WATER WASTAGE IN RESIDENTIAL BUILDINGS THE ROLE OF PLUMBING

By

MUHAMMAD JUNAID KHAN

(00000171914)

A synopsis submitted in partial fulfillment of

the requirements for the degree of

Masters of Science

in

Construction Engineering and Management

Department of Construction Engineering and Management

Post Graduate Wing

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST),

Islamabad, Pakistan

(2019)

This is to certify that the
thesis titled

WATER WASTAGE IN RESIDENTIAL BUILDINGS THE ROLE OF PLUMBING

Submitted by

MUHAMMAD JUNAID KHAN

(00000171914)

has been accepted towards the partial fulfillment of the requirements for the degree of Master of Science in Construction Engineering and Management

Dr. Khurram Iqbal Ahmad Khan

Supervisor,

Department of Construction Engineering and Management,

SCEE, National University of Sciences and Technology (NUST), Islamabad

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by Mr. Muhammad Junaid Khan, registration no. 00000171914, of CEM-08 PG Wing-SCEE has been vetted by undersigned, found complete in all respects as per NUST statutes/ regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/ MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ______________________________

Name of Supervisor: Dr. Khurram Iqbal Ahmad Khan

Date:________________________________

Signature (HOD): _________________________

Date:________________________________

Signature (Dean/ Principal):_________________

Date:_______________________________

This thesis is dedicated to my family and my respected teachers!

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Allah Almighty who always helped me throughout my life and to get through this research degree and thesis.

I would like to pay debt of gratitude to my advisor Assit. Prof. Dr. Khurram Iqbal Ahmed Khan for his profound guidance, valuable time, motivation, personal support and encouragement, to complete this research work. I am also extremely grateful to the committee members, Prof. Dr. Hamza Farooq Gabriel, Assit. Prof. Dr. Abdur Rehman Nasir and Dr. Muhammad Usman Hassan, for their sincere guidance to complete this research work. I am very grateful to all the respondents for their valuable contribution to this research. And in the end, I would like to pay my earnest and honest gratitude to my family for their unconditional support, encouragement, prayers and patience.

ABSTRACT

United Nations Development Programme (UNDP), International Monetary Fund (IMF) and Pakistan Council of Research in Water Resources (PCRWR) reports mention that Pakistan will be facing its worst water draughts by the year 2025 and is a third most water stressed country in the world already. Urbanization, rapid population growth, and the continuous industrial expansion have placed colossal pressure on water resources of the country. The drawn out droughts and minimal development of supplemental water resources have further aggravated the water insufficiency situation. Pakistan has the amplitude availability of ground and surface water resources (128300 mil m^3 and 50579 mil m^3 per year respectively). In consequence per capita availability of water has reduced from 5600 m^3 to 1000 m^3 per annum. In the recent years there has been a huge drop in underground water level due to fast population growth and its urbanization. The water shortage in the capital city of Pakistan is aggravating in the summers as the water level in both Simly and Khanpur dams has not risen. The city requires 110 million gallons daily and that the civic agency has been providing 56 MGD. To minimize water consumption, the developed countries are adapting to green building technologies. Idea of green building is uncommon between masses and the use of grey water is near to none in the city of Islamabad. People avoid upfront costs when constructing their houses and installing utilities for the building. Identifying the clean water loss occurred due to conventional water flow system used in the residential buildings will enable us to find out how water consumption can be minimized with the use of improved plumbing techniques.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION

1.1 Preface

With each passing day population grows, recent analysis by the United Nation revealed that there is an 80% likelihood that the world population, which currently stands at 7.7 billion (Nations, 2018) will increase to between 9.6 and 12.3 billion by the year 2100 (Gerland et al., 2014). Worldwide, more people are living in urban region than in rural region, with 55% of the world's population living in urban regions in 2018. 30% of the total world's population was urban in 1950, and by the year 2050, 68% of the total world's population is forecasted to be urban (Nations, 2018). Rural population of the world has expanded at a leisurely pace since 1950 and is predicted to reach its peak in a few years, which currently stands at 3.4 billion and is expected to decrease around 3.1 billion by the year 2050. Meanwhile the urban population of the world has grown very quickly since 1950s, having grown from 751 million to 4.2 billion in 2018 and an additional 2.5 billion is expected by the year 2050 (Nations, 2018).

Rapid population growth can create a variety of challenges involving environmental (exhaustion of natural resources or pollution), economic (unemployment, low wages, destitution), health (high maternal and child mortality), governmental (poor health investments, education and infrastructure) and social (increased unrest and crime) (Bongaarts, 2013). Major environmental concern is the depletion of water resources especially because of rapid urbanization. Water being the essential part of life is decreasing at alarming rate, global ground water depletion (GWD) has expanded by 22% in ten years, from 240 km^3 to 292 km^3 (2000 – 2010). India and Pakistan used the highest quantity of GWD (30% and 11% of total global GWD) (Dalin, Wada, Kastner, & Puma, 2017).

Due to population increase and relocation from rural areas to cities, more big cities will be built, which will consume more natural resources. This will not only create enormous pressure on water supply, solid waste management and wastewater treatment but also on overall environment. For buildings in general, losses which are caused by a high quantity of water used and wasted in the system, are mostly the result of plumbing design inaccuracy, inaccurate maintenance procedures and bad user habits (de Gois, Rios, & Costanzi, 2015).

Pakistan is facing major water crisis and will face its worst water draughts by the year 2025 and is third most water stressed country in the world already (Pakistan, 2016). To overcome such problems some measures will need to be taken on personal scale as well which not only include the efficient water system but also behavioral pattern of water usage.

It was estimated that around 13.2 gallons of clean water is needed per person per day for human consumption requirements like drinking, sanitation, cleanliness, and cooking (Gleick, 1996). According to the survey conducted in the year 2005, the ordinary American used around 98 gallons of water per day (Kenny et al., 2009), of which approximately 70% water was used indoors (Agency, 2018). Thus, the ordinary American used around 69 gallons of water indoors, more than five times the water consumption estimated by Gleick. Estimates vary, but as per recent research conducted by United States Geological Survey in 2016, each user uses around 80-100 gallons of water per day. 2008 winter data collection for the Gold Coast household samples showed the average water consumption around 157.2 liters per person per day (L/p/d), out of which major portion of 33% was used in shower followed by clothes/ dishwashing at 19% (Stewart, Giurco, Panuwatwanich, Capati, & Willis, 2009). In comparison to that per capita water consumption in Pakistan deviates notably from 30 liter per capita per day (lpcpd) to 350 liter per capita per day (lpcpd) depending on the location, particularly poor are more affected (Bhatti & Nasu, 2010).

Consumption of water varies for the same age group, depending on weather and climate variables (temperature, humidity, precipitation, wind). The effect of maximum temperature is stronger than that of precipitation at the monthly scale on water consumption; hence the connection between weather, climate variables and seasonal water consumption is stronger at the starting of the summer months than the preceding summer months (H. Chang, Praskievicz, & Parandvash, 2014). The water consumption is nearly 41 % of annual water consumption during the months from June to September (Palmer & Hahn, 2002).

The main problems linked to water conservation in urban areas are the rise in cost of water supply, the growth of demand, pollution and dissimilarities in the supply of water resources. The controlled and systematic use of water conservation incorporates both measures as acceptable means of water reuse. Therefore, conservation practices are a productive way to meet the supply and demand of water to new activities and users without endangering the water-bodies supplying and safeguarding the natural environment.

Most user habits are also reliant on the plumbing system being used, for example the types of faucets being used for water consumption activities. Type of pipes and its orientation plays a huge part in varied consumption for a user with similar climatic conditions. Open plumbing systems are greatly affected by the weather conditions, temperature of capital city on peak ranges from 47^{o}c in June to – 6^{o}c in January with the highest humidity levels recorded in June and July. To minimize water consumption, the developed countries are adapting to green building technologies. Idea of green building is uncommon between masses and the use of grey water is near to none in the city of Islamabad. Users avoid upfront costs when constructing their houses and installing utilities for the building.

By overcoming such issue on personal scale not only will solve the water crisis to some extent but will also help in preserving the energy being used to maintain the water temperature. The European Union energy policy dedicates high priority to use of renewable energy and energy reduction. It is reported that 40% of total energy consumption takes place in residential/ commercial buildings, this makes it one of the focus areas (Dombaycı, Gölcü, & Pancar, 2006). Not only the water but Pakistan along with some other developing countries is also currently facing a major deficit of energy and minimizing the water consumption can help save some of that energy. Energy cuts can be achieved by using the proper insulation and finding its life-cycle cost for the instance of using differing fuels such as coal, natural gas or fuel oil (Keçebaş, 2012).

1.2 Problem Statement

1. Pakistan has the world's fourth highest rate of water use. In 1990, Pakistan touched the "water stress line" and crossed the "water scarcity line" in 2005 and is likely facing drought-like situation in the near future (PCRWR, 2016).
2. Water wastage is a big issue in the country (Abid Soleri SDPI, 2018).
3. Water demands of capital city are not being met as the demand stands at 110MGD and supply is 56MGD (Masood NYT, 2015).
4. Lack of awareness among users to use sustainable utilities.

1.3 Research Objectives

The objectives of this thesis research are:

1. To identify the activity with most clean water consumption.
2. To quantify the amount of clean water waste with the focus on highest water usage activity in residential buildings.
3. To compare clean water wasted among different types of available plumbing systems.
4. To provide alternate plumbing solutions acceptable to users.

