Masi et al., 2010; Pinto and Maheswari, 2010).

C. Blackwater

Blackwater refers to wastewater from toilets i.e. wastewater containing the faecal matter and urine. Blackwater is highly polluted with high concentrations of organic pollutants, nutrients and a large variety of microorganisms. Brown water, foul water or sewage is terminology sometimes used to refer black water. The applications of blackwater for recycling are quite limited because it attracts strong denial from the community, which is attributable to the high association of blackwater with the yuck factor by the general community. However, economic/environmental benefits from this reuse are worth consideration in terms of nutrient (nitrogen and phosphorus) recovery (Kujawa-Roeleveld et al., 2005; Voorthuizen et al., 2008). According to Voorthuizen et al. (2008), the nutrient recovery rate of some advanced blackwater stream separation devices, especially for nitrogen and phosphorus, can be as high as 85%; the recovered water can the be sent back to agriculture to replace industrial fertilisers. For these reasons, along with increasing water stress conditions throughout the world, recycled water sourced from blackwater is being used for toilet flushing, agricultural irrigation and outdoor hose tap use, as reported in AWS (2010).

D. Agricultural and Industrial Wastewater

Wastewater produced during the various agricultural activities is termed 'agricultural wastewater' whereas the wastewater produced by industrial activities is termed 'industrial wastewater'. Agricultural wastewater is highly rich in nutrients, pesticides, organic matter, and so on. Industrial wastewater results from human activities associated with raw material processing and manufacturing. The composition of industrial wastewater varies substantially on account of the particular industrial activities. Different industrial wastes, particularly such as those from mining, electro-plating, metal- finishing industries, oil industries etc., discharge significant amounts of heavy metals, oil, grease and other chemicals in various forms. The concentration of these metals in wastewater may therefore rise to a level that can be hazardous to livestock. The practice of reusing agricultural drainage effluent as a source of irrigation water is observed in Australia (Dillon, 2000; McDonald, 2007; Bolan et al., 2009).

E. Municipal Wastewater

In most countries around the world there are no separate sewage collection pipelines, so greywater, blackwater, industrial wastewater and other waste streams from hospitals and commercial facilities are all discharged into municipal sewage systems, rendering municipal wastewater the largest and most significant resource for water reuse. However, this often leads to the presence of a broad spectrum of contaminants (e.g., organic matter, pathogens, inorganic particles) which are potential risks to human health and the environment (UN, 2003; Shatanawi et al., 2007). Municipal wastewater can be reused for industrial, domestic (household/irrigation), natural and agricultural purposes. However, these reuse options require different water qualities which depend upon specific treatment technologies (de Konnig, 2008).

6.2.8 Treatment methodologies

Wastewater treatment conventionally involves a series of physical (coarse sand and soil filtration and ultrafiltration), chemical (coagulation, photo catalytic oxidation, ion exchange and granular activated carbon) and/or biological (aerobic/anaerobic) processes to remove solids, organic matter, inorganic matter, micro-organisms, and often added nutrients (Asano, 1998; Radcliffe, 2004). The degree of treatment is basically governed by the source of water and the intended purpose of use. The purity of the recycled water can vary from ultra-pure water (e.g. in the semi-conductor industry) to primary treated effluent (rarely used in agriculture). The components of wastewater treatment are generally portrayed as preliminary, primary, secondary, tertiary and advanced treatment (Figure 6.2). The core objective of the preliminary stage is the removal of coarse solids and other large materials often found in raw wastewater. Though called the preliminary stage, this stage of wastewater treatment is of great importance for enhancing the operation and maintenance of succeeding treatment units. Preliminary treatment units typically include coarse screening, flow measurement devices, standing-wave flumes, and so on.

The primary stage involves comminution when necessary to reduce the size of large particles such that they will be removed in the form of sludge in subsequent treatment processes. This stage also involves coagulation and/or flocculation before sedimentation. In the absence of these chemical processes, filtration can be applied as an alternative process after sedimentation. The outcome of this stage will be the removal of about half the suspended solids and 25% to 50% reduction of the BOD (FAO, 1992; Radcliffe, 2004). Additionally, approximately 10% of nutrients such as nitrogen and phosphorus are removed. The effluent from this stage is referred to as primary effluent which needs to undergo disinfection if is to be discharged; however, processing wastewater to the primary stage only does not fulfil the current discharge standards (Radcliffe, 2004).

The secondary stage aims to remove biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. Aerobic biological treatment involves the metabolism of the organic matter in wastewater by aerobic bacteria in the presence of oxygen, thereby producing more micro-organisms and inorganic end-products such as CO_2, NH_3, and water (FAO, 1992). The process may involve either slow rate suspended growth processes such as aerated lagoons and stabilisation ponds, or faster processes such as activated sludge technologies. Fixed film processes such as trickling filters may be adopted as an alternative to the activated sludge. These processes are followed by a secondary sedimentation process to separate the biomass produced, which is then subjected to sludge processing. These processes remove up to half the nitrogen and convert the phosphorus to phosphates. There may be a further filtration of the effluent stream, which is then disinfected. About 80-95% of the BOD and suspended solids are removed in the secondary treatment (FAO, 1992; Radcliffe, 2004). This type of recycled water can be used for timed irrigation.

Tertiary treatment involves further removal of nitrogen, phosphorus, additional suspended solids, refractory organics, heavy metals and dissolved solids. This stage involves chemical coagulation, filtration and the use of activated carbon to adsorb hydrophobic organic compounds. In addition, lime can precipitate various cations and metals at high pH. Tertiary treatment is usually the minimum requirement for discharge to water bodies, particularly inland. There are various uses of tertiary effluent including irrigation, in industry, and for watering gardens and flushing toilets.

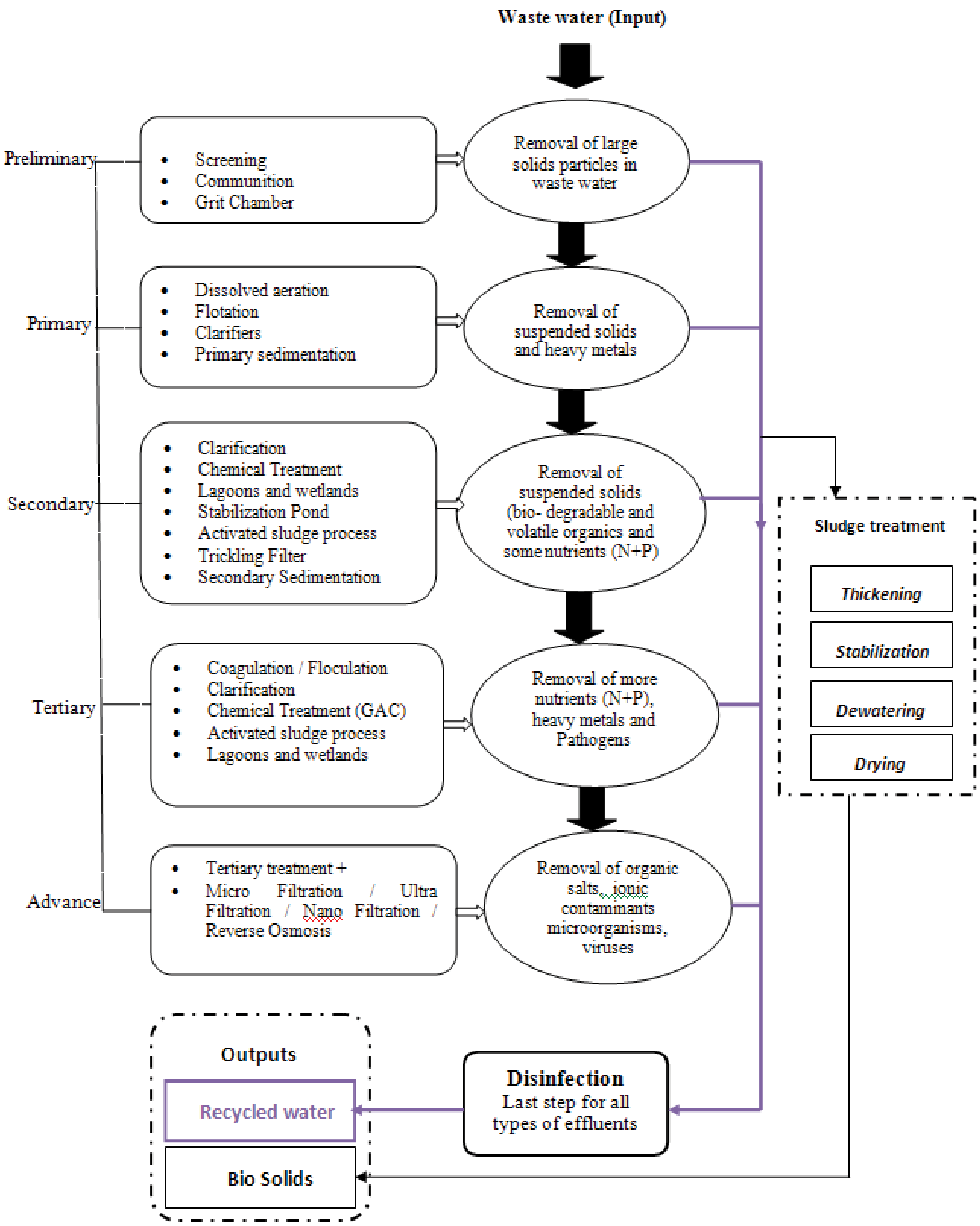

Figure 6.2 Summary of components of treatment methodologies for recycled water (Modified from Radcliffe, 2004)

Advanced treatment comprises membrane technologies which are becoming very popular these days due to their ability to remove micro-elements from the effluent stream. These processes involve membranes whose pore size is large enough to allow water molecules to pass through, but too small to permit the passage of salt, other minerals and large organic molecules. As shown in Figure 6.3, depending on the pore size of the semi-permeable membrane, membrane technologies are classified as

Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF) and Reverse Osmosis (RO). MF membranes have the largest pore size (0.05-2 μm) and typically reject suspended particles, colloids, and bacteria. UF (<0.1 μm) and NF (2 nm) membranes have smaller pores and can remove natural organic matter/soluble macromolecules and dissociated acids/pharmaceuticals/sugars/divalent ions, respectively. RO membranes (0.1 nm) can reject the smallest contaminants, monovalent ions. (Sagle and Freeman, 2004; Greenlee et al., 2009; ATSM, 2010). The choice of membrane is determined by the filtration separation requirements. This type of highly treated recycled water is as good as drinking water and is used for specialised uses such as some manufacturing processes and for river flows.

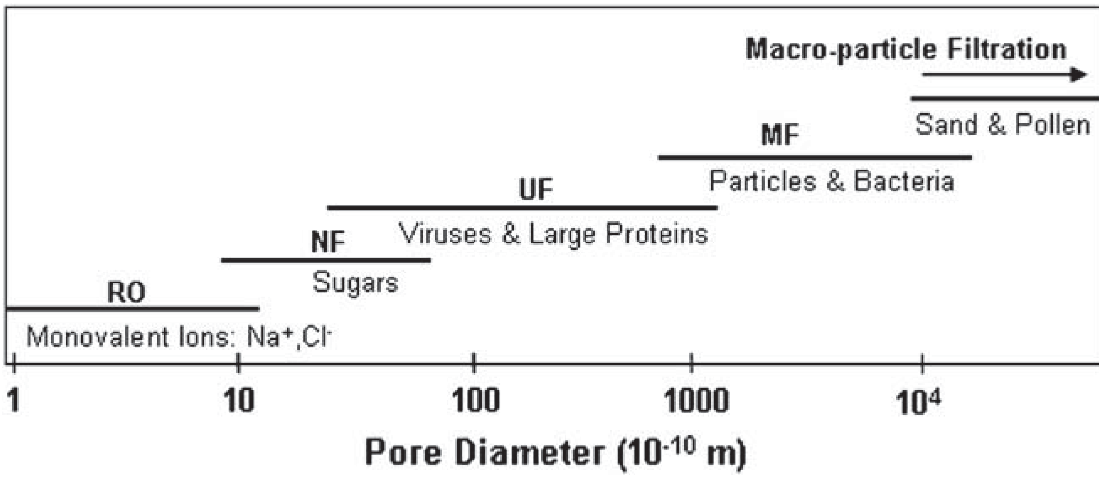

Figure 6.3 Range of nominal pore diameters for commercially available membranes (Adapted from – Lauren et al., 2009**)**

Disinfection is the last step for the recycled water that results from any treatment stage (primary stage to advanced stage). The process of disinfection is most commonly carried out by chlorination and/or ultra violet (UV) light and ozone depending upon the type of end use.

