



An investigation of domestic water consumption in Sirte, Libya

Iman Alharsha, Fayyaz A Memon, Raziye Farmani & Wa'El A. Hussien

To cite this article: Iman Alharsha, Fayyaz A Memon, Raziye Farmani & Wa'El A. Hussien (2022) An investigation of domestic water consumption in Sirte, Libya, Urban Water Journal, 19:9, 922-944, DOI: [10.1080/1573062X.2022.2105239](https://doi.org/10.1080/1573062X.2022.2105239)

To link to this article: <https://doi.org/10.1080/1573062X.2022.2105239>



© 2022 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



Published online: 11 Aug 2022.



Submit your article to this journal [↗](#)



Article views: 932



View related articles [↗](#)



View Crossmark data [↗](#)

An investigation of domestic water consumption in Sirte, Libya

Iman Alharsha^a, Fayyaz A Memon^a, Raziye Farmani^a and Wa'El A. Hussien^b

^aCentre for Water Systems, University of Exeter, Exeter, UK; ^bWater Resources Department, University of Duhok, Duhok, Iraq

ABSTRACT

The paper investigates per capita water consumption in Sirte city using a questionnaire survey data. The data captured included frequency, duration, flow rate, time of water use for each water end-use and household characteristics (demographic and socio-economic). The results show that the average daily per capita water consumption is 255 l/p/d. The per capita water consumption decreases with the increase in family size, while household income does not affect water consumption. Handwash basin tap accounts for the highest water consumption. The diurnal water consumption pattern is different from developed countries patterns and has multiple peaks. To predict the city's future water demand, three statistical models based on multiple linear regression technique (STEPWISE) were developed. The comparison of the developed models suggests that the models based on demographic variables can produce acceptable results and any further inclusion of additional variables (physical characteristics of households) do not necessarily improve the prediction accuracy.

ARTICLE HISTORY

Received 24 November 2021
Accepted 19 July 2022

KEYWORDS

Diurnal pattern; household characteristics; per capita water consumption; STEPWISE regression; water end-use

1. Introduction

Water is a key resource for economic development. Sufficient quantities of water is a must for sustaining life, industrial development, agricultural expansion, and environmental protection (Duarte, Pinilla, and Serrano 2013). Water demand in turn increases due to population growth, urbanization, industrialization and improving living standards (Domene and Saurí 2006; Kenney et al. 2008; Lee, Park, and Jeong 2012; Simukonda, Farmani, and Butler 2018). The demand increases rapidly, particularly in developing countries, to the extent that infrastructure is under enormous pressure. Local water supply authorities and water planners face challenges to adequately provide water supply and sanitation services (Abderrahman 2000; Simukonda, Farmani, and Butler 2018). A combination of these factors has contributed to freshwater scarcity issues in both developed and developing countries (Al-Rashed and Sherif 2000; Hussien, Memon, and Savic 2016).

Additionally, limited water resources and climate uncertainties magnify the water scarcity challenge. The water demand-supply deficit is reaching critical levels in many countries. In 2017, 29% of the global population (2.2 billion people) faced water scarcity (World Health Organization WHO, UNICEF 2019). Two-thirds of the world's population would be living in water-stressed countries by 2025 (Arnell 2004). Consequently, improved water resources management approaches are critical.

For domestic water demand management, there is a need for detailed information on water end-use behavior and household water use patterns to ensure efficient water resources management planning. Domestic water demand is a function of several factors such as econometric variables (Bhatti and Nasu 2010), socio-demographic profiles (Duarte, Pinilla, and Serrano 2013), housing characteristics (Syme, ShaoQ, and

Campbell 2004), accessibility to the water source (Davies et al. 2014), household economic class, water quality, climate and hydrological factors (Slavíková et al. 2013). In order to understand domestic water demand, daily water end-uses (bath, shower, toilet flushing, hand wash basin tap, cooking, dishwashing, laundry, house washing, garden watering, yard cleaning, vehicle washing and swimming pool) should be investigated. Understanding water consumption behaviours through water end uses analysis can also help develop targeted water efficiency campaigns, prioritise retrofitting of water-saving devices and influence consumption behaviours (Marinoski et al. 2014).

In developed countries, domestic water demand has been effectively analysed (Loh and Coghlan 2003; Nauges and Whittington 2009; Willis et al. 2013; Beal, Stewart, and Fielding 2013; Davies et al. 2014). In these countries, several studies have analysed end-use water consumption characteristics (Gregory and Leo 2003; Loh and Coghlan 2003; Syme, ShaoQ, and Campbell 2004; Beal, Stewart, and Fielding 2013). The findings from these studies are broadly similar and indicate diurnal water consumption profiles.