1.4 Advantages of Study

Advantages this study brings forth are:

1. Minimizing the clean water loss.
2. Financially beneficial for consuming less water and energy.
3. Excessive energy being utilized on heating/cooling water to be saved.
4. Awareness related to the issue could improve personal behavior to water consumption.
5. Improvement in plumbing system will increase LEED rating of the building.

1.5 Thesis Organization

This thesis has been organized into five chapters.

Chapter 1 is ‘Introduction.’ It covers introduction to research, problem statement, research objectives and advantages of study. It provides a general overview to the research.

Chapter 2 is ‘Literature Review.’ It explains the previous studies done concerning the residential water consumption and the methods taken to tackle the issue.

Chapter 3 is ‘Research Methodology.’ It explains how research is conducted to achieve the objectives.

Chapter 4 is ‘Results and Discussion.’ It covers the analysis of collected survey data, results and counter measures according to our research objectives.

Finally, Chapter 5 is ‘Conclusions and Recommendations.’ Final conclusions and recommendations have been summarized in this chapter.

Chapter 2

LITERATURE REVIEW

1.1 Background

Work done prior to this research is discussed in this chapter. There has been no similar research conducted related to the water conservation via plumbing system in Pakistan. Some level of research had been conducted in developed countries to obtain data related to water conservation via plumbing in residential and other type of buildings (Inman & Jeffrey, 2006; Willis, Stewart, Panuwatwanich, Williams, & Hollingsworth, 2011). While other studies related to water conservation is widely studied in industrialized nations such as USA, Canada, Australia, New Zealand, Spain, Austria (Domene & Saurí, 2006; Grafton, Ward, To, & Kompas, 2011; P. Mayer & DeOreo, 1999; Ramsey, Berglund, & Goyal, 2017; Stewart et al., 2009; Turner, White, Beatty, & Gregory, 2005). Clean water losses were observed on personal level instead of overall household or whole community. Many factors which affect the water loss on a personal scale involves weather & climate (Slavíková, Malý, Rost, Petružela, & Vojáček, 2013), personal usage behavior, type of plumbing/ system used (Davies, Doolan, van den Honert, & Shi, 2014). These factors differ greatly between indoor and outdoor water uses. A research found that outdoor water consumption mostly depend on watering garden, cleaning yard and swimming pool, which are highly affected by climate, income, way of life and water conservation practices (Syme, Shao, Po, & Campbell, 2004). In contrary to outdoor, other researchers found out that water appliances and water conservation practices affects indoor water use (Gregory & Leo, 2003). Survey results of the study on Indian village revealed that the daily average water consumption was 117 litre per person per capita per day (Omvir. Singh & Turkiya, 2012). While in a Dorogram village of Bangladesh values recorded were found to be 83.17 litre per person per day (Al-Amin, Mahmud, Hosen, & Islam, 2011). For urban and major cities mean water consumption values stood at 398.3 liters per household (91.56 liters per capita) for India that includes Mumbai, Delhi, Hyderabad, Kolkata, Madurai, Ahmedabad and Kanpur (Shaban & Sharma, 2007). Majority of residents in the district of Jaipur barely have access to continuous water barely for less than two hours per day, due to which many residents manage with this spasmodic by storing water in tanks for using throughout the day (Ramsey et al., 2017). Similar water access trend was observed in major cities of Pakistan, only a selected few have 24/7 running water supply. In mega cities like Lahore Rawalpindi and Faisalabad the trend of consumption observed was that the demand of higher income group was twice as much as the lower income group (Bhatti & Nasu, 2010). Percentages of different level of water consumption were calculated by Bhatti and Nasu, which in relation to Rawalpindi city are given below:

Table 1 Water Consumption percentage in Rawalpindi

S. No.	Task	Percentage	Consumption Quantity (litre/ capita/ day)
1	Bath/ Shower	28%	15 – 150
2	Toilet	18%	50 – 60

3	Washing Machine	9%	-
4	Kitchen	16%	-
5	House Cleaning	4%	-
6	Car Cleaning	5%	-
7	Drinking	1%	-
8	Wash basin	13%	-
9	Cooking	4%	5 – 45

1.2Weather & Climate

Temperature is the main element for domestic water consumption, especially in connection with significant outdoor uses (M Cabral, Loureiro, Mamade, & Covas, 2014). Consumption of water varies for the same age group, depending on weather and climate variables (temperature, humidity, precipitation, wind). Any extreme, be it cold or hot affects influences water consumption greatly, though maximum temperature influences a lot more on water consumption at the monthly scale (H. Chang et al., 2014). The water consumption throughout the summer months from June to September is close to 41 % of total annual water consumption (Palmer & Hahn, 2002). Usually, hotter days are corelated with higher water consumption via increased hygiene patterns and outdoor uses, like watering garden or filling swimming pool (Corbella & i Pujol, 2009; Hoffmann, Worthington, & Higgs, 2006). Distribution of monthly water consumption of Portland city from 1960 to 2013 also suggests more water being consumed in warm weather is around 800L/D in the months of July and August (average temperature= 27^{o}C) compared to cold weather, which is around 500L/D in the months of December and January (average temperature= 7^{o}C) (H. Chang et al., 2014). Consumption in outdoor uses is very responsive to weather conditions. Since Islamabad and Rawalpindi mainly contains low-rise buildings, it has been proven that high income inhabitants have higher water consumption in the summers, majorly due to outdoor uses in low- rise buildings (Loh & Coghlan, 2003).

For Low temperatures, people also perceive rainfall as a factor of varying water consumption. Since the water used is mainly indoors it barely affects the consumption amount, they respond more to its occurrence than to its amount (Marta Cabral, Mamade, Loureiro, Amado, & Covas, 2016). Even though rainfall/ water precipitation has an impact on daily water consumption in a statistically significant way (Parandvash & Chang, 2016).

A study based in high water consumption cities of China showed the water consumption per capita per day getting strongly affected by precipitation, investment in water conservation, water heating devices per household for hygienic practices like showering or bathing and total domestic product per capita (Fan, Gai, Tong, & Li, 2017). More exposed the water distribution system is to weather, the more it gets affected, example being the water consumption in zones with relevant outdoor uses (gardens and pools) or tourist spots may be more affected by weather conditions (Gössling et al., 2012). It is import to note the purpose of using of water like people normally shower more in hotter conditions compared to colder conditions because of their hygienic situation. The more knowledge about weather conditions on consumption of water, the better preventive measures can be taken for sustainable period of time.

Mainly in cold weathers, energy consumption is higher because of water heating devices like total energy utilization for domestic hot water in China accounted for about 23.4% of the domestic energy consumption (Press, 2010). While showers alone, that were electrically powered, consumed 24% of standard household consumption in Brazil (Naspolini & Rüther, 2012). Study on UK also showed nearly similar values in 2009, around 18% of total energy was consumed by domestic hot water system (Boait, Dixon, Fan, & Stafford, 2012).

1.3 Personal Behavior

Consumption of water varies for different age-groups; it even varies for similar age individuals which are affected by difference in their preferences. The average annual water consumption of a single household in Los Angeles (LA) was around 1465 L/household/day over the 10 years period (C Mini, Hogue, & Pincetl, 2014). While nearly similar values were noted for San Diego at 1181 L/household/day (William B. DeOreo et al., 2011), a big difference is visible with UK’s water usage averaging 349 L/ household/ day (DEFRA, 2008). It goes on to show that people preference varies greatly in different parts of the world, either due to their socio cultural differences or because of individual preferences.

Survey based on 227 urban households in Indian Urban region of Jaipur suggests that most of users acknowledge the significance of water conservation, but they do not necessarily save water themselves because it require personal effort or financial investment (Ramsey et al., 2017). In fact a study shows that the end users who are aware about their appliances water saving capability frequently engage in counterpoise behavior, using these appliances more often or for longer periods (Campbell, Johnson, & Larson, 2004) unless they are reminded to conserve water, they consume less overall (Willis, Stewart, Panuwatwanich, Jones, & Kyriakides, 2010).

Since water consumption varies depending on many factors including individual's preference, hence different authors present different values such as:

Table 2 Water consumption per person

S. No.	Water usage per person (Gal/ day)	Source
1	80-100	(Survey, 2016)
2	37.5	(DEFRA, 2008)
3	98	(Kenny et al., 2009)
4	41.5	(Stewart et al., 2009)
5	30.9	(Omvir. Singh & Turkiya, 2012)
6	22.2	(Al-Amin et al., 2011)
7	13.2	(Gleick, 1996)

To control the water consumption, it is normally not that productive when left to the individual. As observed in California, voluntary restriction of water usage is less effective compared to more strict obligatory outdoor watering limitations and pricing measures as shown by the 23% reduction in City's average single family house water use during the summer of 2010 to that of 2008 (Caroline Mini, Hogue, & Pincetl, 2015). Approximately 70% water is used indoors and 30% outdoors (Agency, 2018). These values are affected by their geographical locations as well.

On a more micro level, men tend to consume more water in their daily food/ beverages compared to women as proven by the study conducted on their urine osmolality (Malisova et al., 2016). Other habits such as bathing, showering, brushing, shaving etc. are more dependent on personal preference rather than biological need of water consumption as energy. The highest use of household water is flushing the toilet followed by taking showers and baths according to USGS but all researchers do not agree with it. Given below is estimated water use for typical house hold conducted by USGS.