6.3 Design criteria of educational leaflets for recycled water

6.3.1 Background

Distribution of educational leaflets can be easily done via post, however in a world of information overload, the key concern is whether or not the targeted community will read the leaflet. As can be experienced in our day to day life, members of the general public already receive an abundance of unsolicited mail. It is very common for people to browse their mail quickly looking for anything of interest; therefore, it is very important to grab their attention at that particular moment. Use of emotional words and images which catch the eye at the very first look, making sure that the aim of the educational leaflet stands out, is very important. It is imperative to make sure that the educational leaflets are really attractive at first sight to the targeted audience, such that they are curious to know what is inside. A leaflet that displays a lot of words and requires too much effort to understand will not be read by the general community. Placing too much information on an educational leaflet is a common mistake that limits the effectiveness of the information campaign. It is very important to identify a single key message that has to be communicated, rather than flooding the reader with too many different pieces of information. There is no doubt that an educational leaflet can contain more than one message; however, the focus should be on the message that matters most and that the community is targeted to understand, which a carefully designed leaflet can help to do.

The quality of an educational leaflet depends upon its readability, availability and usefulness. Surveys carried out regarding educational leaflets in the medical sector revealed that many people do not value the written information that they receive with their medicines (Grime et al., 2007) which can be attributed to the poor readability and the presentation or format of the leaflet (Koo et al., 2002; Vander et al., 1991). In addition, many researchers (Basara et al., 1997; Rolland, 2000; Mwingira and Dowse, 2007) in this area suggest that the content of the leaflets is often perceived by the reader to be too technical and complex. Inevitably, educational leaflets on medicines are complicated by the number of technical words compared to educational leaflets on recycled water. However, certain issues in recycled water are also associated with many technical words; hence, attention should be paid to making sure, as far as possible, that the educational leaflets do not contain complex technical words and that they have high readability values. Dowse et al. (2011) further advocated that a well-designed, attractive, user-friendly leaflet is more likely to be read. Therefore, it is of great importance to make the leaflets attractive enough to catch the eye with good shape and size. Hesketh and Laidlaw (1997) proposed that a novel shape can be very effective and eye-catching, and the authors presented an example of medicine bottle-shaped leaflet that could stimulate interest in the medical field. Similarly, a related novel shape should be selected for a leaflet on recycled water.

Visuals or pictograms in educational material or information leaflets are of great importance for communicating information in a simple manner. Paivio's dual coding theory (Paivio, 1990) suggests that humans possess both visual and verbal information processing systems. Anderson (2000) suggests that if humans are presented with only one means of information, memory capacity for visual information seems to be greater. However, the author further posits that learners will remember and transfer material better if they encode the material both visually and verbally, so that they have two separate ways of accessing the information in memory. Hence, both pictures and words should be used in the design of the leaflet. However, according to cognitive load theory (Chandler and Sweller, 1991; Sweller, 1988, 1989, 1994; Sweller and Chandler, 1994), caution must be exercised when designing and organising instructional material that includes both visual and verbal elements to avoid an irrelevant cognitive load being created.

Apart from all the facts stated above for the effective design of leaflets, it is of great importance to explore what the general public genuinely seeks to know, and what kind of information regarding recycled water makes them comfortable and more confident about using recycled water for various purposes. Therefore a small community consultation program was carried out in several suburbs in Sydney. The procedure is outlined below.

6.3.2 Methodology

A preliminary educational leaflet was designed and a community consultation program was carried out in few suburbs of Sydney in order to elicit people's opinions of the content of the educational leaflet, its layout and format, and their views on what additional information they would require to make them comfortable and confident about using recycled water. The details of the consultation process and the analysis tool have been presented in section 3.4 in chapter 3.

6.3.3 Results and Discussions

The survey respondents consisted of 58% females and 42% males. The majority of the respondents (63%) were in the age group 30 to 50. 40% of respondents claimed to be well-informed about recycled water and 16% claimed to be very well-informed, whereas 29% of respondents revealed that they knew a little about recycled water and 11% revealed that they knew very little about recycled water. 4% of the respondents said that they knew nothing about recycled water. A weak positive significant relationship exists between gender and knowledge about recycled water ($r = 0.3$, $p = 0.01$) revealing a different level of awareness between the genders. Almost 68% of respondents agreed and 16% strongly agreed that recycled water is one strategy for dealing with the water shortage problem, while 16% of respondents disagreed with this statement. Almost all (96%) respondents believed that an educational leaflet on recycled water would help them to understand more about recycled water ($\chi^2 = 75.41$, df = 1, $p = 0.000$). A majority of respondents (72%) would prefer to receive educational leaflets via post to their homes, whereas 17% of respondents would prefer another option, such as a website, articles in the newspaper, etc. A significant negative relationship exists between gender and the mode of receiving information on recycled water ($r = -0.4$, $p = 0.000$) revealing that there is significant difference in preference between the genders. A positive significant relationship ($r = 0.3$, $p = 0.05$) exists between age and acknowledgement of recycled water as one of the solutions to deal with recycled water. This reveals that there is significant difference in opinion among different age groups regarding the importance of recycled water.

The survey results also indicated that the general public would prefer to be assured that the recycled water is good and safe enough to use for new end uses. Almost 78% of respondents were concerned about the safe quality of the recycled water; 59% were concerned about the source of the recycled water, 32% were concerned about the treatment methodology used and 48% were concerned about the cost of the recycled water (Figure 6.4). However, when given the option to rank these variables, the safe quality of recycled water was the first concern of 51%, followed by the source of recycled water as the first concern of 18% of the respondents, while treatment methodology and cost was chosen by 16% and 15% of the respondents respectively as their first concern ($\chi^2 = 68.73$, $p = 0.000$).

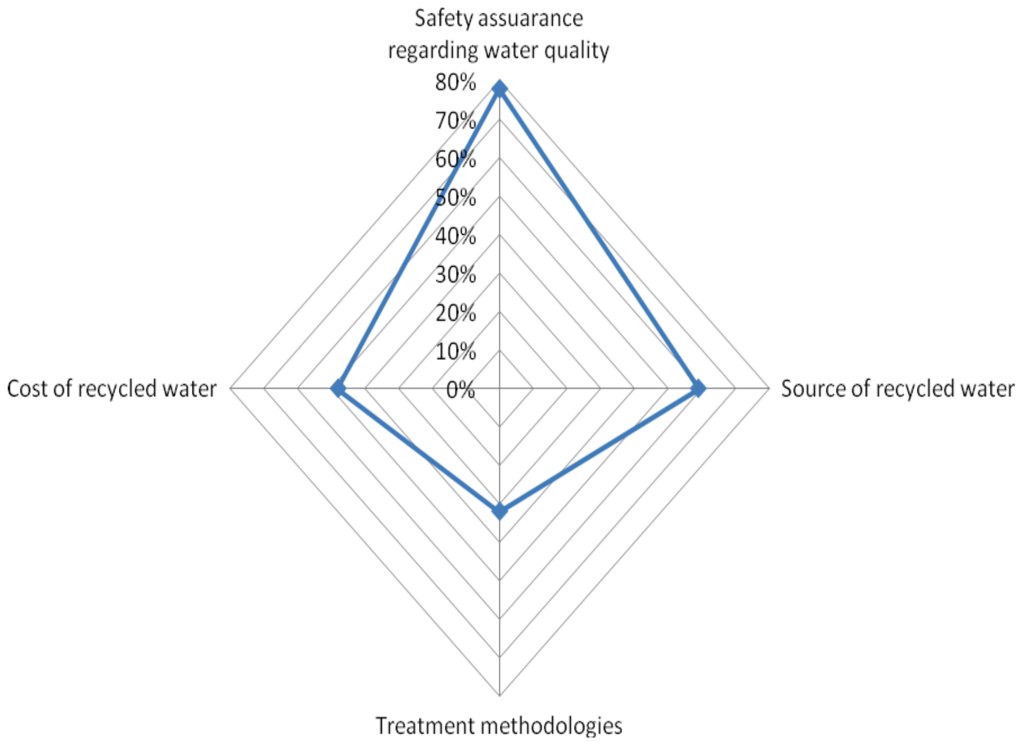

Figure 6.4 Preferantial factors to be presented in educational leaflets

Other preliminary findings from the community survey, specifically related to an educational leaflet on recycled water for washing machines, are:

1. The information provided to the public should be simple.
2. Most people in the focus group mainly want to be assured that the water they will be using for recycled water is safe.
3. People revealed that they would be more confident if they could see role models using recycled water for washing clothes.
4. The need for using reclaimed water needs to be explained—what will happen if we don't use it?
5. Several participants found the use of pictures very helpful in increasing the awareness of people about the current water scarcity.

Simpson and Stratton (2011) developed eight criteria for evaluating the content and format of available booklets and websites (34 in total) related to recycled water. The review was carried out in the 2008-09. The authors focused on the content of the information on recycled water provided for the community. By following those eight criteria, analysing and following the websites and booklets listed, and accommodating feedback from the community consultation, the criteria for the design of educational leaflets for the new end use of recycled water in urban areas has been developed as follows-

Criteria for content of an educational leaflet on recycled water-

- Assurance of safety of recycled water (for particular purpose)
- Information on present urban water crisis
- Information on the need for water recycling for sustainable urban water management
- Information about the recycled water and its types (fit for purpose)
- Clear explanation of sources of recycled water (wastewater and its types)
- Information about the existing end uses of recycled water (potable and non-potable)
- Existing examples of the use of recycled water to motivate people to use it

Criteria for the overall look (attractiveness) of an educational leaflet on recycled water

- Should involve emotional words to make people curious to read it
- Should be of an appealing shape and size to make it more attractive to read
- Should be readable with a Flesch readability score of 50 or over
- Should contain pictorial representations of the message so that the message is easily and robustly absorbed into people’s minds.

6.4 Conclusions

Well-designed educational leaflets play an important role in the dissemination of knowledge about recycled water and can figure largely in bringing the general community to a state of readiness to accept recycled water and its end uses. The effective design of educational leaflets includes the clear presentation of information with an assurance about the safety of recycled water for the targeted end use. In addition, the leaflets should be simple, easy to understand, and attractive in appearance. Motivating factors, such as the presentation of a clear picture of the current water crisis and its consequences should be well-presented to encourage people to use recycled water.

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CHAPTER 7

COMMUNITY ATTITUDE SURVEY

7.1 Introduction

Australia targets to increase the water reuse from 16.8% in the year 2009/10 to 30% per year in 2015 (Whiteoak et al., 2012). To meet this aggressive water recycling targets, more recycled water schemes together with new end uses should be further explored and developed. After agriculture, the household sector falls as the second highest water user in Australia (ABS, 2012). Therefore, due consideration should be given for conservation of more household water with recycled water. Recycled water supply in form of dual reticulation system has already begun in some suburbs of Australia. However, the existing end uses of recycled water in such systems are limited for landscape irrigation, car washing and toilet flushing. Hence, adding up new end uses of recycled water to the existing end uses is a must for system optimization and sustainability. Washing machine as a new end use of recycled water in dual reticulation system is well recognised for its great potential benefits. The influence of laundry water consumption is significant (almost 20%) on household water consumption of different states of Australia (ABS, 2004; Mainali et al., 2011) and so is in most of the countries of the world (Pakula and Stamminger, 2010). Few studies on the use of recycled water for washing machines (O'Toole et al., 2008; Storey, 2009; Mainali et al., 2011a, 2013; Chen et al., 2012) were carried out. However, studies investigating on social aspects to analyse public's acceptance and their concerns on this new end use are sparse.