Domestic water consumption varies according to the time of the day, day of the week and season of the year. Daily variations in domestic water consumption are represented in the form of diurnal time patterns. These patterns are the main tool for studying and understanding the variations of households water use during the day. Several studies have investigated diurnal time patterns for various end uses such as shower, bath, toilet flushing, dishwashing and laundry. However, all these studies were in developed countries and they provide limited details on end uses such as tap, other domestic and external uses. In addition, some end uses such as vehicle washing, cooking and house floor washing (room, kitchen and

toilets) are not discussed in these studies. Moreover, there is a lack of studies on developing countries, especially in the North African countries. This study not only investigates the missing water end uses but attempts to develop water consumption diurnal profiles segregated at a micro-component level. The information developed via this study can help towards improved water demand management and an evidence-based (data-driven) water supply and wastewater management infrastructure design and operation. The average daily water consumption, peak day and peak hour demand are the major parameters for designing and construction of water delivery infrastructure (Beal and Stewart 2014).

In developing countries, several studies have modelled and estimated domestic water demand using different households socio-economic characteristics. These are the number of women in the household in Ukunda, Kenya (Mu, Whittington, and Briscoe 1990), education level in Faisalabad, Pakistan (Madanat and Humplick 1993), family size in Madagascar, Southern Africa (Larson, Minten, and Razafindralambo 2006) and walking time to water source in Freetown City, Sierra Leone (Ibrahim, Memon, and Butler 2021). Besides evaluating the influence of socio-economic characteristics on per capita consumption patterns in urban areas of Duhok city, Iraq and Freetown City, Sierra Leone, Hussien, Memon, and Savic (2016) and Ibrahim, Memon, and Butler (2021) considered physical household characteristics (e.g. built-up area, garden area, number of rooms, kitchen, toilet and number of floors) to develop effective models for domestic water demand estimation. However, they did not take into account the number of kitchens and toilets in the investigated typical households. The present study also attempts to develop data driven water consumption forecasting models using a holistic approach that includes all the investigated water end uses for a typical city in Libya.

2. Materials and methods

2.1. Study area

Libya is one of the water-stressed countries. It is an arid and dry country with about 94.5% of the country being a desert (PCSC 2003; GMRWUA 2005). The rainy season in the country is very short with a limited amount of rainfall. Around only 5% of the country receives more than 100 mm every year (Abufayed and El-Ghuel 2001; Bindra et al. 2013). The water scarcity problem in Libya was managed by pumping groundwater from the south for agriculture, industry, and domestic uses (Abufayed and El-Ghuel 2001).

The city of Sirte is located in the north of Libya between 31° 12' 32.11" North and 16° 35' 19.18' East (Figure 1). It has a population of around 128,123 inhabitants and an area of 77.66 km² (SMP 2018). The arid climate of the city is affected by the Mediterranean Sea in the north and the desert in the south. The temperature varies during the year. It ranges from 8 to 23°C in winter and from 18 to 31°C in summer. Relative humidity ranges between 65% in March and 78% in July. The annual rainfall in Sirte ranges between 7 and 435 mm/year with an average of 189 mm/year (WWCI 2019).

The water source in the city derives from Man-Made River Project (MMRP). The MMRP was designed and implemented to transfer huge volumes of groundwater from south of Libya to the north through 4 m diameter pipes (Pim and Binsariti 1994; Abderrahman 2000, 2008; Nasar 2015). The water is stored in large reservoirs located in different cities in Libya. Sirte city has two of these reservoirs (Figure 1) (McKenzie, Elsaleh, and PARKMAN 1994). From these reservoirs, the water is supplied to many competing uses. These include agricultural and livestock which use 83% of the water, municipalities that get 14% of the water which they distribute for domestic use and industries that use 3% (GMRWUA 2005). The estimated water consumption for Sirte city from MMRP is 12 million m³/year which is fully supplied by the city municipality (GMRWUA 2006).