Table 3 Typical Water use at Home

Activity	**Consumption**
Bath	On average 36 gallons usage.
Shower	2 – 5 gallons of water usage depending on the type of shower installed
Teeth brushing	Latest bath faucets use around 1 gallon per minute, whereas older models use over 2 gallons.
Face/ Hands washing	1 gallon

Dishwasher	6-16 gallons depending on the type of dishwasher installed. Manual dishwashing wastes more water comparatively.
Dish washing (hands)	Around 8-27 gallons use depending on the efficiency.
Clothes washer	25 – 40 gallons/load depending on type of washer being used.
Toilet flush	1.6 – 4 gallons depending on toilet type used. On average 3 gallons are used.
Drinking water	8 ounces per small glass excluding the water used for cooking.
Outdoor watering	Depending on the size of area to be watered such as lawns/ yards/ pots etc. On average 2 gallons per minute water flow, depending on outdoor faucet.

On a personal scale people normally do not realize about the affects individual actions on water wastage. Food production for a single individual consumes water around 3496 L/D, cooking/ preparing at home consumes 10% of water, out of which around 50% is wasted (Laspidou, 2014). So from a household water user view, details about their personal water usage behaviors can guide to recognizing extravagant water usage practices or water leaks at site, offering the footing for a sustainable behavioral alteration and saving cost on water bills (Anda, le Gay Brereton, Brennan, & Paskett, 2013).

1.4 Plumbing

Consumption of water varies greatly depending on the type of plumbing used that can vary from closed indoor techniques to open outdoor ones. Normally open outdoor techniques are used for easy maintenance and to avoid walls dampening. In the past, pipes normally used were made of cast iron but now different PVC and other types of piping material is taking its place to minimize the costs or any extra advantages associated with new type of material.

Pipe selection varies depending on their maintenance which is directly affected by temperature and leakage. It causes economic loss not only to the water industry but also represents an environmental problem and a possible hazard to public health with regard to polluted water (Puust, Kapelan, Savic, & Koppel, 2010). The total amount of water leaked differs widely between countries. Around 6 billion m^3 water is lost due to plumbing leakages every year in China (Li, Huang, Xin, & Tao, 2015).

1.4.1 Types of Plumbing pipe

Pipes commonly used for plumbing worldwide are such as PEX, Copper, and PVC. Out of which PEX (cross-linked polyethylene made out of plastic material) is preferred because of its durability (less corrosive) and easy installment in metal applications. Most plumbing pipes being used in under developed/ developing countries are either copper or PVC depending on their application and the geographical location in which they are installed. Regarding this research, major advantage PVC/PEX holds over the rest is in terms of its insulation/ high heat-resistance while copper is prone to rust with lower heat resistance. Given below is the table of different type of pipes used for plumbing:

Table 4 Thermal Conductivity of Pipes

S.No.	**Pipe**	**Thermal Conductivity (W/m K)**	**Durability**	**Remarks**
1	Stainless Steel	50.2 (Young & Sears, 1992)	30-50 years	Good but very expensive. Used in highly corrosive areas.
2	PEX	0.41 (Institute, 2014)	50 years	Very good indoor usage. Not good for outdoor because of UV rays.
3	Copper	385.0 (Young & Sears, 1992)	20-50 years	Most traditional. Requires good plumbing technique to install.
4	PVC	0.19 (ToolBox, 2011)	50-70 years	Used for hot/ cold potable water and sewerage applications.
5	CPVC	0.139	50-70 years	Can withstand higher temperature (200F)

				compared to PVC (140F)
6	Cast Iron	79.5 (Young & Sears, 1992)	75-100 years	Better used for water distribution systems (larger in size)
7	Brass	109.0 (Young & Sears, 1992)	40-70 years	Great rust resistance.
8	Galvanized	50.2 (Young & Sears, 1992)	20-50years	Formation of rust is high. Can be used to transport grey/ non potable water

Note that these values vary greatly depending on other material components involved and pipe widths.

1.4.2 Insulation

The principal cost components in a residential heating system are transference and supply pipe layout, which often ranges from 40% - 60% of the project's total cost. Most of these costs are connected to the equipment in the plumbing system. Usage of un-insulated pipes permits trimming in pipe material costs by more than half (Bloomquist, 2001). The most productive way to lessen heat losses are to choose pipe and insulation materials, then to decide diameter of pipe and its insulation thickness (Danielewicz, Śniechowska, Sayegh, Fidorów, & Jouhara, 2016). A better insulation will ease the burden not only on heating devices but also on the cost to choose thicker pipes, it will also reduce burden on environment to produce less electricity.

Different types of pipe insulations are there such as mineral/ glass wool, flexible/ rigid foams, polyethylene, cellular glass and aerogel. Their selection depends on many factors like consumer requirement, pipe system, geography, placement location etc.

1.5 Smart Techniques

There is a huge potential to overcome water losses by using different type of smart techniques. These techniques might not be suitable for developing countries because of economic implications, but they prove there is a high chance of reduction in water consumption with right tools and techniques.

A evaluation of applications for the fitting of water-saving devices mainly in the western Australia and United States found out that retrofitting plumbing and appliances replacement could save around half of the indoor water use (Inman & Jeffrey, 2006). A research in Spain found that the water used indoor could be lowered to about 30% by adjusting water flows in faucets and fitting low-flush toilets (Domene et al, 2004). The study conducted at a household level at regional Victoria state in Australia has revealed that the integrated use of unconventional water supplies in conjunction with water efficient appliances can save close to 77% of total clean water use in contrast to the average 90s residential water use in the similar region (Willis et al., 2011). Same type of water use or piping system is still being used in Pakistan. Even though values, attitudes and beliefs are significant components in water conservation, but they might not always transfer into conservation behavior (Saurí, 2013).

Public awareness campaign related studies show good results in terms of reduction in consumption values, for example California observed 20% decrease in water consumption (Renwick & Green, 2000) while in England the values predicted close to 20 litres per capita per day by means of campaigns and water saving appliances (Shove, Franceys, & Morris, 2010).

1.6 Highest water consumption activity

Factor analysis based on 20 different researches suggested the activity of shower/ bath consuming highest amount of water (objective 1).

Table 5 Factor analysis of water consumption activities

Rank	**Attributes**	**Literature Score**	**Normalized Score**	**Accumulated Scored**	**References**
1	Shower/ Bath	100	0.315457413	0.315457413	(Bari, Begum, Nesadurai, & Pereira, 2015; Beal, Stewart, & Fielding, 2013; Bhatti & Nasu, 2010; William B DeOreo, Mayer, Dziegielewski, & Kiefer, 2016; Ghosh, Kansal, & Aghi, 2016; Guragai, Hashimoto, Oguma, & Takizawa, 2018; Keshavarzi et al., 2006;

					Loh & Coghlan, 2003; Makki, Stewart, Beal, & Panuwatwanich, 2015; P. W. Mayer et al., 1999; Mead, 2008; Nguyen, Stewart, Zhang, Sahin, & Siriwardene, 2018; Rathnayaka et al., 2015; Roberts, 2005; Omvir Singh & Turkiya, 2013; Stewart et al., 2009; Survey, 2016; Vieira, Jorge, & Covas, 2017; Willis, Stewart, Giurco, Talebpour, & Mousavinejad, 2013)
2	Toilet	57	0.179810726	0.495268139	(Bari et al., 2015; Beal et al., 2013; Bhatti & Nasu, 2010; William B DeOreo et al., 2016; Ghosh et al., 2016; Guragai et al., 2018; Loh & Coghlan,

					2003; Makki et al., 2015; P. W. Mayer et al., 1999; Mead, 2008; Nguyen et al., 2018; Rathnayaka et al., 2015; Roberts, 2005; Omvir Singh & Turkiya, 2013; Stewart et al., 2009; Survey, 2016; Vieira et al., 2017; Willis et al., 2013)
3	Clothes Wash	57	0.179810726	0.675078864	(Bari et al., 2015; Beal et al., 2013; Bhatti & Nasu, 2010; William B DeOreo et al., 2016; Ghosh et al., 2016; Guragai et al., 2018; Loh & Coghlan, 2003; Makki et al., 2015; P. W. Mayer et al., 1999; Mead, 2008; Nguyen et al., 2018; Rathnayaka et al., 2015; Roberts, 2005; Omvir Singh & Turkiya, 2013;

					Stewart et al., 2009; Survey, 2016; Vieira et al., 2017; Willis et al., 2013)
4	Faucet	51	0.160883281	0.835962145	(Bari et al., 2015; Beal et al., 2013; Bhatti & Nasu, 2010; William B DeOreo et al., 2016; Loh & Coghlan, 2003; Makki et al., 2015; P. W. Mayer et al., 1999; Mead, 2008; Nguyen et al., 2018; Rathnayaka et al., 2015; Roberts, 2005; Omvir Singh & Turkiya, 2013; Stewart et al., 2009; Survey, 2016; Vieira et al., 2017; Willis et al., 2013)
5	Dish Washing	15	0.047318612	0.883280757	(Bari et al., 2015; Beal et al., 2013; Bhatti & Nasu, 2010; William B DeOreo et al., 2016; Ghosh et al., 2016;