It is a fact that successful implementation of a wastewater reuse project depends not only on its technical and environmental feasibility, but primarily on the support and the acceptance from the general public. Dishman et al. (1989) concluded that "the technical aspects of potable water reuse can be resolved, but the issue of public acceptance could kill the proposal". There are evidences of many recycled water projects which have failed due to lack of community support (Mainali et al., 2011b). These projects include not only the (indirect) potable reuse schemes but also the non-potable reuse projects including one in the Netherlands (Hurlimann and Dolnicar, 2010). To introduce any new end use of recycled water, it is without doubt a major challenge to achieve the public acceptance and support, especially when the use is with more personal contacts. Many researchers (Hartley, 2003; Po et al., 2003; Marks, 2006; Hurlimann and Dolnicar, 2010; Mainali et al., 2011b) advocate that no program using recycled water can be initiated without public acceptance. It is therefore very crucial to identify the nature of public response regarding the use of recycled water in washing machines. Since long, majority of studies have investigated public acceptance of recycled water for various uses. Pioneers in this field (Bruvold and Ward, 1970; Bruvold, 1972) and many others (Stone and Company, 1974; Sims and Baumann, 1974; Olson et al., 1979; Bruvold et al., 1981; Milliken and Lohman, 1983; Lohman and Milliken, 1985; Ahmad, 1991; Madany et al., 1992; Sydney water, 1999; Jeffery, 2002; Hills et al., 2002; ARCWIS, 2002; Friedler et al., 2006; Marks et al., 2006; Hurlimann, 2006; Hurlimann 2007, Roseth, 2008; Alhumoud and Madzikanda, 2010; Pham et al., 2011) are some of the studies conducted basically in USA and Australia and some from UK, Qatar, Bahrain, Kuwait and Israel. Table 7.1 provides an overview of these studies (except Jeffery, 2002). It is noted that only household uses of recycled water from these studies are taken into consideration for this study. In all studies, highest level of opposition is observed as the use becomes increasingly closer to personal physical contact.

It is observed that since late 1960s, studies investigating community attitude towards the use of recycled water have been observed in US whereas in Australia, detail studies began only in the late 1990s and in rest of the countries very few numbers of similar studies are carried out till date. Almost all (except Bruvold et al., 1981; Madany et al., 1992; Hills et al., 2002) studies cover the willingness of the community to use recycled water for washing machines. In general, the percentage opposing the use is more or less the same for all studies. However, the detail investigation of people's attitude towards this new end use for recycled water has not been addressed in these studies as their study purpose was different. Pham et al. (2011) carried out a detail study on community attitudes regarding this new end use. However, the survey sample size was small and only covers the Sydney region. Hence, this study incorporates different locations of Australia with a larger sample size (n = 478). It basically analyses the community perceptions, concerns and reservations to use recycled water for washing machine. The further conditions required making the community more confident and comfortable to use recycled water in washing machines are explored. Moreover, the comparative study regarding the attitude and concerns of the non-users, perspective users and the current users of recycled water have been carried out. The study can be of great value to the decision makers who intend to introduce the washing machine as a new end use of recycled water in the dual reticulation systems for substantial conservation of drinking water.

Table 7.1 Percentage of respondents opposing the specific uses of recycled water- Various international studies

Relevant studies \ Various uses	Drinking (%)	Cooking (%)	Showering (%)	Swimming (%)	Cloth washing (%)	Car washing (%)	Garden irrigation (%)	Toilet flushing (%)
Pham et al. (2011); n = 223 Australia (Sydney)	-	-	94	81	40	27	22	4
Alhumoud & Madzikanda (2010); n= 2200 Kuwait	78	78	60	-	53	17	-	-
Roseth(2008); n = 3050 Australia (Five major cities)	82	77	64	51	45	14	14	10
Hurlimann (2007); n = 305 Australia (Bendigo)	58	-	38	-	28	-	1	1
Hurlimann (2006); n= 197 Australia (Melbourne)	56	-	41	-	35	-	1	1
Friedler et al. (2006); n= 256 Israel	89	-	-	69	62	20	22	15

Marks et al. (2006); n = 2504 Australia	68^	46^	24^	-	27	8	4	3
ARCWIS (2002)**; n = 685 Australia	74	-	52	-	30	-	4	4
Hills et al. (2002); n = 1055 UK	-	-	-	-	-	-	-	1
Sydney Water (1999); n= 900 Australia	69	62	43	-	22	-	3	4
Madany et al. (1992); n= 500 Baharain	92	89	80	63	-	-	-	-
Ahmad (1991); n = 100 or 50 Qatar (Doha)	-	-	-	-	-	50	50	60
Lohman & Milliken (1985); n= 403 USA	67	55	38	-	30	-	3	4
Milliken & Lohman (1983); n= 399 USA	63	55	40	-	24	-	1	3

Bruvold et al. (1981); n = 140 USA	58	-	-	-	-	-	5	-
Olsen et al. (1979)*; n = 244 USA	54	52	37	25	19	-	6	7
Sims & Baumann (1974); n =400 USA	44	42	-	15	15	-	-	-
Stone & Kahle (1974)** ; n = 1000 USA								
Stone & Company (1974)^^; n =549 USA	32	28	17	-	16	-	11	-
Bruvold (1972); n = 972 USA	56	55	37	24	23	-	3	23
Bruvold & Ward (1970); n = 50 USA	54	54	32	28	24	-	10	12

*Cited in Bruvold (1988) **Cited in Po et al. (2003) ^^Cited in Hurlimann (2008) ^Question phrased 'water mixed with recycled water and treated to drinking water quality

7.2 Methodology-

7.2.1 Survey plan design and execution

A questionnaire was developed based upon the literature review and the feedbacks from the previous study (Pham et al. 2011). A survey plan was designed accordingly. The survey incorporated the general public from three categories - non-user of recycled water from few suburbs (Dunbogan and Laurieton) of Port Macquaire, perspective user of recycled water from few suburbs (Manor Lake and Wyndham Vale) of Melbourne and the current user of recycled water from Newington in Sydney. The details of the methodology have been presented in section 3.5 in Chapter 3. The Survey locations have been presented in figure 7.1. Almost 503 people were approached for the survey among which almost 95% responded to the survey.

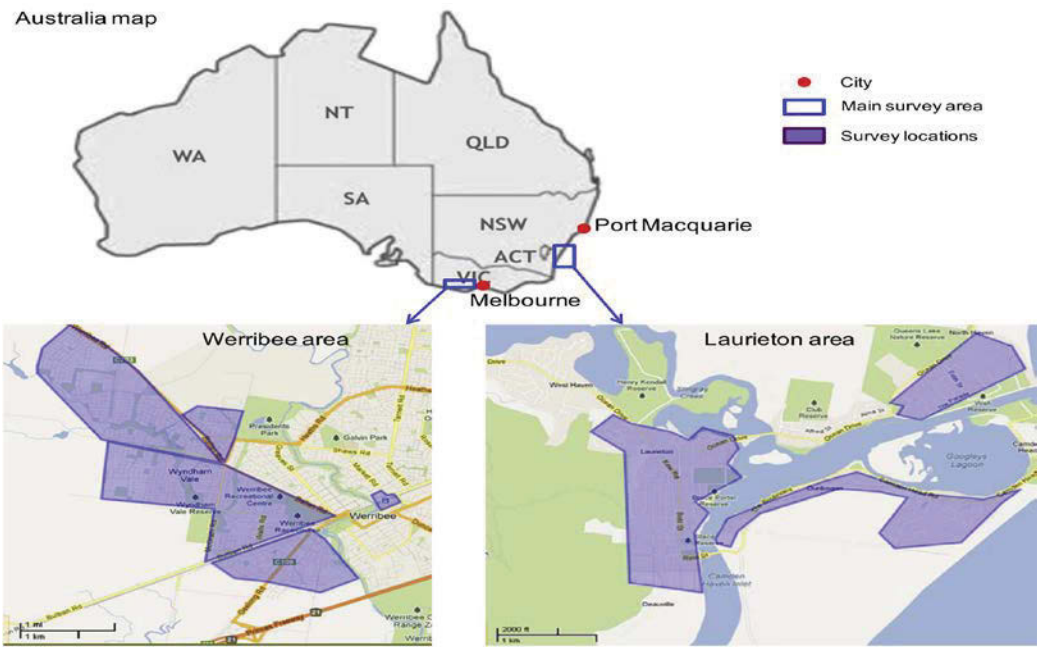

Figure 7.1 Geographical locations of the survey areas in Port Macquarie and Melbourne, Australia (Chen et al., 2013).

7.3 Results and Discussion

7.3.1 General features of three study sites

The general features and the comparative chart in terms of household size, washing machine type, washing frequency and other general details of three study sites are presented in Table 7.2. A total of 478 people from three study areas including 55% of females and 45% of males completed the questionnaire. Percentage respondents in Port Macquarie represent the proper sample representation of population of Port Macquarie which comprises 48% of males and 52% of females (ABS, 2011a). The ratio of respondents in Melbourne (only 37% of males) however is not an exact representation of the population of Melbourne which comprises of 49% of males and 51% of females (ABS, 2011b). This could be attributed to the reason that door to door survey was carried out in this area and mostly the ladies were more likely to participate for the survey in their homes. In Sydney, number of males completing the questionnaire is higher than females which are in contrast to Port Macquarie and Melbourne (χ^2= 8.25, df=2; p = 0.000). However, this can be better explained by the fact that many areas in greater Sydney is characterised with high sex ratios which includes Homebush Bay - Silverwater where there were 121.9 males for every 100 females as per the statistical report from ABS (2011c).

The majority of households in the study areas are small sized family or the nuclear family (1-3 people) followed by households with the medium sized family (4-6 people) as presented in Table 7.2. In Port Macquarie, almost third quarter of households in the study areas is small sized family which reflects the average household size of Port Macquarie which is 2.3 persons per dwelling as per the report of ABS (2011). The household size in Port Macquarie is smaller than the average of all three study sites; however, the washing frequency of the households in Port Macquarie is higher than that of the average of three study areas. In an average, most of the households washing frequency is 3-4 times (40%) or 1-2 times (34%) a week whereas majority of households (77%) in Port Macquarie wash the clothes 5-6 times a week. In this study, significantly higher number (almost third quater) of the respondents support the use of recycled water for washing machines (χ^2 = 527.40, df = 3; p = 0.000); higher than many other studies previously conducted (Friedler et al., 2006; Hurlimann, 2006; Roseth, 2008; Alhumoud and Madzikanda, 2010 and Pham et al., 2011).

The survey results revealed that almost all participants use washing machines in their home for washing clothes which agrees very well with the report from ABS (2008) which states that 97% of households in Australia have washing machines. The number of top loading washing machines is higher (almost 65%) than the number of front loading washing machine as suggested by ABS (2011c) which states that 68% of households use top loading washing machines in Australia. The number of front loading washing machine in Sydney and Melbourne are quite higher than in Port Macquarie (Table 7.2). Both the study areas in Sydney and Melbourne are newly developed areas and therefore new setup might have given rise to the purchasing of more water efficient and energy efficient option which is frontloading washing machine compared to top loading (Mainali et al., 2011). However, the dominant type of washing machine is the top loading washing machine. Use of water and energy efficient devices should be given more priority for a sustainable future.

Table 7.2 General details of all three study areas

		Total	Port Macquarie	Melbourne	Sydney
Sample Size	N	478	175	152	151
Gender (%)	Males	45	47	37	48
	Females	55	53	63	52
Age (%)	18-29	4	3	5	5
	30-39	32	32	36	29
	40-49	32	24	33	39
	50-59	15	21	13	11
	60+	13	20	11	9
Household size (%)	1-3	53	70	41	47
	4-6	44	29	55	52
	7-9	3	1	4	1
	>10	0	0	0	0
Washing Machine type (%)	Top loading	65	72	65	58
	Front loading	30	28	35	42
Wash Frequency/week	1-2 times	35	36	37	31
	3-4 times	38	41	29	45

(%)	5-6 times	12	10	14	11
	>7 times	15	13	19	14
Wash detergents type (%)	Powder	55	54	60	51
	Liquid	25	34	18	21
	Mixture of Powder and Liquid	20	12	22	27
Acknowledgement of importance of recycled water (%)	Strongly Agree	30	29	32	30
	Agree	61	57	62	64
	Disagree	7	10	4	5
	Strongly disagree	2	4	2	1
Attitude about receiving recycled water (%)	Very happy	35	23	32	31
	Quite happy	40	47	47	51
	Unsure/don't know	12	23	16	16
	Not happy	12	5	3	3
	Very unhappy	1	2	1	1

7.3.2 Concerns and willingness to use recycled water

Almost 90% of the total respondents agreed and strongly agreed with the statement that recycled water is an important alternative of potable water for non-potable uses whereas 10% disagree and strongly disagree with the same. Five different statements were given to the respondents as options to justify their reasons for agreeing recycled water is an important alternative of potable water for non potable purposes. The results indicate the fact that recycled water saves valuable drinking water and concerns for environment were the most important reasons to agree that recycled water is valuable. Majority of participants (70%) who identified themselves as being supportive of water recycling picked these two statements as their preferred options (χ^2 = 591.09, df = 5; p = 0.000). Only 6% of the respondents who supported the use of recycled water prioritise saving money as an important factor. Hence, it is observed that recycled water saves our valuable drinking water and environmental concerns should be emphasized in a public information campaign to motivate them to use recycled water. However, all the reasons are apparently important. Similarly, 6% of the total respondents preferred health reasons as the option for not agreeing recycled water as a valuable resource where as 2% selected the statement that recycled water is not clean enough to use.