					Guragai et al., 2018; Makki et al., 2015; P. W. Mayer et al., 1999; Nguyen et al., 2018; Rathnayaka et al., 2015; Omvir Singh & Turkiya, 2013; Survey, 2016; Vieira et al., 2017; Willis et al., 2013)
6	Leaks	12	0.03785489	0.921135647	(Bari et al., 2015; Beal et al., 2013; Bhatti & Nasu, 2010; William B DeOreo et al., 2016; Loh & Coghlan, 2003; P. W. Mayer et al., 1999; Mead, 2008; Nguyen et al., 2018; Roberts, 2005; Stewart et al., 2009; Willis et al., 2013)
7	Area Cleaning	7	0.022082019	0.943217666	(Bari et al., 2015; Bhatti & Nasu, 2010; William B DeOreo et al., 2016; Ghosh

					et al., 2016; Keshavarzi et al., 2006; P. W. Mayer et al., 1999; Omvir Singh & Turkiya, 2013)
8	Drinking	5	0.015772871	0.958990536	(Bari et al., 2015; Bhatti & Nasu, 2010; Ghosh et al., 2016; Omvir Singh & Turkiya, 2013; Survey, 2016)
9	Cooking	5	0.015772871	0.974763407	(Bari et al., 2015; Bhatti & Nasu, 2010; Ghosh et al., 2016; Omvir Singh & Turkiya, 2013; Survey, 2016)
10	Car Cleaning	5	0.015772871	0.990536278	(Bari et al., 2015; Bhatti & Nasu, 2010; Keshavarzi et al., 2006; Omvir Singh & Turkiya, 2013; Survey, 2016)
11	Residential Livestock	2	0.006309148	0.996845426	(Keshavarzi et al., 2006; Omvir Singh & Turkiya, 2013)

12	Evaporative Cooler	1	0.003154574	1	(Nguyen et al., 2018)

Chapter 3

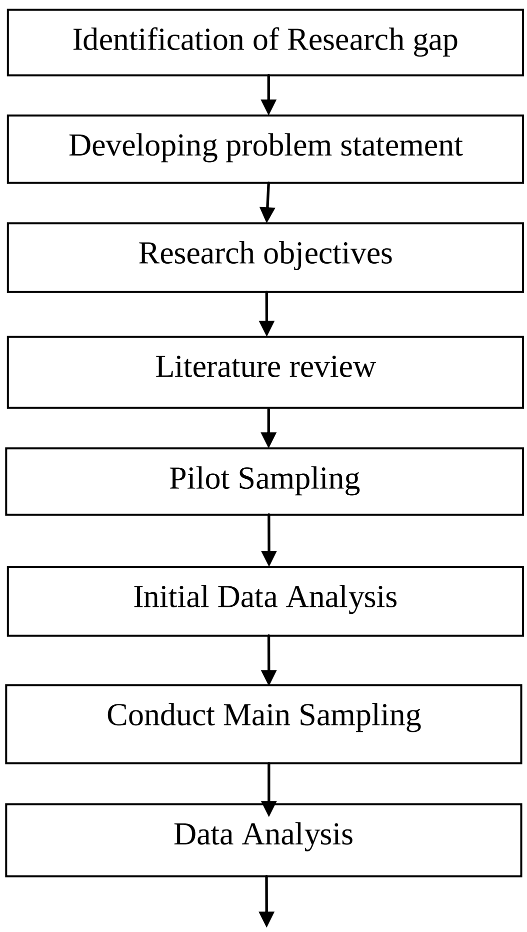
METHODOLOGY

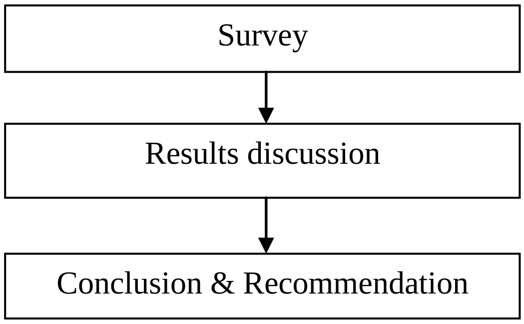
3.1 Introduction

This chapter explains the intended approach to achieve the remaining objectives of this research, mentioned in Chapter 1. Techniques like literature review, water collection data, surveys, experiments and case studies will be used in this research.

3.2 Research Design

The schematic representation of working methodology which includes integration of multiple techniques is presented in terms of a flow chart.





3.3 Water Collection Data Technique

In most of the developed countries water meters are used to measure the volume of residential/ commercial water used. Water consumption of building, which is standardized as litres/capita/day is determined by number of factors such as climate and weather conditions; type of water usage components installed; water use habits.

To quantify the water losses in residential buildings due to bathing, calculate water consumption from person to person in a household (standard houses, apartments, university hostels, bungalows etc.) with the bathroom they utilize mostly for bathing, since bathing uses about 33% of the water (Stewart et al., 2009).

There are many types of water meters commonly in use. Displacement water meter being used in residential/ small commercial applications, velocity water meter calculate volume through velocity of flow, and other water meters such as electromagnetic and ultrasonic water meters. The selection of meter depends on the type of end user, flow measurement method, flow rates required, and precision requirements. We can use displacement water metering if sampling is done on collective household scale instead of on personal scale. In this case, since the water is being measured at the household level on a personal level, simple water collection technique will be used to collect the water in measured buckets by running shower/ tap water

The person under consideration will adjust the shower/ tap to their liking, observe and collect the water wasted in a measured bucket till their desired temperature water starts running. Average temperature recorded for bathing and showering by researchers in the Japan was around 40C and 41C respectively (Hong, 1991; Kamata, 1992). Since the clean water waste being collected here was right before the person starts showering, the selection of required water temperature was left at user's choice. Similar researches of bathing/ showering also involved direct interaction of human with water being used (Hashiguchi, Ni, & Tochihara, 2002; Tochihara, 1999; Wilkes, Mason, & Hern, 2005). After the desired water temperature for shower was reached, we removed the bucket and measured the water wasted in the meantime. Length of pipe from geyser (for cold weather only) and its orientation to observe the pattern change was also checked.

3.3.1 Limitations

Certain Limitations were followed due to geographical and socioeconomic factors of sampling locations:

1. Water was collected from the residents of Islamabad & Rawalpindi only (2018 year average high/ low temperature; 28.83^{o}C/ 15.08^{o}C) (NOAA, 2018).
2. Winter water waste was collected only in the months of December – March (2018 year average high/ low temperature; 20.75^{o}C/ 6.75^{o}C) (NOAA, 2018)
3. Mean temperature of total sampling data was around 12.8^{o}C.

4. Water wasted was collected from the households using gas geysers because of vast majority users.
5. Types of residential buildings used for sampling were flats, hostels, single family house.
6. Mainly suitable for South Asian urban areas, or for regions with the similar social, geographical, environmental, economical factors.

3.4 Pilot Sampling

Experiment was performed on standard house of 5 residents (varying gender and age). 2 gas geysers were installed to keep the water warm on each floor. Water waste was calculated from the bathroom they utilize for bathing. Given below are the results:

Table 6 Pilot Water Waste Sample Data

S. No	Date	Time	Gender	Age (years)	Temperature (°C)	Pipe Length (ft)	Waste per shower (litres)	Pipe Orientation	Pipe type
1	30-12-18	9:00	Male	65	13	70	7	Hidden	PVC
2	30-12-18	9:00	Female	60	13	70	6.5	Hidden	PVC
3	30-12-18	9:00	Male	25	13	36	6	Exposed	PVC
4	30-12-18	9:00	Female	21	13	20	3.5	Partial	PVC
5	30-12-18	9:00	Male	19	13	36	6.5	Exposed	PVC

The table above shows total of 29litres water being wasted per shower (highest consumption activity) in a single household (objective 2). Initial sampling indicates that pipe orientation and length affects the water loss directly, exposed and lengthy pipes are affected more.

3.5 Surveys

A survey was performed on the users water waste data was collected from. Their level of acceptance with the current plumbing system being used at their homes and selection of different and improved system were main focus point of this survey. Questions about different type of improvements such as type of plumbing, insulation and rerouting techniques were asked from the same individuals water waste was collected from. Survey conducted is attached as annexure – A.

Chapter 4

RESULTS & DISCUSSION

5.1 Main Sampling

Overall data was collected from around 20 different residential buildings (single family house, flats, hostels) involving 66 residents in total. The criteria taken in to account were living standard and household economic class which was determined by the type of building they were living in (owned, rented out). The houses were surveyed from lower income class to high income class depending on area of residence and monthly household income. Around 56% of the respondents were below the age of 30 because nearly 64% of Pakistani population is younger than 30 (Ahmad, 2018).