The matrix of choices of respondents to express what would make them more confident and comfortable to use recycled water for washing machine is presented in Table 7.3. Wilcoxon Signed Ranks Test was employed to analyse the most important condition. The results from the test revealed that 'knowing that recycled water saves valuable drinking water' was chosen as the most influencing factor by 82% of the respondents. The result is statistically valid as shown in Table 7.3.

Table 7.3 Wilcoxon Signed Ranks Test for ranking the most preferred condition by the community which would make them more confident to use recycled water in washing machine

	KNW	REA	HAV	WAT	DUAL	NOT
KNW		Z= -5.108	Z= -4.306	Z= -4.180	Z= -4.412	Z= -5.126
REA						Z= -7.729
HAV					*Z= -1.97*	Z= -8.214
WAT						Z= -7.509
DUAL						Z= -8.062

Bold number: Level of significance p = 0.000

Italic number: Level of significance at p < 0.05

KNW- Knowing that recycled water saves valuable drinking water

REA- Reading about recycled water being used in washing machines by other customers

HAV- Having a small unit of pre-treatment of water to assure the quality and safety of water

WAT- Watching a scientist or expert recommends the use of recycled water in washing machines

DUAL- Knowing that recycled water will be supplied to your home together with drinking water using separate pipe lines

NOT- I could not be assured

Positive response for ‘having a small unit of pre-treatment of water to assure the quality and safety of water’ was shown by 76% of the respondents. Reading about recycled water being used in washing machines by other customers was chosen by 71% of the respondents followed by 65% of positive response for “watching a scientist or expert recommend the use of recycled water in washing machines”. Supply of recycled water in a dual pipe system was chosen by 64% of the respondents as a fact to make them more confident and comfortable to use recycled water for laundry. No significant difference was revealed among other choices though to rank them in an order. Significant difference is observed between HAV and DUAL (p = 0.049). Hence, it is of utmost importance to let the community understands that recycled water plays an important role to save the valuable drinking water.

More than 90% of the respondents from the non-user group as expected reckoned they have no idea if they are receiving recycled water in future. On the other hand, from the perspective user group, half of the respondents reckoned that though they have dual pipe system, they have no idea when they will be receiving recycled water in future whereas 30% revealed they know they will be receiving recycled water soon. However, almost 70% of respondents from both the non-user and perspective user groups are happy and very happy about receiving recycled water to their home in future. In current user group of recycled water, almost 85% of the respondents are happy and very happy about receiving recycled water in their home whereas only 10% are unsure about it.

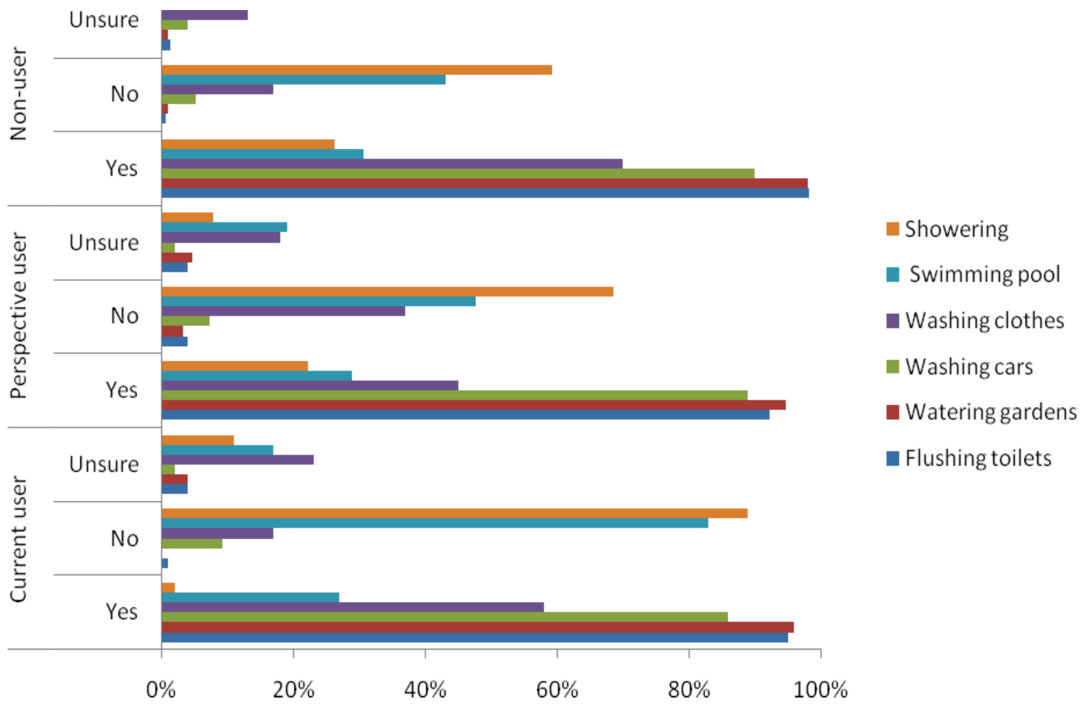

Figure 7.2 Willingness to use recycled water for various enduses for three categories of users of recycled water

Respondents were asked if they are willing to use recycled water for six different end uses of recycled water. Results from Figure 7.2 clearly show that the percentage of respondents willing to use recycled water decreased gradually from option of watering gardens, to flushing toilets, washing cars, washing clothes, filling a swimming pool and showering in all three study areas. This trend has very well agreed with the conclusion made almost 40 years ago by Bruvold (1972) that people differentiate between the kinds of uses and show the highest level of opposition when asked about close to body uses, such as swimming and bathing. This finding has been replicated in all successive studies on public acceptance of recycled water in Australia (McKay and Hurlimann, 2003; Po et al., 2003; Hurlimann, 2006; Marks et al., 2006; Roseth, 2008; Dolnicar and Schäfer, 2009; Pham et al., 2011) etc. However, results from a survey (Ahmad, 1991), that was conducted in Qatar was in severe contrast to most results obtained elsewhere. A large percentage of the respondents opposed the reuse options and no influence of degree of contact was observed. This could be because of the different cultural background and religious aspects. Hence, the location plays a huge role in people's attitude.

The comparative analysis of willingness to use recycled water for washing machine among three user categories of recycled water has been summarised in Figure 7.3. The percentage of respondents who are happy and very happy about receiving recycled water in perspective user group and current user group is higher compared to non-user group (Table 7.2). However, it is observed that 58% of respondents in the current user group are willing to use recycled water for laundry whereas only 45% of respondents are willing for the same in perspective user group. This finding is in line with the statement made by (Dolnicar et al., 2011) concluding that prior experience with using water from alternative sources, increases the stated likelihood of use. On the other hand, 70% of respondents are willing to use recycled water for washing machine in non-user group. In terms of receiving information about recycled water, the perspective user group is ahead than the non-user group as expected whereas in terms of willingness to use recycled water for laundry, the non-user group is ahead of the perspective user group and so is the current user group. For other end uses like toilet flushing, garden irrigation and car washing there is not significant difference in terms of %; however, for washing machine the difference is remarkable and significant ($\chi^2 = 52.73$, df = 6; p = 0.000). The reasons for this can be attributed to the fact that community in Newington, Sydney (the current user group) have already been exposed to the use of recycled water and are observed to be happy with the use so as they are willing to accept the new end use in spite of the higher contacts with the human body. In the perspective user group in Melbourne, people are only mentally and emotionally prepared for using recycled water but they do not have yet physical contact with the same and thus may be more reserved to use it for the uses which involve higher degree of contact. On the other hand, in Port Macquarie it is not yet confirmed whether the supply of recycled water in future is guaranteed or not. For this reason, people might have less reservation for using the recycled water for laundry.

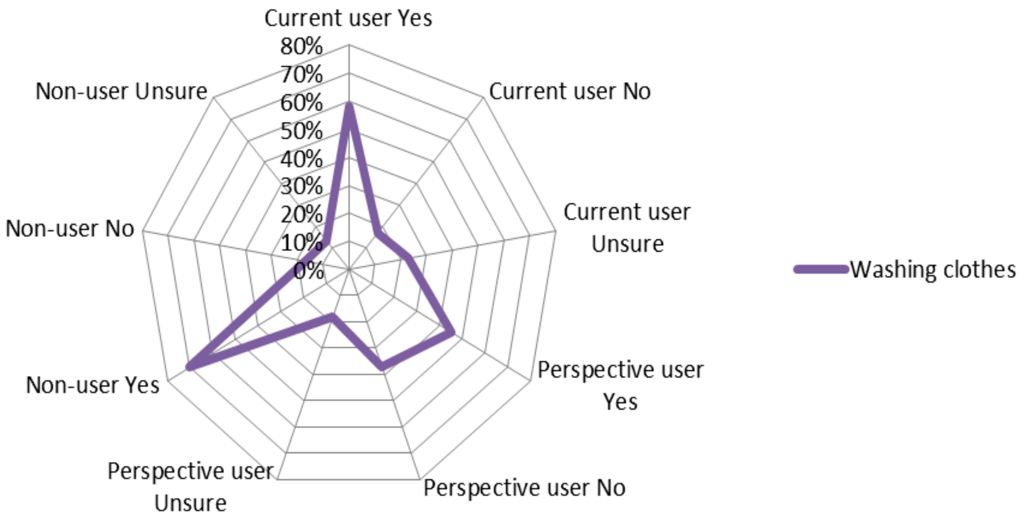

Figure 7.3 Comparitive analysis of willingness to use recycled water for washing machine among three user categories of recycled water.

Another distinct observation was made in the survey that among 478 participants when asked whether they do support the use of recycled water specifically for laundry; almost 70% support the use. However, respondents when asked for their willingness to use recycled water for laundry along with other end use options, lesser number of respondents (only 57%) are willing to use recycled water for washing machines. The trend is exactly the same in all three study sites (Figure 7.4).This may be because the general public when given many choices differentiate the uses in terms of degree of contact and are more reserved to say yes to the uses with high personal contact. However, when they are focussed specifically for the use of recycled water for a particular purpose like washing machines, they are bit flexible. Further analysis is required to check if it works similarly with each individual end-use. However, in the study, there exists a strong positive correlation between the willingness of the respondents to use recycled water for laundry and the overall support in all three studies ($r = 0.43$, $p = 0.000$).