However, the accuracy and reliability of the collected data is questionable and demand for extensive survey. Given below is main water waste sample data:

Table 7 Main Water Waste Sample Data

S. No	Date	Time	Gender	Age (years)	Temperature (^oC)	Pipe Length (ft)	Waste per shower (litres)	Pipe Orientation	Pipe type
1	03-03-19	17:00	Male	23	13	52	8	Exposed	Iron
2	03-03-19	17:00	Male	25	13	72	10	Exposed	Iron
3	03-03-19	17:00	Male	23	13	92	12	Exposed	Iron
4	03-03-19	17:00	Male	21	13	112	15	Exposed	Iron
5	03-03-19	18:00	Female	19	13	52	7	Exposed	Iron
6	03-03-19	18:00	Female	23	13	72	10.5	Exposed	Iron

7	03-03-19	18:00	Female	22	13	92	12.5	Exposed	Iron
8	03-03-19	18:00	Female	22	13	112	16	Exposed	Iron
9	03-03-19	17:30	Female	24	13	60	7	Partial	Iron
10	03-03-19	17:30	Female	22	13	60	6	Partial	Iron
11	11-03-19	8:30	Male	23	11	56	8	Partial	Iron
12	11-03-19	8:30	Female	28	11	62	8.5	Partial	Iron
13	11-03-19	8:30	Female	30	11	62	8.5	Partial	Iron
14	11-03-19	8:30	Female	58	11	56	9	Partial	Iron
15	11-03-19	8:30	Male	67	11	56	9.5	Partial	Iron
16	11-03-19	10:00	Male	62	11	32	6	Partial	PVC

17	11-03-19	10:00	Female	55	11	32	5	Partial	PVC
18	11-03-19	10:00	Female	27	11	20	3	Hidden	PVC
19	11-03-19	10:00	Male	19	11	28	3	Hidden	PVC
20	11-03-19	9:00	Male	70	11	12	1.5	Hidden	PVC
21	11-03-19	9:00	Male	44	11	60	8	Partial	PVC
22	11-03-19	9:00	Female	40	11	60	8.5	Partial	PVC
23	11-03-19	9:00	Male	11	11	28	3	Hidden	PVC
24	11-03-19	9:00	Male	42	11	50	8	Exposed	Iron
25	11-03-19	9:00	Female	39	11	38	4	Hidden	Iron
26	11-03-19	9:00	Female	10	11	38	4	Hidden	Iron

27	11-03-19	9:30	Female	63	11	25	5	Exposed	Iron
28	11-03-19	9:30	Male	48	11	33	4	Partial	Iron
29	11-03-19	9:30	Female	40	11	33	4	Partial	Iron
30	11-03-19	9:30	Male	30	11	25	4	Exposed	Iron
31	11-03-19	9:30	Female	33	11	25	4.5	Exposed	Iron
32	13-03-19	20:30	Male	65	14	40	6	Partial	PVC
33	13-03-19	20:30	Female	30	14	22	3	Partial	PVC
34	13-03-19	20:30	Female	26	14	32	3.5	Partial	PVC
35	13-03-19	20:30	Female	23	14	32	4.5	Partial	PVC
36	13-03-19	20:30	Male	19	14	20	4	Partial	PVC

37	13-03-19	22:00	Male	43	14	24	3	Partial	PVC
38	13-03-19	22:00	Female	41	14	24	4.5	Partial	PVC
39	13-03-19	22:00	Male	12	14	24	4	Partial	PVC
40	13-03-19	21:00	Female	56	14	44	4.5	Hidden	Iron
41	13-03-19	21:00	Male	32	14	26	3	Hidden	Iron
42	13-03-19	21:00	Male	28	14	38	4	Hidden	Iron
43	13-03-19	21:00	Female	27	14	26	3	Hidden	Iron
44	13-03-19	21:00	Female	25	14	44	4	Hidden	Iron
45	13-03-19	21:30	Female	49	14	26	3	Hidden	Iron
46	13-03-19	21:30	Female	27	14	38	4.5	Hidden	Iron

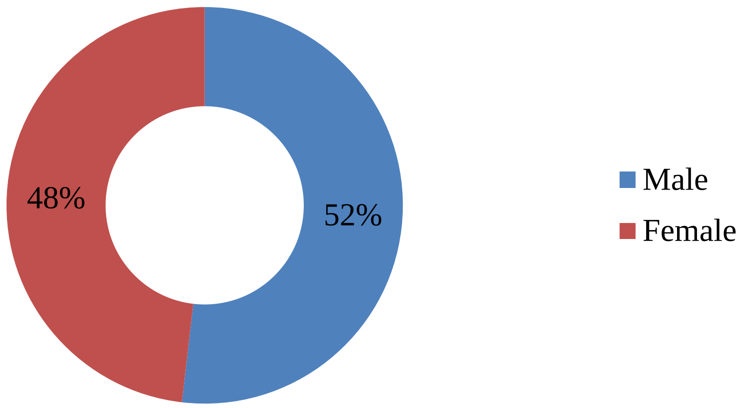
47	13-03-19	21:30	Female	24	14	26	3	Hidden	Iron
48	13-03-19	21:30	Male	15	14	38	4	Hidden	Iron
49	19-03-19	19:30	Male	68	14	18	3	Exposed	PVC
50	19-03-19	19:30	Male	62	14	18	3	Exposed	PVC
51	19-03-19	19:30	Male	30	14	30	4	Partial	PVC
52	19-03-19	20:00	Female	24	14	10	2	Partial	PVC
53	19-03-19	20:00	Male	27	14	10	1.5	Partial	PVC
54	19-03-19	20:00	Male	62	14	27	3.5	Partial	PVC
55	19-03-19	20:00	Female	57	14	27	3.5	Partial	PVC
56	19-03-19	20:30	Female	21	14	15	3	Exposed	PVC

57	19-03-19	20:30	Male	20	14	15	2.5	Exposed	PVC
58	19-03-19	20:30	Male	26	14	22	3.5	Exposed	Iron
59	19-03-19	20:30	Male	28	14	22	4.5	Exposed	Iron
60	19-03-19	20:30	Male	25	14	22	2	Exposed	Iron
61	19-03-19	20:30	Male	26	14	22	4	Exposed	Iron

5.2 Survey & Data Results

Different parameters show different results. Personal preference scale shows the results. On average clean untouched water waster per shower observed was 5.42 liters per shower per person. While study of this city showed that shower constitute of only 28% water consumption (Bhatti & Nasu, 2010), rest of the waste from remaining 72% could be improved by tackling one major point. Figure 1 shows that men tend to waste slightly more clean water compared to women when showering.

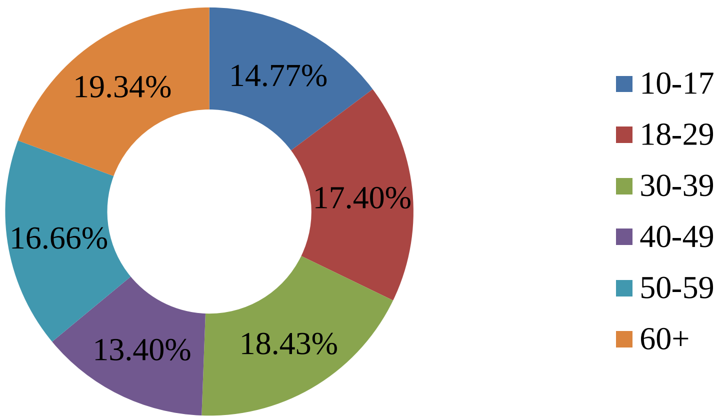
Figure 1 Gender based water waste comparison



Age based comparison didn't show any significant change in consumption values, that may be affected due to the other factors involved. Though it does marginally coincide with their water consumption habit values already proven by urine osmolality tests (Malisova et al., 2016).

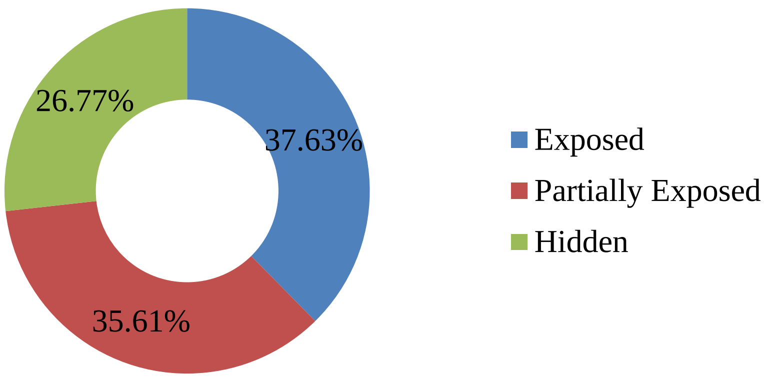
While Figure 2 shows an uneven trend but an increase in water wastage for more aged group is visible, consumption values may differ greatly.

Figure 2 Age based water waste comparison



Since the selection and orientation of plumbing pipes are one of the most common and important factor, the figure 3 here shows the slight increase in water wastage when pipes are more exposed that hidden. A significant difference of 10.86% is visible between exposed plumbing system and hidden plumbing system.

Figure 3 Comparison of water waste due to pipe orientation



Irregular trend was observed in income based comparison. Less check on water metering and bill collection means that the wastage comes down to the appliances involved. Lower income people had lesser number and lower quality of heating appliances/ plumbing system which is visible in fig 4 with wastage percentages.

Figure 4 Income based comparison of water waste

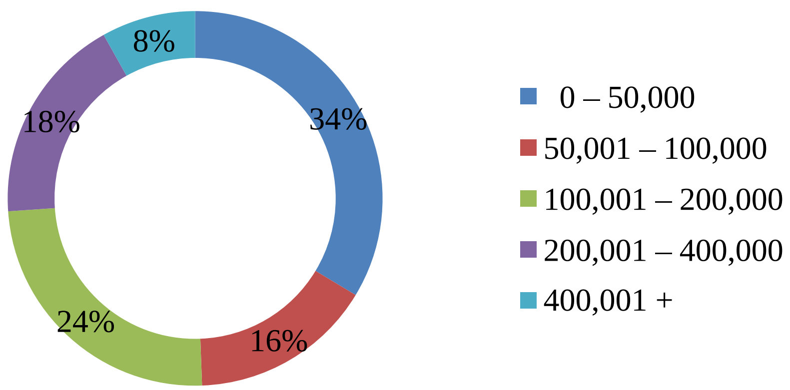
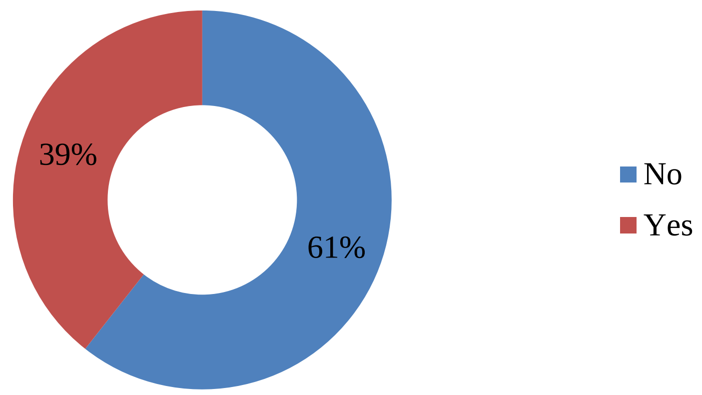


Figure 4 also proves the studies conducted in industrialized countries, showing higher-income respondents are more likely to waste less water by installing water-efficient appliances than their poorer counterparts (Grafton et al., 2011; Stewart et al., 2009; Turner et al., 2005) though another study reported the opposite as well (Willis et al., 2011). The consumption and wastage values showed different results in other study based on economical factor of user (Tarrant & Cordell, 1997) and nearly similar results were observed here. Chinese IWC was more efficient at reducing the amount of water consumption in high-consumption cities than in low consumption cities (Fan et al., 2017). Our results are also consistent with the study of researchers (Gregory & Leo, 2003) who investigated the relationship between water use and income in terms of per capita in 65 countries.