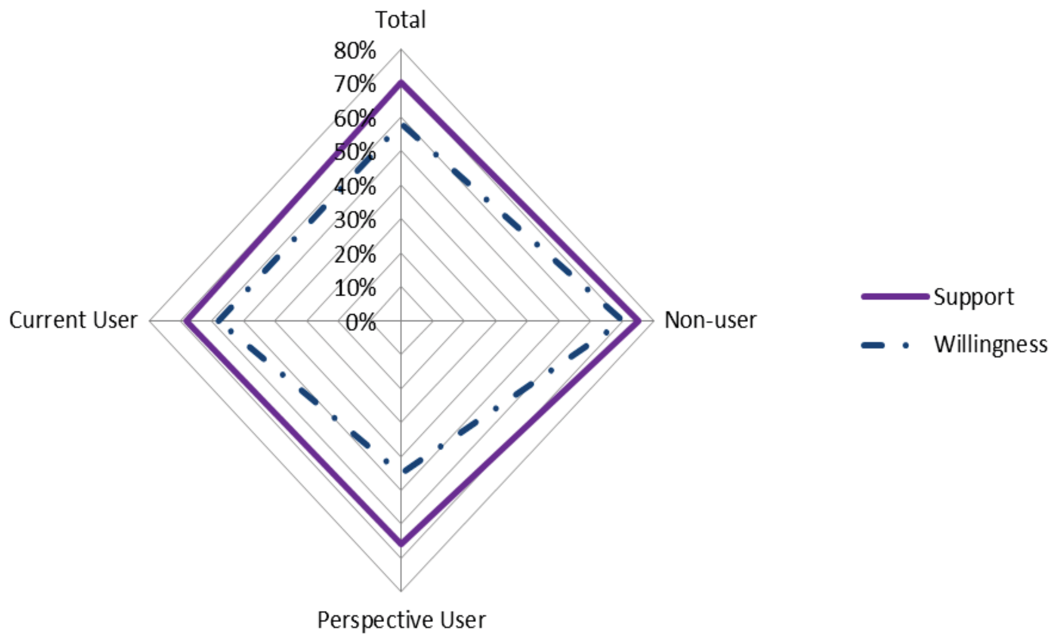

Figure 7.4 Percentage difference among the three user groups in terms of their willingness to use recycled water for washing machine and to support the new end use.

The concerns of community from three study sites when using recycled water for washing clothes has been presented in Figure 7.4. Health has been always observed as one of the main concern among the people when use of recycled water is considered. Hence in this survey, to be familiar with core concern of people for using recycled water for laundry, excluding the option health, respondents were asked if they are concerned about the other effects of recycled water on cloth colour, potential damage to cloth, effect on washing machine, potential odour and the increased cost. Surveyors experienced that people consider health as a main concern and seek for the option for it. However, other concerns were also given due consideration by the general community.

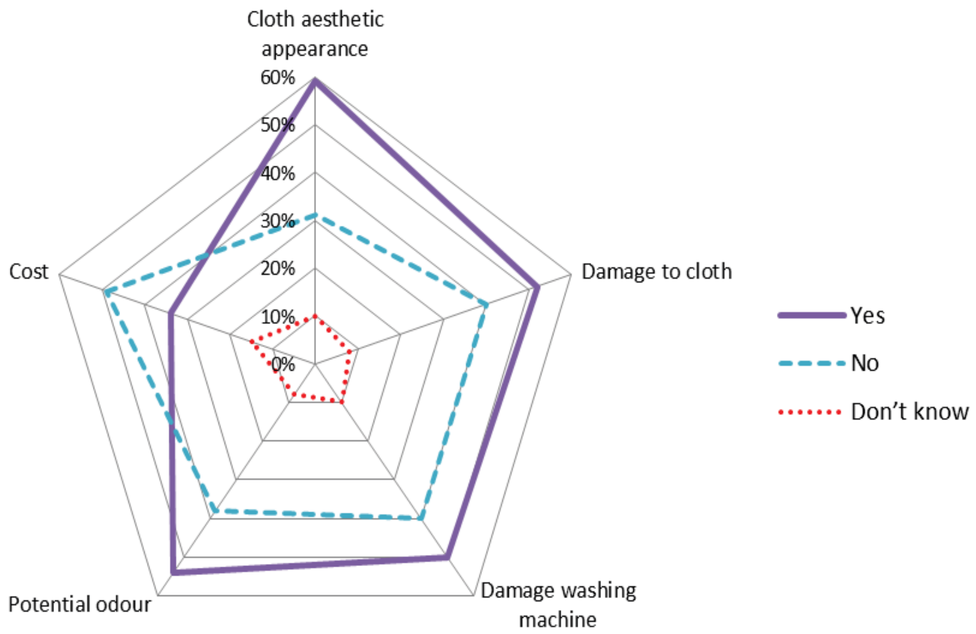

Figure 7.5 Concerns of the community regarding the use of recycled water for washing machine.

As indicated in Figure 7.5, almost all concerns are given due consideration by almost half of the total respondents. Basically, 59% of the people expressed their concern about the potential odour of the recycled water followed by 54% of people who are concerned for the aesthetic appearance of the cloth, 50% of the people are concerned about potential damage to cloth, 48% of the respondents are concerned about the effects of recycled water on washing machines and 41% of the respondents are concerned about the increased cost. From, this analysis, it is observed that people support the use of recycled water in washing machine; however, they wanted to be guaranteed in terms of such issues. Wilcoxon Signed Ranks Test was employed to choose the most influential concern but no significant difference was observed ($p > 0.05$). Therefore, along with the health issue, it is of great importance to address all other concerns listed above with sufficient experimental investigations. Comparing the three study sites, in an average 60% of the respondents from the perspective user group showed their concerns on the effect of recycled water whereas only 40% of the respondents from non-user group showed their concern for the same revealing that the perspective users of recycled water are more concerned rather than the non users. This finding is similar with the findings from Higgnis et al.(2002) in which almost 90% of the respondents who are the perspective user of recycled water showed higher concern for the quality of recycled water whereas only 50% of the respondents who are the non-user of recycled water showed their concerns. Among the current user group, only 45% showed their concern on the effect of recycled water. This finding is again in line with the statement made by (Dolnicar et al., 2011) concluding that prior experience with using water from alternative sources, increases the stated likelihood of use. A study undertaken in Denmark investigating the use of rainwater and greywater for toilet flushing (Albrechtsen, 2002) found out that in the instances of grey water use for toilet flushing, there were several complaints regarding bad smell, with one particular plant shut down because of the complaints. Hence, it is of great importance to understand the attributes of the recycled water fit for use. Positive responses to all of the above concerns demand the higher quality of recycled water for using in washing machines. Hurlimann and Mckay (2006) advocate that recycled water for washing machine needs to be of higher quality. Therefore, it is noteworthy that the targeted communities are clarified and well explained with supporting experimental evidences regarding these issues prior to the implementation of this new end use. Also, commencing this new end use in some of the urban suburbs supplied with dual reticulation system can help immensely to motivate the other target groups for the same.

7.3.3 Correlation between the variables

The correlation between the levels of support using recycled water for washing clothes with age, genders, frequency of washing, place, willingness to use recycled water, attitude about receiving recycled water at home, acknowledgement of recycled water as an important alternative source etc are analysed and presented in Table 7.4. Positive significant relation is revealed between the household size and frequency of washing ($r = 0.4$, $p = 0.000$). However, no significant relationship was found between the machine type and the washing frequency ($p > 0.05$). In contrast to the results from Melbourne and Sydney, in Port Macquarie weak negative significant relationship exists between machine type and washing frequency ($r = -0.16$, $p < 0.05$) indicating increased washing frequency with front loading type of washing machine. As a part of analysis, it was revealed that 55% of participants are using powder detergents, whereas 25% reckoned to use liquid detergents and 20% are using both. There was no significant relationship between the type of washing detergents and washing frequency.

Many factors have been investigated in regards to their influence on willingness of using recycled water. Past studies found that some demographic characteristics such as gender, age and education influence attitudes towards recycled water use. However Marks (2004) in a his review article found that there is little evidence that demographic factors, apart from gender can predict acceptance of recycled water use. In all three studies, no correlation has been found between age and level of support for using recycled water in washing machine (Table 7.4) which is in line with the findings on potable reuse by Marks (2004). However, the results revealed no correlation between gender and level of support which matches with some other works (Jeffrey and Jefferson, 2003; Friedler et al., 2006) but contradicts the findings on potable reuse by Marks (2004) and Bruvold (1984). Weak negatively correlated significant relationship exists between gender and acknowledgement of the importance of recycled water and weak negatively correlated significant relationship was found between gender and attitude about receiving recycled water at their homes among the non-user group unlike the current user group and perspective user group. This revealed that from the non-user group, the males were observed to be happier in terms of receiving recycled water at homes than females and also males were way ahead than females to agree that recycled water is important. These findings are in line with the findings from many researchers (Baumann and Kasperson, 1974; Lohman and Milliken, 1985; Tsagarakis et al., 2007; Nancarrow et al., 2008; Dolnicar and Schafer, 2009).

Table 7.4 Correlation between variables

		Washing frequency	Acknowledge the importance of recycled water	Attitude about receiving recycled water	Willingness to use recycled water	Overall Support
P			r =-0.2 p= 0.009	r=-0.2 p= 0.02		
M	Gender					
S		r = 0.25 p= 0.002			r = 0.2 p = 0.05	
P	Age		r = -0.2 p = 0.02	r = -0.18 p= 0.02		
M		r = -0.19 p = 0.02		r = -0.16 p= 0.05		

S			r = 0.2 p = 0.03			
P		--	--	r =0.65 p= 0.000	r = 0.2 p = 0.006	r = 0.43 p=0.00
M	Acknowledge the importance of recycled water	--	--	r =0.52 p= 0.000		
S		--	--	r =0.33 p= 0.000		r = 0.3 p=0.000
P	Attitude about receiving recycled water	--	--	--	r = 0.32 p = 0.000	r = 0.6 p=0.000
M		--	--	--	r = 0.12 p = 0.03	r = 0.17 p=0.04

S		--	--	--	r = 0.13 p = 0.000	r = 0.35 p=0.000
P		- -	--	--	--	r=0.43 p=0.000
M	Willingness to use recycled water	- -	--	--	--	r=0.41 p=0.000
S		- -	--	--	--	r = 0.24 p=0.003

Note: Presented values- significant al P<0.05 or better.

P- Port Macquarie; M- Melbourne; S- Sydney

In all studies, significant positive relationship was observed between acknowledgement of importance of recycled water and attitude about receiving recycled water at homes. Similarly, significant positive relationship was observed between acknowledgement of the importance of recycled water and willingness to use recycled water for washing machines and acknowledgement of the importance of recycled water and overall support for the use of recycled water in washing machines. Mild positive significant relationship was revealed between willingness to use recycled water for washing machines and overall support for the use of recycled water for washing machines ($r = 0.4$, $p = 0.000$) among the non-user group and the current user group ($r = 0.4$, $p = 0.000$) whereas only weak positive significant relationship was observed ($r = 0.2$, $p = 0.000$) among the perspective user group of recycled water (Table 7.4).

In addition to this, among the perspective user group, weak positive relationship was observed between acknowledgement of the importance of recycled water and willingness to use recycled water for washing machines ($r = 0.2$, $p = 0.006$) and acknowledgement of the importance of recycled water and overall support for the use of recycled water in washing machines ($r = 0.3$, $p = 0.000$). This gives us the general idea that the residents in this area acknowledged the importance of recycled water and they are happy to use the recycled water for less contact uses; however, they are reserved to use the same for high contact uses like washing clothes.

7.3.4 Cost of recycled water and information on recycled water

Regarding the cost of recycled water, as presented in Figure 7.6, the respondents who thought the cost of the recycled water to be lower than that of drinking water occupied 45%, 55% and 47% from non-user, perspective user and current user categories respectively. 19% of the respondents from the non user group, 15% from the perspective user group and 31% from the current user group are of the opinion that the price would remain same as that of drinking water.

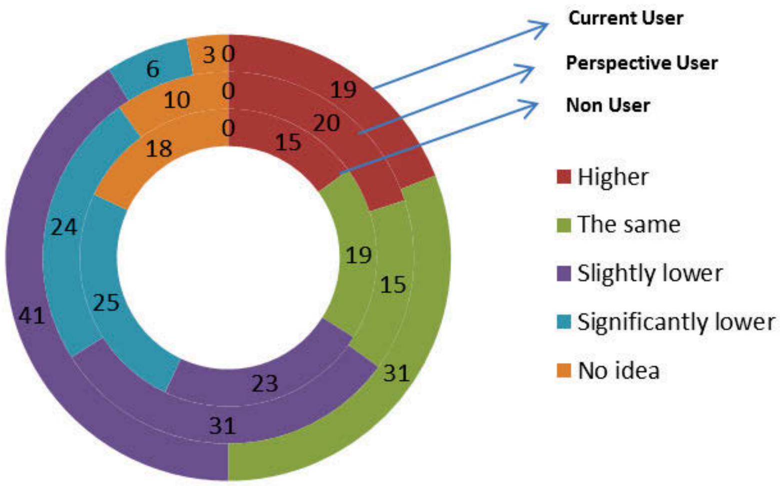

Figure 7.6 Percentage of respondents in regards to their opinion about the cost of recycled compared to that of drinking water among the three user groups.

In a question about the information or updates on recycled water provided to the community, as expected in the non user community, the higher percentage of respondents (81%) revealed to have not enough information on recycled water supply to their homes (χ^2 = 178.24, df = 2, p = 0.000). However, remarkable percentage of respondents (65% and 45%) from the perspective and current user group also reckoned to have not enough information which was unexpected results. 11% from non user, 22% from perspective user and 45% of current user group expressed to be well informed about this (χ^2 = 179, df = 2, p = 0.000) while 8% from non user, 12% from perspective user and 15% from current user are unsure about the information or updates on recycled water provided to the community.

Information always plays an important role and influences the community's acceptance rate of recycled water (Roseth, 2008). Therefore, due consideration should be given to this aspect prior to the implementation of the new end use of recycled water. Most of the respondents (76%) had chosen brochures or the educational leaflets as the best method for them to get information on recycled water followed by articles or advertisements in newspapers (58%) and website or e-mail (35%). Personal visit by the concerned authorities were not much favoured by the general public. Hardly 20% chose this option and generally the people from the age group 50 to 60+ were supporting this option. This may be attributed to the reason that with the increasing age increases the preoccupation about health aspects among others.

7.3.5 Feedbacks from the current user of recycled water

In Newington Sydney, the respondents were asked if they are using recycled water for six end uses listed as flushing toilets, watering gardens, washing cars, washing cloths, filling a swimming pool and showering. Results from Figure 7.7 clearly shows that the percentage of respondents using recycled water for flushing toilets (94%), watering gardens (91%) and washing cars (86%) are very high. This findings is in line to the statements made by many researcher (Hurlimann 2008; Roseth 2008; Pham et al., 2011; Mainali et al., 2011a) that the uses of recycled water in the existing dual reticulation system is confined within toilet flushing, garden irrigation and car washing. About 5% of the respondents are unsure if they are using recycled water for flushing toilets and irrigating gardens though they are aware that they have dual pipe system at home. Almost 3% revealed that they are not using recycled water for garden watering as they are living in an apartment. 86% of the respondents are using recycled water for washing their cars whereas 9% of the respondents are not using recycled water for washing their cars. Few of them reckoned to wash their cars at car washing parlours and few of them revealed that they used the recycled water to wash their cars in the beginning but found out the patches/spots on the car body surface. Hence, they stopped washing cars with recycled water.

65% of the respondents claimed they are not using recycled water for washing machines whereas 24% of the respondents claimed they are unsure about the connection of recycled water line to their washing machines and are not really sure about it. 16% of the respondents claimed they are already using recycled water in washing machines without any major problems. Among those who claimed to be using recycled water already when asked if they are concerned on the effects of recycled water on cloth colour, potential damage to cloth, potential odour and effect on washing machine, 100% answered with no concern to all as their reply. Instead few complain about the consumption of more detergent which they believe is because of the result of strong hardness of the water. Otherwise they all seem to be very happy about using recycled water in washing machine.

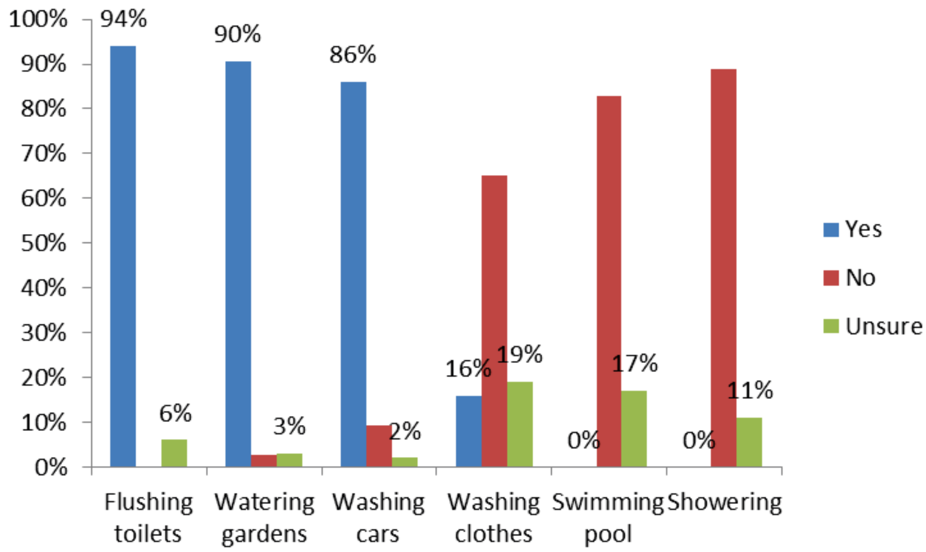

Figure 7.7 Current use of recycled water for various enduses in Newington

In a question about the level of satisfaction, 80% of the respondents revealed that they are satisfied among which 20% reckoned to be very satisfied with the recycled water to present (χ^2 = 69, df = 4, p = 0.000). The % of respondents not satisfied with the recycled water is only 4%. When the respondents were asked if they have any specific complains or concerns regarding the quality of recycled water, 70% of the respondents reckoned to have no specific complain. However, few respondents (7%) revealed colour of the recycled water as their specific concern and few (10%) revealed odour, saltiness, and clearness of recycled water as their major specific concerns. Few of the respondents who are already using recycled water for washing machines, claimed that due to the higher salinity problem excess amount of detergent is required to wash clothes in washing machines as mentioned above. Very few are disappointed because of the suspended soil like particles seen in the toilet pan after flushing while few did complain about the spots appeared in the cars after washing with recycled water. Health issues were picked up as their major concern by only 6% of the respondents and many believe that the recycled water so supplied by the concerned authorities is safe enough without any health effects. Only 1 % revealed cost as the major concern. Almost 75% of the respondents are quite happy and very happy to receive recycled water in their homes whereas 20% of the respondents are unsure about it and 4% and 1% are not happy and very unhappy respectively.

In an overall analysis, it is observed that the community in Newington in Sydney are very happy to make use of recycled water fit for purpose end uses. They actually feel very proud for being able to conserve huge amount of drinking water replacing with recycled water and contributing on sustainable urban water management. The community believe that the dual reticulation system should be the model for all future developments and should also be retro fitted to the existing developments.

7.4 Conclusions

The results of this study provide crucial information on community's perception to recycled water use for household laundry. Generally, the survey shows a considerable support for the notion of using recycled water for the new end use.

- Among the listed end uses of recycled water, as expected, lesser support was observed for the uses with higher physical contacts.
- In addition to the health issues, community's basic concerns regarding the new end use are the impact of recycled water on the colour of clothes, potential damage to cloth, potential damage to the washing machine and potential odour.
- Among the three categories of user groups of recycled water, the perspective user are more concerned and have more reservations for the use of recycled water in washing machines.
- The current users of the recycled water in Newington are very happy with the supply of recycled water and are willing to accept the new end use to the system.
- The non-users group show less concerns and are more willing to use recycled water for laundry.

The information presented in this paper can be beneficial for recycled water retailers and decision makers, who aim to introduce water recycling schemes via dual pipe system in the urban communities to ensure sustainable urban water. The introduction of washing machine as a new end use of recycled water in urban Australian suburbs is acceptable by the communities involved.

UTS

University of Technology, Sydney

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This thesis deals with introduction of laundry as a new end use of recycled water in dual reticulation systems for the sustainable urban water management in Australia. There are number of significant conclusions outlined as the outcomes of this research study.

INVESTIGATIONS WITH SYNTHETIC WATER TO DETERMINE MAVs OF HEAVY METALS IN RECYCLED WATER FOR WASHING CLOTHES

- 1 mg/L of Fe, 1 mg/L of Pb, 10 mg/L of Zn, 2 mg/L of Cu and 1 mg/L of Mn are the MAVs in recycled water for using in washing machine in terms of tensile and tearing strengths.
- No signs of corrosion on washing machine was observed throughout the washing of cloth samples up to 50 cycles with varying concentrations of Fe, Pb, Zn, Cu and Mn. The results also indicated that even at higher concentrations of these heavy metals, there is no impact on the machine's aesthetic appearance and functional system.
- 1 mg/L of Mn, 0.3 mg/L of Fe, 2 mg/L of Pb, 2 mg/L of Cu and 10 mg/L of Zn are the MAVs in terms of washing machine durability as indicated by LSI test.
- In terms of aesthetic appearance of cloths, on the basis of SEM analysis, the MAVs of heavy metals in recycled water for laundry were found to be 2 mg/L of Cu, 1 mg/L of Fe, 1 mg/L of Mn, 1 mg/L of Pb and 10 mg/L of Zn, respectively and on the basis of spectrometer analysis, the MAVs of heavy metals in recycled water for laundry were 2 mg/L of Cu, 1 mg/L of Fe, 0.1 mg/L of Mn, 0.5 mg/L of Pb and 10 mg/L of Zn respectively.

INVESTIGATIONS WITH REAL RECYCLED WATER

- No significant change in the tensile and tearing strengths of cloth samples washed in recycled water (from all three providers) compared to the cloth samples washed in tap water at identical conditions were revealed. Hence, recycled water is safe and has no impacts on cloth durability.

- In terms of aesthetic appearance of cloths, on the basis of SEM analysis and spectrometer analysis, no change in surface morphology and colour of the cloth samples indicated no negative impacts of recycled water on cloth aesthetic appearance.
- No microbiological contamination was detected in cloth samples washed in recycled water.
- No signs of corrosion or scaling on washing machine throughout the washing of cloth samples up to 50 cycles with recycled water from three different providers was observed. Thus, there is no impact on the machine's aesthetic appearance and functional system.
- As indicated by LSI test, recycled water from all three providers is stable and has no tendency of corrosion or scaling.

EDUCATIONAL LEAFLETS

- Well-designed educational leaflets play an important role in dissemination of knowledge about recycled water and hence can play an important role in bringing the general community in the state of readiness to accept the recycled water and its end uses.
- The proper design of the educational leaflets includes clear presentation of information on safety assurance of use of recycled water for the targeted end use.
- In addition to this, the leaflets should be simple and well understandable with attractive appearance.
- Motivating factors like clear picture of the current water crisis and their consequences, explanation of existing dual reticulation systems should be well presented for encouraging the people to use the recycled water.

COMMUNITY ATTITUDE SURVEY

- Among the listed end uses of recycled water, as expected, lesser support was observed for the uses with higher physical contacts.

- In addition to the health issues, community's basic concerns regarding the new end use are the impact of recycled water on the colour of clothes, potential damage to cloth, potential damage to the washing machine and potential odour.

- Among the three categories of user groups of recycled water, the perspective user are more concerned and have more reservations for the use of recycled water in washing machines.

- The current users of the recycled water in Newington are very pleased with the supply of recycled water and are willing to accept the new end use to the system.

- The non-users group show less concerns and are more willing to use recycled water for laundry.

8.2 Recommendations

- The MAVs of heavy metals in recycled water for laundry were recommended to be 2 mg/L of Cu, 0.3 mg/L of Fe, 0.5 mg/L of Mn, 0.5 mg/L of Pb and 10 mg/L of Zn. It is important to note that these MAVs of heavy metals were suggested only considering their effects on cloth durability, aesthetic aspects of cloth quality and durability of washing machine. Similar tests with other heavy metals and elements are recommended.

- The information collected from the community attitude survey are beneficial for recycled water retailers and decision makers, who aim to introduce water recycling schemes via dual pipe system in the urban communities to ensure sustainable urban water. Further similar community survey incorporating other current users, perspective users and non-users of recycled water are recommended.

- The use of recycled water in washing machine is feasible in all aspects and therefore, it is recommended that introduction of this new end use should be made to all existing and proposed dual reticulation systems.

- Educational leaflets play an important role in dissemination of knowledge about recycled water and hence can play an important role in bringing the general community in the state of readiness to accept the recycled water and its end uses. Further community consultation with large number of participation is suggested for more secure results.

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PUBLICATIONS

PUBLICATIONS

Journal Publications:

Mainali B, Pham TTN, Ngo HH, Guo W, Miechel C, O'Halloran K, Muthukaruppan M, Listowski A. 2014. Introduction and feasibility assessment of laundry use of recycled water in dual reticulation systems in Australia. Science of the Total Environment. 470-471: 34-43.