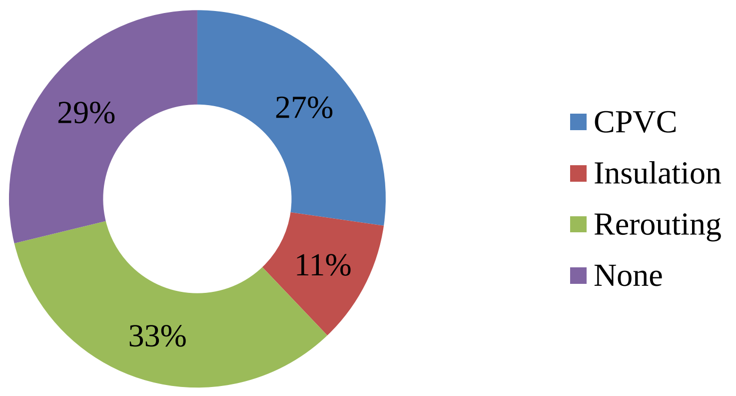
Most of the respondents weren't satisfied with their current plumbing system as shown in figure 5.

Figure 5 Satisfaction with current system



Change in the plumbing system was presented to everyone (economic and environmental aspects involved), which swayed the decision of 10% respondents to try the newer/ improved system of their choosing. Most of the younger respondents were in favor of grey water usage through rerouting shown in figure 6.

Figure 6 Selection of plumbing system preference



Around 36 out of 66 respondents were still using cast iron plumbing system, mainly those living in old apartments. Most of them agreed on switching their pipe types to PVC/ CPVC, while a few agreed with rerouting the unused water. Idea of insulating or rerouting was new to most respondents; they were presented with their financial and environmental implications. Most of the older users were hesitant in using used water (grey water) but agreed on clean water reuse.

Chapter 5

CONCLUSIONS & RECOMMENDATIONS

Water demand management is defined as "policy that stresses making better use of existing supplies, rather than developing new ones"(Kay, Franks, & Smith, 1997). Deveril also defined it as a practical strategy that helps in improving the equitable, efficient and sustainable use of water (Deverill, 2001). Being a developing country building newer plumbing system might be a huge strain on country economically. Underfunding by the government and low revenue collection over the decades has weakened the capacity of municipal governments to fund, build, and maintain infrastructure. Since Pakistan's water quality ranks as 80th out of 122 nations (Quality, 2019), the final decision of selection was left at user's discretion. Most of the respondents in survey agreed with the idea of using grey water to avoid the wastage. Wastage can also be minimized though other ways as well like retrofitting, changing the taps, appliances etc.

Influence of self-efficacy may not play as large a role in consumer behavior in Pakistan, but familial influences on behavior may play a larger role in water-use behaviors (Kumar et al., 2015) as proven by study in Zhangye city of China, which showed citizens influence on water consumption pattern due to their social norms (G. Chang, 2013). Using water-saving appliances is the most efficient method of saving water unconsciously and is easier to achieve than behavioral changes (Dieu-Hang, Grafton, Martínez-Espiñeira, & Garcia-Valiñas, 2017) which is largely dependent on the economic condition of household (Pakula & Stamminger, 2010).

Though dependency on natural gas water heaters cannot be taken away due to it being economical and effective, the centralized system efficiency stands at only 29–56%, which is much lower than that of 78-80% system efficiency of natural gas water heaters, showing that centralized DHW systems are inefficient in comparison, resulting in serious energy wastage (An, Yan, Deng, & Yu, 2016).

6.1 Plumbing system overview

Basic changes required from the results shown are change in type of pipe used, orientation of pipe and behavioral change caused by awareness. Following points elaborate on it.

1. Figure 3 shows that only change in pipe orientation from exposed to hidden could result in nearly 10.86% clean water waste reduction. Even partial change would result in 2.02% reduction of water. Plumbing design should be part of building drawings (keeping in view the orientation of sun to building)
2. When hidden, type of pipe didn't affect the clean water waste values too much, shows barely 1-3% change. But when the pipes were exposed their thermal coefficient values played a major role in determining clean water waste values.
3. When plumbing system was exposed, users with cast iron plumbing system wasted around 7.9 litres of clean water per shower on average compared to the users with PVC pipes wasting around 4 litres of clean water per shower. Type of pipe material plays important role when plumbing system is exposed.

4. Insulation is not really a necessity for this type of environment because of weather and economic conditions, mostly preferred in harsher environments.
5. Figure 6 shows that most users were on board with clean water reuse, the survey swayed the decision of 10% respondents who were satisfied with their plumbing system and switching to efficient system to conserve water.

6.1.1 Rerouting water

Grey-water is mildly used water from users bathroom sinks, showers, tubs and washing machines. It is not the water that has come into contact with any highly contaminated items such as feces from the toilet flush. For residential grey-water systems simple designs are best that use simple, low-tech systems that use gravity whenever possible, instead of pumps. Its usage varies from increasing the productivity of sustainable backyard ecosystems, garage uses, toilet flushing etc. More complex systems are best suited for multi-family, commercial, and industrial scale systems but initial cost increase is to be expected. Most Simpler Grey Water reuse type includes washing machine to directly water the plants, water pumped into the polyethylene water storage with the hose place in the area to be watered. Other simpler ways are to use shower and kitchen drains, there is a probability of clogging but usage of mulch basins greatly reduces the risk in kitchen.

Another simple and flexible grey water system that doesn't alter the existing plumbing system is "laundry-to-landscape" (Ludwig, 2004), where the drain hose is directly attached to a diverter valve which allows switching between sewer/ septic and grey water system. It is a low cost, low maintenance method and in most cases most fundamental place to design grey water system.

Not everyone can use there grey water for outdoor purposes. There are simpler ways to use the grey or clean water indoors like collecting in bucket while warming up the shower. Simple designs such as "sink positive" and complicated ones like Brac/ Greyter system (mostly industrial level) also exists to use the grey or clean water indoors. Sink Positive is a retrofit used on the toilet lid that turns it into a sink, which delivers clean, environmental friendly and touch-free hand wash with every flush (Scelfo, 2009).

6.2 Policy Changes

There are about 80% unmetered water supply connections in mega cites of Pakistan (Bhatti & Nasu, 2010), due to which users do not think much about water waste and there is a lack of awareness. Most users out of those metered watered supply connection avoid paying water bills because it's not enforced. Some studies show the impacts of water billing/ pricing on water consumption, lower water consumption values show higher water prices correlation with in the developed world especially the ones focusing on volumetric readings (Campbell et al., 2004; Dalhuisen, Florax, De Groot, & Nijkamp, 2003; Dandy, Nguyen, & Davies, 1997; Grafton et al., 2011; Hewitt & Hanemann, 1995; Taylor, McKean, & Young, 2004).

Policy changes at government level will be required

1. To enforce proper water metering and billing.
2. Limited/ controlled use of water boring at household level should be enforced with proper checks.

3. Most of the times plumbing designs does not exist in residential building drawings and are left at the discretion of plumber/ contractor, inclusion of plumbing design in building drawings would improve overall water system at homes.

REFERENCES

Agency, E. P. (2018). Indoor Water Use in the United States. Retrieved from https://www.epa.gov/watersense/how-we-use-water

Ahmad, S. (2018). Unleashing the potential of a young Pakistan. Retrieved from http://hdr.undp.org/en/content/unleashing-potential-young-pakistan

Al-Amin, M., Mahmud, K., Hosen, S., & Islam, M. A. (2011). *Domestic water consumption patterns in a village in Bangladesh.* Paper presented at the 4th Annual Paper Meet and 1st Civil Engineering Congress, Dhaka, Bangladesh.

An, J., Yan, D., Deng, G., & Yu, R. (2016). Survey and performance analysis of centralized domestic hot water system in China. *Energy and Buildings*, *133*, 321-334.

Anda, M., le Gay Brereton, F., Brennan, J., & Paskett, E. (2013). Smart metering infrastructure for residential water efficiency: Results of a trial in a behavioural change program in Perth, Western Australia.

Bari, M., Begum, R. A., Nesadurai, N., & Pereira, J. J. (2015). Water consumption patterns in greater Kuala Lumpur: potential for reduction. *Asian Journal of Water, Environment and Pollution, 12*(3), 1-7.