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Mainali B, Ngo HH, Guo W, Pham TTN, Listowski A, O'Halloran K, Thompson M, Muthukaruppan M . 2012. Maximum Allowable Values of Copper and Manganese in Recycled Water for Washing Machines. Presented in IWA Conference Busan Korea, 2012 and published in the conference proceedings.

Mainali B, Ngo HH, Guo W, Pham TTN, Wang XC, Johnston A. 2010. SWOT analysis to assist identification of the critical factors for the successful implementation of water reuse schemes. Presented in CESE Conference 2010, Cairns Australia.

Submitted Papers to Journals: (Status- Under review)

Pham TTN, **Mainali B**, Ngo HH, Guo W. **Impacts of various heavy metals in recycled water for laundry on fabric quality.** Submitted to the journal **Desalination and water treatment.**

University of Technology, Sydney

APPENDIX 1

<u>Evaluating responses to use of recycled water for washing machines.</u>

<u>(Survey in Port Macquarie- Non- user of recycled water)</u>

The following research questions are being focused in this phase of the academic work.

- *Is the general public aware of the existing water shortage problems?*
- *What is the people's attitude and reactions towards the use of recycled water for different end uses?*
- *Are they willing to accept the use of recycled water in washing machines?*
- *What will be their major concern to use recycled water in washing machines?*

Specifically, we are interested in your personal opinions regarding recycled water in different uses, especially household laundry. In order to have useful and accurate results, please read each question carefully and answer it to the best of your knowledge. There are no correct or incorrect responses and you do not have to answer all questions because some of them may not be applicable to you. However, it is encouraged to provide as much information as possible and all responses to this survey will remain confidential. Your support will help us gather relevant information and we hope the analysis and results will eventually provide a contribution to the lessening of the present acute problem of water shortage and a better future for all of us.

Thank you for your participation in this survey.

Sincerely yours,

Post Macquarie-Hastings Council and University of Technology Sydney

1. Do you have washing machine at home?
   - ☐ Yes [Go to question no 2]
   - ☐ No

   (a) . How often do you visit a Laundromat? (Excluding dry cleaning)

   ☐ 1 to 2 times a week ☐ 3 to 4 times a week

   ☐ 5 to 7 times a week ☐ more than 7 times a week

   (b). How much do you pay weekly for Laundromat services?

   AUD

2. Is your washing machine a front or top loader?

   ☐ Front ☐ Top

3. What type of washing detergent do you use in your washing machine?
   - ☐ Powder only
   - ☐ Liquid only
   - ☐ Mixture of powder and liquid

4. How many people reside in your home?

   ☐ 1 to 3 people ☐ 4 to 6 people

   ☐ 7 to 9 people ☐ More than 10 people

5. How often do you use the washing machine?

   ☐ 1 - 2 times a week ☐ 3 - 4 times a week

   ☐ 5 to 6 times a week ☐ 7 or more times a week

6. Did you know that your property will be receiving recycled water in 2014?

   ☐ Yes ☐ Yes, but was not sure of the date

   ☐ No

7. Recycled water is an important alternative to drinking water at the present time. Do you:
   - ☐ Strongly agree
   - ☐ Agree
   - ☐ Disagree [Go to question 9]
   - ☐ Strongly disagree [Go to question 9]

8. Why do you agree?
   - ☐ Because it saves our valuable drinking water
   - ☐ It provides an alternative to drinking water
   - ☐ It saves money
   - ☐ Other (Please specify)

9. Why do you disagree? Please specify reasons.
   - ☐ Recycled water costs too much to produce
   - ☐ It is not clean enough to reuse
   - ☐ Health reasons
   - ☐ The desalination plant will already provide recycled water
   - ☐ Other (Please specify)

10. What best describes your attitude about receiving recycled water to your home in future?
    - ☐ Very happy
    - ☐ Quite happy
    - ☐ Unsure/don't know
    - ☐ Not happy
    - ☐ Very unhappy

11. For which of the following would you be willing to use recycled water?

	YES	NO	UNSURE
■ Flushing toilets	☐	☐	☐
■ Watering gardens	☐	☐	☐
■ Washing cars	☐	☐	☐
■ Washing clothes	☐	☐	☐
■ Filling a swimming pool	☐	☐	☐
■ Showering	☐	☐	☐

12. Would you be concerned of the effect recycled water could have if used in your washing machine on the following:

[Answer YES, NO, DON'T KNOW]

☐ Effect of recycled water on the colour of clothes

☐ Potential damage to clothes when using recycled water

☐ Effect on the washing machine when using recycled water

☐ Potential odour caused by recycled water

☐ Increased cost when using recycled water

13. Would the following reassure you if you were able to use recycled water in a washing machine? [Answer YES, NO or DON'T KNOW]

☐ Knowing that recycled water saves valuable drinking water

☐ Reading about recycled water being used in washing machines by other customers

☐ Having a small unit for pre-treatment of water to assure the quality and safety of the water

☐ Watching a scientist or expert recommend the use of recycled water in washing machines

☐ Knowing that recycled water will be combined with drinking water when supplied to your home

14. What do you think the cost of using recycled water at your home will be?

☐ Much higher than the cost of drinking water

☐ Higher than the cost of drinking water

☐ The same as drinking water

☐ Slightly lower cost than drinking water

☐ Significantly lowers than drinking water

15. Have you received enough information or updates about the supply of recycled water to your home?

☐ Yes

☐ No

☐ Unsure/Neither Yes or No

16. What is the best method for you to receive additional information about using recycled water in the home? [Tick as many as appropriate]

☐ Website or email

☐ Educational leaflets and flyers via mail

☐ Personal visit by Port Macquarie-Hastings council staff to your house

☐ Articles or advertisements in newsletters or the newspaper

17. Overall, would you support the use of recycled water in washing machines?

☐ Support ☐ Uncertain ☐ Against

~END~

<u>Thank you again for providing your valuable time in this survey !!</u>

UNIVERSITY OF TECHNOLOGY SYDNEY

City West Water

Evaluating responses to use of recycled water for washing machines.

(Survey in Melbourne- Perspective user of recycled water)

Dear City West Water Customer

City West Water is committed to providing its customers with sustainable, cost effective services. One service provided by City West Water is the supply of high quality recycled water to homes in Wyndham Vale. To continue to meet customer expectations, City West Water has partnered with The University of Technology Sydney (UTS) to undertake research into the suitability of using recycled water in residential home laundries.

The following survey comprises of a number of questions developed by UTS for use in their academic research. These questions do not reflect current City West Water policy.

Specifically, we are interested in your personal opinions regarding recycled water in different uses, especially household laundry. This survey will remain confidential. Your support will help us gather relevant information and we hope the analysis and results will eventually contribute to the use of recycled water in residential homes.

If you have any further questions regarding recycled water please see the attached postcard. For any question regarding this survey, feel free to contact me on (03) 9313 8376 or ncorby@citywestwater.com.au.

Thank you for your participation in this survey.

Yours sincerely

Nigel Corby

Integrated Water Projects Manager

City West Water

1. Do you have a washing machine at home?

☐ Yes [Go to question no 2]
☐ No

(a) . How often do you visit a laundromat? (excluding dry cleaning)

☐ 1 to 2 times a week ☐ 3 to 4 times a week
☐ 5 to 7 times a week ☐ more than 7 times a week

(b). How much do you pay weekly for Laundromat services?

AUD

2. Is your washing machine a front or top loader?

☐ Front ☐ Top

3. What type of washing detergent do you use in your washing machine?

☐ Powder only
☐ Liquid only
☐ Mixture of powder and liquid

4. How many people reside in your home?

☐ 1 to 3 people ☐ 4 to 6 people
☐ 7 to 9 people ☐ More than 10 people

5. How often do you use the washing machine?

☐ 1 - 2 times a week ☐ 3 - 4 times a week
☐ 5 to 6 times a week ☐ 7 or more times a week

6. Did you know that your property will be receiving recycled water in December 2013?

☐ Yes ☐ Yes, but was not sure of the date
☐ No

7. Recycled water is an important alternative to drinking water for non-potable uses at the present time. Do you:

☐ Strongly agree

☐ Agree

☐ Disagree [Go to question 9]

☐ Strongly disagree [Go to question 9]

8. Why do you agree?

☐ Because it saves our valuable drinking water

☐ It provides an alternative to drinking water

☐ It saves money

☐ Other (Please specify)

9. Why do you disagree? Please specify reasons.

☐ Recycled water costs too much to produce

☐ It is not clean enough to reuse

☐ Health reasons

☐ The desalination plant will already provide recycled water

☐ Other (Please specify)

10. What best describes your attitude about receiving recycled water to your home in 2014?

☐ Very happy

☐ Quite happy

☐ Unsure/don't know

☐ Not happy

☐ Very unhappy

11. For which of the following would you be willing to use recycled water?

	YES	NO	UNSURE
■ Flushing toilets	☐	☐	☐
■ Watering gardens	☐	☐	☐
■ Washing cars	☐	☐	☐
■ Washing clothes	☐	☐	☐
■ Filling a swimming pool	☐	☐	☐
■ Showering	☐	☐	☐

12. Would you be concerned of the effect recycled water could have if used in your washing machine on the following: [Answer YES, NO, DON'T KNOW]

	YES	NO	DK
■Effect of recycled water on the colour of clothes	☐	☐	☐
■Potential damage to clothes when using recycled water	☐	☐	☐
■Effect on the washing machine when using recycled water	☐	☐	☐
■Potential odour caused by recycled water	☐	☐	☐
■Increased cost when using recycled water	☐	☐	☐

13. Would the following reassure you if you were able to use recycled water in a washing machine? [Answer YES, NO or DON'T KNOW/MAYBE]

	YES	NO	DK/M
■ Knowing that recycled water saves valuable drinking water	☐	☐	☐
■ Reading about recycled water being used in washing machines by other customers	☐	☐	☐
■ Having a small unit for pre-treatment of water to assure the quality and safety of the water	☐	☐	☐
■ Watching a scientist or expert recommend the use of recycled water in washing machines	☐	☐	☐
■ Knowing that recycled water will be supplied to your			

home together with drinking water using separate pipelines ☐ ☐ ☐

14. What do you think the cost of using recycled water at your home will be?

☐ Much higher than the cost of drinking water

☐ Higher than the cost of drinking water

☐ The same as drinking water

☐ Slightly lower cost than drinking water

☐ Significantly lowers than drinking water

15. Have you received enough information or updates about the supply of recycled water to your home?

☐ Yes

☐ No

☐ Unsure/Neither Yes or No

16. What is the best method for you to receive additional information about using recycled water in the home? [Tick as many as appropriate]

☐ Website or email

☐ Brochures and flyers via mail

☐ Personal visit by City West Water staff to your house

☐ City West Water Community Trailer at Wyndham Vale community events

☐ Articles or advertisements in newsletters or the newspaper

17. Overall, would you support the use of recycled water in washing machines?

☐ Support ☐ Uncertain ☐ Against

Thank you again for providing your valuable time in this survey

Evaluating responses to use of recycled water for washing machines.

(Survey in Sydney- Current user of recycled water)

The following research questions are being focused in this phase of the academic work.

- *Is the general public aware of the existing water shortage problems?*
- *What is the people's attitude and reactions towards the use of recycled water for different end uses?*
- *Are they willing to accept the use of recycled water in washing machines?*
- *What will be their major concern to use recycled water in washing machines?*

Specifically, we are interested in your personal opinions regarding recycled water in different uses, especially household laundry. In order to have useful and accurate results, please read each question carefully and answer it to the best of your knowledge. There are no correct or incorrect responses and you do not have to answer all questions because some of them may not be applicable to you. However, it is encouraged to provide as much information as possible and all responses to this survey will remain confidential. Your support will help us gather relevant information and we hope the analysis and results will eventually provide a contribution to the lessening of the present acute problem of water shortage and a better future for all of us.

Thank you for your participation in this survey.

Sincerely yours,

Sydney Olympic Park Authority and University of Technology Sydney

1. Do you have washing machine at home?

☐ Yes [Go to question no 2]

☐ No

(a) . How often do you visit a Laundromat? (Excluding dry cleaning)

☐ 1 to 2 times a week ☐ 3 to 4 times a week

☐ 5 to 7 times a week ☐ more than 7 times a week

(b). How much do you pay weekly for Laundromat services?