Beal, C. D., Stewart, R. A., & Fielding, K. (2013). A novel mixed method smart metering approach to reconciling differences between perceived and actual residential end use water consumption. *Journal of Cleaner Production, 60,* 116-128.

Bhatti, A. M., & Nasu, S. (2010). Domestic Water Demand Forecasting And Management Under Changing Socio: Economic Senario.

Bloomquist, R. G. (2001). Geothermal district energy system analysis, design, and development. *Text-book of European Summer School on Geothermal Energy Applications*, 213.

Boait, P. J., Dixon, D., Fan, D., & Stafford, A. (2012). Production efficiency of hot water for domestic use. *Energy and Buildings, 54*, 160-168.

Bongaarts, J. (2013). Demographic trends and implications for development. Retrieved from https://iussp.org/en/event/17/programme/paper/6755

Cabral, M., Loureiro, D., Mamade, A., & Covas, D. (2014). Water demand projection in distribution systems using a novel scenario planning approach. *Procedia Engineering, 89*, 950-957.

Cabral, M., Mamade, A., Loureiro, D., Amado, C., & Covas, D. (2016). Modeling the effect of weather conditions on urban water demand in multiple network areas: a practical approach to improve monthly and seasonal operation. *Journal of Water Supply: Research and Technology-Aqua, 65*(8), 612-625.

Campbell, H. E., Johnson, R. M., & Larson, E. H. (2004). Prices, Devices, People, or Rules: The Relative Effectiveness of Policy Instruments in Water Conservation 1. *Review of policy research, 21*(5), 637-662.

Chang, G. (2013). Factors influencing water conservation behavior among urban residents in China's arid areas. *Water Policy, 15*(5), 691-704.

Chang, H., Praskievicz, S., & Parandvash, H. (2014). Sensitivity of urban water consumption to weather and climate variability at multiple temporal scales: The case of Portland, Oregon. *International Journal of Geospatial and Environmental Research, 1*(1), 7.

Corbella, H. M., & i Pujol, D. S. (2009). What lies behind domestic water use?: a review essay on the drivers of domestic water consumption. *Boletín de la Asociación de Geógrafos Españoles*(50), 297-314.

Dalhuisen, J. M., Florax, R. J., De Groot, H. L., & Nijkamp, P. (2003). Price and income elasticities of residential water demand: a meta-analysis. *Land Economics*, *79*(2), 292-308.

Dalin, C., Wada, Y., Kastner, T., & Puma, M. J. (2017). Groundwater depletion embedded in international food trade. *Nature, 543*(7647), 700.

Dandy, G., Nguyen, T., & Davies, C. (1997). Estimating residential water demand in the presence of free allowances. *Land Economics*, 125-139.

Danielewicz, J., Śniechowska, B., Sayegh, M., Fidorów, N., & Jouhara, H. (2016). Three-dimensional numerical model of heat losses from district heating network pre-insulated pipes buried in the ground. *Energy, 108*, 172-184.

Davies, K., Doolan, C., van den Honert, R., & Shi, R. (2014). Water-saving impacts of Smart Meter technology: An empirical 5 year, whole-of-community study in Sydney, Australia. *Water Resources Research, 50*(9), 7348-7358.

de Gois, E. H., Rios, C. A., & Costanzi, R. N. (2015). Evaluation of water conservation and reuse: a case study of a shopping mall in southern Brazil. *Journal of Cleaner Production, 96*, 263-271.

DEFRA. (2008). *Future water: the Government's water strategy for England* GOV.UK Retrieved from https://www.gov.uk/government/publications/future-water-the-governments-water-strategy-for-england

DeOreo, W. B., Mayer, P. W., Dziegielewski, B., & Kiefer, J. (2016). *Residential end uses of water, version 2*: Water Research Foundation.

DeOreo, W. B., Mayer, P. W., Martien, L., Hayden, M., Funk, A., Duffield, M. K., & Davis, R. (2011). *CALIFORNIA SINGLE-FAMILY WATER USE EFFICIENCY STUDY*. Retrieved from http://www.allianceforwaterefficiency.org/WorkArea/DownloadAsset.aspx?id=9001

Deverill, P. (2001). Sharing it out: Introducing water demand management strategies for small towns. In *WELL task* (Vol. 513): LSHTM.

Dieu-Hang, T., Grafton, R. Q., Martínez-Espiñeira, R., & Garcia-Valiñas, M. (2017). Household adoption of energy and water-efficient appliances: An analysis of attitudes, labelling and complementary green behaviours in selected OECD countries. *Journal of environmental management, 197*, 140-150.

Dombaycı, Ö. A., Gölcü, M., & Pancar, Y. (2006). Optimization of insulation thickness for external walls using different energy-sources. *Applied Energy, 83*(9), 921-928.

Domene, E., & Saurí, D. (2006). Urbanisation and water consumption: Influencing factors in the metropolitan region of Barcelona. *Urban Studies, 43*(9), 1605-1623.

Fan, L., Gai, L., Tong, Y., & Li, R. (2017). Urban water consumption and its influencing factors in China: evidence from 286 cities. *Journal of Cleaner Production, 166*, 124-133.

Gerland, P., Raftery, A. E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., . . . Lalic, N. (2014). World population stabilization unlikely this century. *Science, 346*(6206), 234-237.

Ghosh, R., Kansal, A., & Aghi, S. (2016). Implications of end-user behaviour in response to deficiencies in water supply for electricity consumption–A case study of Delhi. *Journal of Hydrology, 536*, 400-408.

Gleick, P. H. (1996). Basic water requirements for human activities: meeting basic needs. *Water international, 21*(2), 83-92.

Gössling, S., Peeters, P., Hall, C. M., Ceron, J.-P., Dubois, G., & Scott, D. (2012). Tourism and water use: Supply, demand, and security. An international review. *Tourism management, 33*(1), 1-15.

Grafton, R. Q., Ward, M. B., To, H., & Kompas, T. (2011). Determinants of residential water consumption: Evidence and analysis from a 10-country household survey. *Water Resources Research, 47*(8).

Gregory, G. D., & Leo, M. D. (2003). Repeated behavior and environmental psychology: the role of personal involvement and habit formation in explaining water consumption 1. *Journal of Applied Social Psychology, 33*(6), 1261-1296.

Guragai, B., Hashimoto, T., Oguma, K., & Takizawa, S. (2018). Data logger-based measurement of household water consumption and micro-component analysis of an intermittent water supply system. *Journal of Cleaner Production, 197*, 1159-1168.

Hashiguchi, N., Ni, F., & Tochihara, Y. (2002). Effects of room temperature on physiological and subjective responses during whole-body bathing, halfbody bathing and showering. *Journal of physiological anthropology and applied human science, 21*(6), 277-283.

Hewitt, J. A., & Hanemann, W. M. (1995). A discrete/continuous choice approach to residential water demand under block rate pricing. *Land Economics*, 173-192.

Hoffmann, M., Worthington, A., & Higgs, H. (2006). Urban water demand with fixed volumetric charging in a large municipality: the case of Brisbane, Australia. *Australian Journal of Agricultural and Resource Economics, 50*(3), 347-359.

Hong, Y. (1991). Experimental study on the usability of residential hot water supply system. Part 2 Showering and bathing. *JSHASE Trans, 45*, 43-59.

Inman, D., & Jeffrey, P. (2006). A review of residential water conservation tool performance and influences on implementation effectiveness. *Urban Water Journal, 3*(3), 127-143.

Institute, P. P. (2014). *R-Value and Thermal Conductivity of PEX and PE-RT* Retrieved from https://plasticpipe.org/pdf/tr48-r-value-thermal-conductivity-pex-pe-rt.pdf

Kamata, M. (1992). Experimental study on the usability of residential hot water supply system. Part 3 Shampoo, water-spreading plates of shower head, physiological responses in using hot water. *JSHASE Trans, 48*, 59-72.

Kay, M., Franks, T., & Smith, L. (1997). *Water: economics, management and demand*: E & FN Spon, Chapman Hall.

Keçebaş, A. (2012). Determination of insulation thickness by means of exergy analysis in pipe insulation. *Energy conversion and management, 58*, 76-83.

Kenny, J. F., Barber, N. L., Hutson, S. S., Linsey, K. S., Lovelace, J. K., & Maupin, M. A. (2009). *Estimated use of water in the United States in 2005* (1411326008). Retrieved from

Keshavarzi, A., Sharifzadeh, M., Haghighi, A. K., Amin, S., Keshtkar, S., & Bamdad, A. (2006). Rural domestic water consumption behavior: A case study in Ramjerd area, Fars province, IR Iran. *Water research, 40*(6), 1173-1178.

Kumar, V., Kumar, A., Ghosh, A. K., Samphel, R., Yadav, R., Yeung, D., & Darmstadt, G. L. (2015). *Enculturating science: community-centric design of behavior change interactions for accelerating health impact.* Paper presented at the Seminars in perinatology.

Laspidou, C. (2014). ICT and stakeholder participation for improved urban water management in the cities of the future. *Water Util. J, 8*, 79-85.

Li, R., Huang, H., Xin, K., & Tao, T. (2015). A review of methods for burst/leakage detection and location in water distribution systems. *Water Science and Technology: Water Supply, 15*(3), 429-441.

Loh, M., & Coghlan, P. (2003). *Domestic water use study in Perth, Western Australia, 1998-2001*: Water Corporation Perth.

Ludwig, A. (2004). Greywater for trees and landscape. *The overstory book: cultivating connections with trees*.