AUD

2. Is your washing machine a front or top loader?

☐ Front ☐ Top

3. What type of washing detergent do you use in your washing machine?

☐ Powder only ☐ Liquid only ☐ Mixture of powder and liquid

4. How many people reside in your home?

☐ 1 to 3 people ☐ 4 to 6 people

☐ 7 to 9 people ☐ More than 10 people

5. How often do you use the washing machine?

☐ 1 - 2 times a week ☐ 3 - 4 times a week

☐ 5 to 6 times a week ☐ 7 or more times a week

6. Recycled water is an important alternative to drinking water for non-potable uses at the present time. Do you:

☐ Strongly agree

☐ Agree

☐ Disagree [Go to question 8]

☐ Strongly disagree [Go to question 8]

7. Why do you agree?

- ☐ Because it saves our valuable drinking water
- ☐ It provides an alternative to drinking water
- ☐ It saves money
- ☐ Environmental concerns
- ☐ Other (Please specify)

8. Why do you disagree? Please specify reasons.

- ☐ Recycled water costs too much to produce
- ☐ It is not clean enough to reuse
- ☐ Health reasons
- ☐ The desalination plant will already provide recycled water
- ☐ Other (Please specify)

9. What best describes your attitude about receiving recycled water at your home?

- ☐ Very happy
- ☐ Quite happy
- ☐ Unsure/don't know
- ☐ Not happy
- ☐ Very unhappy

10. For which of the following are you using/ (willing to use) recycled water?

	YES	**NO**	**UNSURE**	**Remarks**
Flushing toilet	☐	☐	☐	---------------
Watering garden	☐	☐	☐	---------------
Washing cars	☐	☐	☐	
Washing clothes	☐	☐	☐	--------------
Filling a swimming pool	☐	☐	☐	---------------
Showering	☐	☐	☐	---------------

11. How satisfied are you with the recycled water to present?

☐ Very satisfied

☐ Quite satisfied

☐ Unsure/don't know

☐ Not satisfied

☐ Very unsatisfied

12. Do you think there is any risk involved with using recycled water?

☐ Yes (☐ Danger to children/pets ☐ Hygiene ☐ Health issues ☐ Cross connection)

☐ No

☐ Don't know

13. Do you have any specific complains or concerns regarding the quality of recycled water?

☐ Color ☐ Odour ☐ Saltiness

☐ Health issues ☐ Clearness ☐ Cost

14. Would you be concerned of the effect recycled water could have if used in your washing machine on the following: [Answer YES, NO, DON'T KNOW]

	YES	NO	DK
• Effect of recycled water on the **colour** of clothes	☐	☐	☐
• Potential damage to **clothes** when using recycled water	☐	☐	☐
• Potential **odour** caused by recycled water	☐	☐	☐
• Effect on the **washing machine** when using recycled water	☐	☐	☐
• Increased **cost** when using recycled water	☐	☐	☐
	☐	☐	☐

15. Would the following reassure you if you were able to use recycled water in a washing machine? [Answer YES, NO or DON'T KNOW/MAYBE]

	YES	NO	DK/M
■ Knowing that recycled water saves valuable drinking water	☐	☐	☐
■ Reading about recycled water being used in washing machines by other customers	☐	☐	☐
■ Having a small unit for pre-treatment of water to assure the quality and safety of the water	☐	☐	☐
■ Watching a scientist or expert recommend the use of recycled water in washing machines	☐	☐	☐
■ I could not be reassured	☐	☐	☐

16. What do you think the cost of using recycled water at your home will be?

☐ Much higher than the current cost

☐ Higher than the current cost

☐ The same as current cost

☐ Slightly lower than current cost

☐ Significantly lowers than current cost

17. Do you intend to recommend recycled water to other customers (e.g., friends or family members)?

☐ Yes, definitely ☐ Yes, probably

☐ Unsure/ Don't know ☐ No

18. Have you received enough information or updates about recycled water at your home?

☐ Yes ☐ No ☐ Unsure

19. What is the best method for you to receive additional information about using recycled water in the home? [Tick as many as appropriate]

☐ Website or email

☐ Educational leaflets and flyers via mail

☐ Personal visit by Sydney Olympic Park Authority staff to your house

☐ Articles or advertisements in newsletters or the newspaper

20. Overall, would you support the use of recycled water in washing machines?

☐ Support ☐ Uncertain ☐ Against

~END~

Thank you again for providing your valuable time in this survey !!

<u>Community consultation for best design of Education leaflets</u>

The following research questions are being focused in this phase of the academic work.

- *Is the general public aware of the existing water shortage problems?*
- *What level of knowledge do people have about recycled water?*
- *What is the specific information they want to know about recycled water?*
- *What will be their major concern to use recycled water in washing machines?*

Specifically, we would like to get your feedbacks in order to improve and prepare best design criteria of educational leaflets on recycled water. In order to have useful and accurate results, please read each question carefully and answer it to the best of your knowledge. There are no correct or incorrect responses and you do not have to answer all questions because some of them may not be applicable to you. However, it is encouraged to provide as much information as possible and all responses to this survey will remain confidential. Your support will help us gather relevant information and we hope the analysis and results will eventually provide a contribution to the lessening of the present acute problem of water shortage and a better future for all of us.

Thank you for your participation in this survey.

Sincerely yours,

University of Technology Sydney

1. Your residential postcode ☐ ☐ ☐ ☐

2. In which age group do you belong?

☐ 18 and under ☐ 19~29 ☐ 30~40

☐ 41~51 ☐ 52~61 ☐ 62+

3. How well you know about recycled water?

☐ Very well ☐ Well ☐ A little bit ☐ Very little ☐ Nothing

4. Recycling water is one of the solutions to deal with water shortage problems.

☐ Strongly agree

☐ Agree

☐ Disagree

☐ Strongly disagree

5. Do you think educational leaflets on recycled water will help you understand more about recycled water?

☐ Yes ☐ No

6. You prefer to receive educational leaflets on recycled water

☐ At home via post

☐ In a group discussion

☐ I do not want one

☐ Prefer other means like web sites, articles on news paper etc.

7. Would you like to get following information in Educational leaflets?

	Yes	No
■ Safety assurance of quality of recycled water	☐	☐
■ Source of recycled water	☐	☐
■ Treatment methodologies	☐	☐
■ Cost of recycled water	☐	☐

8. How would you rate the following options according to their need to be included in educational leaflets? [Please rank your answer from 1 to 4; 1 being the most important factor]

- Safety assurance of quality of recycled water ☐
- Source of recycled water ☐
- Treatment methodologies ☐
- Cost of recycled water ☐

9. Do you find it necessary to cite the existing successful reuse schemes?

☐ Yes, because I want to know more

☐ Yes, because I want to be more assured

☐ No, the assurance that recycled water is safe for use is enough.

☐ No this will be more complex and too long.

10. Do you find this educational leaflet a well designed for information on use of recycled water for washing machines?

☐ Yes

☐ No

11. How would you rate this educational leaflet? [Please rank your answer from 1 to 5; 1 being the most important factor]

☐ Simple and well understandable

☐ Very informative

☐ Looks attractive

☐ Delivers the message in a well manner

☐ Others (please specify)

12. How would you rate this educational leaflet? [Please rank your answer from 1 to 5; 1 being the most important factor]

☐ Too many technical terms

☐ Complex to understand

☐ Not very informative

☐ Has no specific message

☐ Others (please specify)

13. Any specific suggestions to improve the quality of educational leaflets. [Please rank your answer from 1 to 4; 1 being the most important factor]

☐ More pictures should be used to explain the things

☐ Should be made more simpler

☐ Treatment methods of recycled water should be discussed.

☐ Others (please specify)

~END~

Thank you again for providing your valuable time in this survey !!

University of Technology, Sydney

APPENDIX 2

IS RECYCLED WATER SAFE TO USE?
YES, as long as it is used as intended it is safe for range of applications.
Recycled water is subjected to an array of quality testing to ensure that it is fit for use. (NWQMS

Some places in the world are successfully using the recycled water for drinking purposes as in Singapore - where recycled water constitutes approximately 3% of mu-

Recommended uses of recycled water-

- Irrigation
- Industrial Uses
- Household uses
  - Garden irrigation
  - Toilet flushing
  - Car Washing

New End use of recycled water in households can be WASHING MACHINE.

Laundry use requires up to 20% of total water consumption for households. Therefore substituting with recycled water can save considerable amount of water.

Is it safe to use recycled water for Washing Clothes?

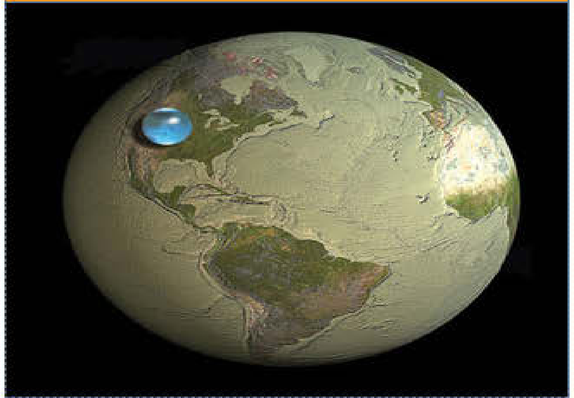
YES, It is safe to use recycled water for Washing machine.
-Class A Recycled water is provided for households uses which meets almost the quality of drinking water.
-Study revealed that there is no health effects to use such water for laundry.
-Study revealed that such water does not have any bad impacts on the cloth and washing machines.

Recycled water use in Australia

- South Australia targets to increase wastewater recycling to 33% by 2025.
- The cities of Perth, Melbourne and Canberra have targets of achieving 20% water recycling by 2010-12.
- Gold Coast Queensland targets to increase wastewater recycling from 20% to 80% by 2056.

ARE YOU AWARE?
Our mother EARTH is running dry of fresh water.

There is no 'creation' of 'new' water on the planet.



Only 0.007% (the tiny bubble) of all water on earth is accessible for direct human uses.

Are you alarmed about the current water crisis and water scarcity?

In 20th Century,
Population increased 3times
Water use increased 6times.

Today,
More than 50 countries,
1.1 billion people suffer from a dramatic shortage of water.

In the next 30 years-
- Water use will increase 3times.
- At least 40% of the world's population will suffer from a chronic water shortage.

Australia is one of the high water stress regions of the world (IWMI, 2006).

By 2030 in Australia,
- 33 % population increase in urban areas
- sustainable urban water management is a big challenge for Australia.

Many Australian cities are already facing water restrictions.

Drinking water conservation is the most.

Solution to this problem?

Recycling of water.

What is RECYCLED WATER?
Wastewater treated to a suitable standard for specific uses in homes, agriculture or industries.

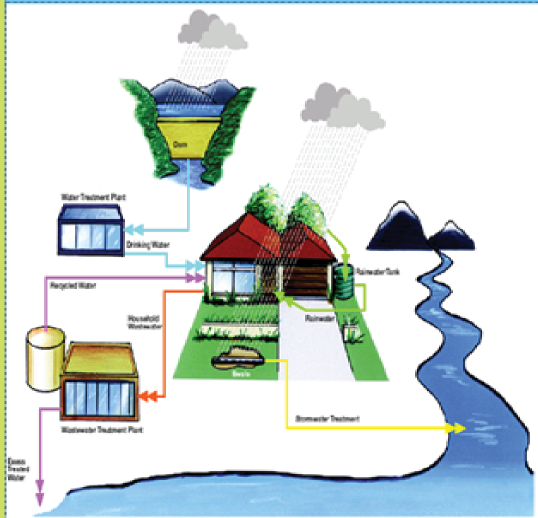
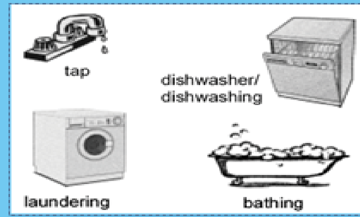


Figure-The use and reuse of water through water cycle.

What is WASTEWATER?
The spent or used water from households and industries that contains dissolved or suspended matter.

GREYWATER – The wastewater generated at home, except from the toilet.



BLACKWATER- Wastewater containing, or likely to be contaminated by, human waste matter (e.g. toilet wastewater or waters contaminated by toilet wastewater).

STORMWATER -Wastewater collected from surface runoff following a rain. For eg. Runoff water from rocks, roads and driveways.