Makki, A. A., Stewart, R. A., Beal, C. D., & Panuwatwanich, K. (2015). Novel bottom-up urban water demand forecasting model: revealing the determinants, drivers and predictors of residential indoor end-use consumption. *Resources, Conservation and Recycling, 95*, 15-37.

Malisova, O., Athanasatou, A., Pepa, A., Husemann, M., Domnik, K., Braun, H., . . . Kapsokefalou, M. (2016). Water intake and hydration indices in healthy European adults: the European Hydration Research Study (EHRS). *nutrients, 8*(4), 204.

Mayer, P., & DeOreo, W. (1999). Residential End Uses of Water, Aquacraft, Inc. *Water Engineering and Management, Boulder, CO*.

Mayer, P. W., DeOreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B., & Nelson, J. O. (1999). Residential end uses of water. In: Amer Water Works Assn.

Mead, N. (2008). Investigation of domestic water end use.

Mini, C., Hogue, T., & Pincetl, S. (2014). Patterns and controlling factors of residential water use in Los Angeles, California. *Water Policy, 16*(6), 1054-1069.

Mini, C., Hogue, T. S., & Pincetl, S. (2015). The effectiveness of water conservation measures on summer residential water use in Los Angeles, California. *Resources, Conservation and Recycling, 94,* 136-145.

Naspolini, H. F., & Rüther, R. (2012). Assessing the technical and economic viability of low-cost domestic solar hot water systems (DSHWS) in low-income residential dwellings in Brazil. *Renewable energy, 48,* 92-99.

Nations, U. (2018, 16 May, 2018). 2018 Revision of World Urbanization Prospects. Retrieved from https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html

Nguyen, K. A., Stewart, R. A., Zhang, H., Sahin, O., & Siriwardene, N. (2018). Re-engineering traditional urban water management practices with smart metering and informatics. *Environmental Modelling & Software, 101*, 256-267.

NOAA. (2018). National Centers for Environmental Information (NCEI). Retrieved from https://www.ncdc.noaa.gov/

Pakistan, U. N. D. (2016). *Water Security: Pakistan's most Critical Development Challenge*. Retrieved from Development Advocate Pakistan:

Pakula, C., & Stamminger, R. (2010). Electricity and water consumption for laundry washing by washing machine worldwide. *Energy Efficiency, 3*(4), 365-382.

Palmer, R., & Hahn, M. (2002). The impacts of climate change on Portland's water supply: An investigation of potential hydrologic and management impacts on the Bull Run system.

Parandvash, G. H., & Chang, H. (2016). Analysis of long-term climate change on per capita water demand in urban versus suburban areas in the Portland metropolitan area, USA. *Journal of Hydrology, 538*, 574-586.

Press, C. B. I. (2010). Annual report on China building energy efficiency.

Puust, R., Kapelan, Z., Savic, D., & Koppel, T. (2010). A review of methods for leakage management in pipe networks. *Urban Water Journal, 7*(1), 25-45.

Quality, P. I. o. (2019). Crisis of Water Quality in Pakistan. Retrieved from http://piqc.edu.pk/crisis-of-water-quality-in-pakistan/

Ramsey, E., Berglund, E., & Goyal, R. (2017). The impact of demographic factors, beliefs, and social influences on residential water consumption and implications for non-price policies in Urban India. *Water, 9*(11), 844.

Rathnayaka, K., Malano, H., Maheepala, S., George, B., Nawarathna, B., Arora, M., & Roberts, P. (2015). Seasonal demand dynamics of residential water end-uses. *Water, 7*(1), 202-216.

Renwick, M. E., & Green, R. D. (2000). Do residential water demand side management policies measure up? An analysis of eight California water agencies. *Journal of environmental economics and management, 40*(1), 37-55.

Roberts, P. (2005). *Yarra Valley Water: 2004 residential end use measurement study*: Yarra Valley Water Melbourne.

Saurí, D. (2013). Water conservation: Theory and evidence in urban areas of the developed world. *Annual Review of Environment and Resources, 38*, 227-248.

Scelfo, J. (2009, MARCH 11, 2009). Five Beginners' Steps to a Greener Home. *New York Times*. Retrieved from https://www.nytimes.com/2009/03/12/garden/12greenhome.html?_r=2&scp=1&sq=sinkpositive&st=cse

Shaban, A., & Sharma, R. (2007). Water consumption patterns in domestic households in major cities. *Economic and Political Weekly*, 2190-2197.

Shove, E., Franceys, R., & Morris, J. (2010). *Behavioural change and water efficiency*. Paper presented at the ESRC (Economic and Social Research Council) Seminar Series-Mapping the Public Landscape, United Kingdom.

Singh, O., & Turkiya, S. (2012). A survey of household domestic water consumption patterns in rural semi-arid village, India. *Springer Netherlands*. doi:https://doi.org/10.1007/s10708-012-9465-7

Singh, O., & Turkiya, S. (2013). A survey of household domestic water consumption patterns in rural semi-arid village, India. *GeoJournal, 78*(5), 777-790.

Slavíková, L., Malý, V., Rost, M., Petružela, L., & Vojáček, O. (2013). Impacts of climate variables on residential water consumption in the Czech Republic. *Water Resources Management, 27*(2), 365-379.

Stewart, R. A., Giurco, D., Panuwatwanich, K., Capati, B., & Willis, R. (2009). Gold Coast domestic water end use study. *Water: Journal of the Australian Water Association, 36*(6), 84.

Survey, U. S. G. (2016, 02 December, 2016). How much water does the average person use at home per day? Retrieved from https://water.usgs.gov/edu/qa-home-percapita.html

Syme, G. J., Shao, Q., Po, M., & Campbell, E. (2004). Predicting and understanding home garden water use. *Landscape and Urban Planning, 68*(1), 121-128.

Tarrant, M. A., & Cordell, H. K. (1997). The effect of respondent characteristics on general environmental attitude-behavior correspondence. *Environment and behavior, 29*(5), 618-637.

Taylor, R. G., McKean, J. R., & Young, R. A. (2004). Alternate price specifications for estimating residential water demand with fixed fees. *Land Economics, 80*(3), 463-475.

Tochihara, Y. (1999). Bathing in Japan: a review. *Journal of the human-environment system, 3*(1), 27-34.

ToolBox, E. (2011). Plastics - Thermal Conductivity Coefficients. Retrieved from https://www.engineeringtoolbox.com/thermal-conductivity-plastics-d_1786.html.

Turner, A., White, S., Beatty, K., & Gregory, A. (2005). Results of the largest residential demand management program in Australia. *Water Science and Technology: Water Supply, 5*(3-4), 249-256.

Vieira, P., Jorge, C., & Covas, D. (2017). Assessment of household water use efficiency using performance indices. *Resources, Conservation and Recycling, 116*, 94-106.

Wilkes, C. R., Mason, A. D., & Hern, S. C. (2005). Probability Distributions for Showering and Bathing Water-Use Behavior for Various US Subpopulations. *Risk Analysis: An International Journal, 25*(2), 317-337.

Willis, R. M., Stewart, R. A., Giurco, D. P., Talebpour, M. R., & Mousavinejad, A. (2013). End use water consumption in households: impact of socio-demographic factors and efficient devices. *Journal of Cleaner Production, 60*, 107-115.

Willis, R. M., Stewart, R. A., Panuwatwanich, K., Jones, S., & Kyriakides, A. (2010). Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. *Resources, Conservation and Recycling, 54*(12), 1117-1127.

Willis, R. M., Stewart, R. A., Panuwatwanich, K., Williams, P. R., & Hollingsworth, A. L. (2011). Quantifying the influence of environmental and water conservation attitudes on household end use water consumption. *Journal of environmental management, 92*(8), 1996-2009.

Young, H. D., & Sears, F. W. (1992). *University physics*.

ANNEXURE

Annexure – A

WATER WASTAGE IN RESIDENTIAL BUILDINGS

THE ROLE OF PLUMBING

Department of Construction Engineering and Management

National University of Sciences and Technology (NUST),

Islamabad, Pakistan

Secondary Questionnaire

Goal of this secondary survey is to select a solution to water wastage based on user's preferences. Indirect goal of this survey is to create awareness and its impacts on user.

Name of respondent:

1. Sex:
   - ☐ Male
   - ☐ Female
2. Age:
   - ☐ 10 – 17
   - ☐ 18 – 29
   - ☐ 30 – 39
   - ☐ 40 – 49
   - ☐ 50 – 59

- ☐ 60 +

3. Income per month in PKR (Household):
   - ☐ 0 – 50,000
   - ☐ 50,001 – 100,000
   - ☐ 100,001 – 200,000
   - ☐ 200,001 – 400,000
   - ☐ 400,001 +
4. Water waster per shower (Main Sampling Data):
5. Number of showers per day in December to March (per week converted to daily)?
   - ☐ 0.15 – 0.29 (1 – 2 per week)
   - ☐ 0.42 – 0.57 (3 – 4 per week)
   - ☐ 0.71 – 0.86 (5 – 6 per week)
   - ☐ 1 – 1.42 (7 – 10 per week)
   - ☐ 1.5 – 2 (11 – 14 per week)
   - ☐ 2 + (more than 14 per week)
6. Have there been any problems or failures of the current plumbing system recently (month)?
   - ☐ Yes
   - ☐ No
7. Are you satisfied with your current plumbing system?
   - ☐ Yes
   - ☐ No
8. Willingness for upgrading current plumbing system with:

- ☐ Pipe type change (CPVC)
- ☐ Re-routing pipes (Grey water usage)
- ☐ Pipe insulation
- ☐ None