2.2. Data collection

In this study, a comprehensive water consumption survey was conducted at the household level. The survey was prepared in both English and Arabic language with 72 multiple choice questions, attached as appendix/supplementary material. The ultimate objective of the survey was to collect data on household characteristics and water end-use parameters. The collected information on household characteristics included the number of people living in a household (children, elders, adult males and females) and their ages, household type, number of rooms, number of kitchens and toilets, number of floors, total built-up area, garden area and total monthly income. Regarding household water consumption, the survey included questions on the frequency, duration of end-use and flow rate of each end-use (i.e. bath, shower, hand wash basin tap, toilet flushing, dishwashing, clothes washing (manually or using the machine), room, kitchen and toilet floor washing, garden watering, vehicle washing and swimming pool. In addition, the time of water use for each activity during the day was also captured.

The survey was distributed for the winter season in December 2017 and February 2018. It was distributed to over 400 local staff and students of the faculties of engineering and medicine in the University of Sirte and 380 replies were received. For the students, the survey was given as coursework. Because of the absence of meters to measure the water flow rate and duration, the students were trained to measure the duration and flow rate of water. This was done using clocks and buckets for collecting water for each end-use. By this approach, the water consumption was calculated for each end-use as a function of frequency, flow rate and duration of running water.

To make sure all students made accurate measurements, the method was tested by some members of staff from the faculties who had meetings where they explained how the measurements should be done as directed by the first author. Then, the method was separately tested by the first author and 10 purposively selected educated people from the community. The results from this test were compared with those from the members of staff. From the comparison of results and discussions with the members of staff, the first author decided on the acceptable ranges for flow rate and duration of all water end uses. The ranges were used to check and control students'



Figure 1. Sirte city location in Libya, MMRP distribution system (GMRWUA 2005) and the distribution of surveyed households in the city.

answers thereby providing reasonably reliable data. The values that were outside the acceptable ranges were rejected. With regards to diurnal water end-uses patterns, every participant recorded the time when using water for all end uses. The

collected data were analysed using IBM SPSS Statistics Version 25 package. The analysis included calculations of statistical parameters (i.e. average, minimum, maximum and distribution shape identification through kurtosis and skewness) for the

characteristics of the 380 households. The analysis also determined the correlation coefficient which is a statistical parameter that shows whether and how strongly pairs of variables are related. The correlation coefficient was calculated for the relationship between household water consumption (l/hh/d) and household characteristics.

2.3. Development of statistical models

The data collected from 380 households were divided into 70% as calibration set (i.e. training) while the remaining 30% was spared for validation (i.e. testing) purposes. In particular, the calibration data set was used to develop statistical models to predict household water consumption as a function of demographic and physical characteristics. The household demographic characteristics were family size, number of children, elders, adult males and females. Physical characteristics were total household built-up area, garden area, number of rooms, number of kitchens, number of toilets, number of floors and household income. The validation set was then used towards evaluating the performance of the model after it learnt from the calibration set.

Three regression models were developed using the multiple linear regression (STEPWISE) technique implemented in IBM SPSS Statistics (v. 25) software. The STEPWISE technique has been used widely to predict water demand (Cevik 2007; Hussien, Memon, and Savic 2016; Yasar, Bilgili, and Simsek 2012; Ibrahim, Memon, and Butler 2021). The best subset model was used for daily household water consumption estimation.

3. Results and discussion

3.1. Household characteristics

The collected data of surveyed households in Sirte City were analysed. The statistical parameters of household characteristics are shown in Table B1 (Appendix B). The analysis shows that the average number of people in a household is 6.58 (Figure 2(a)) which is approximately equivalent to the average standard family size (7.04) in Duhok city, Iraq (Hussien, Memon, and Savic 2016). The average number of children, adult males females and elders is 1.86, 2.10 2.32 and 0.33 respectively (Table B1, Appendix B). These numbers are broadly comparable with earlier study (Hussien, Memon, and Savic 2016) for the developing countries context similar to Libya. Table B1 (Appendix B) shows that 77% of families live in houses and 23% in apartments. Out of 380 households, 305 were single-storey, 69 were double-storey and only 6 were triple-storey. The average number of rooms in a household was 6. The average number of kitchens in each apartment was 1.6 Table B1 (Appendix B). However, it varied from 1 to 5 kitchens in a house depending on the number of people living in a house, the number of floors and the house size. The number of toilets in an apartment is 1 to 2 toilets, while, in a house, it ranged between 1 and 6 depending on the size of the house and the number of floors.

The socio-economic characteristics of the households show that the total built-up area for a house or apartment in the investigated area ranges between 100 and 650 m² with about 31.45 m² as a garden area. The average monthly household income is £1335.493.¹ Figure 2 shows the frequency distribution of household characteristics.

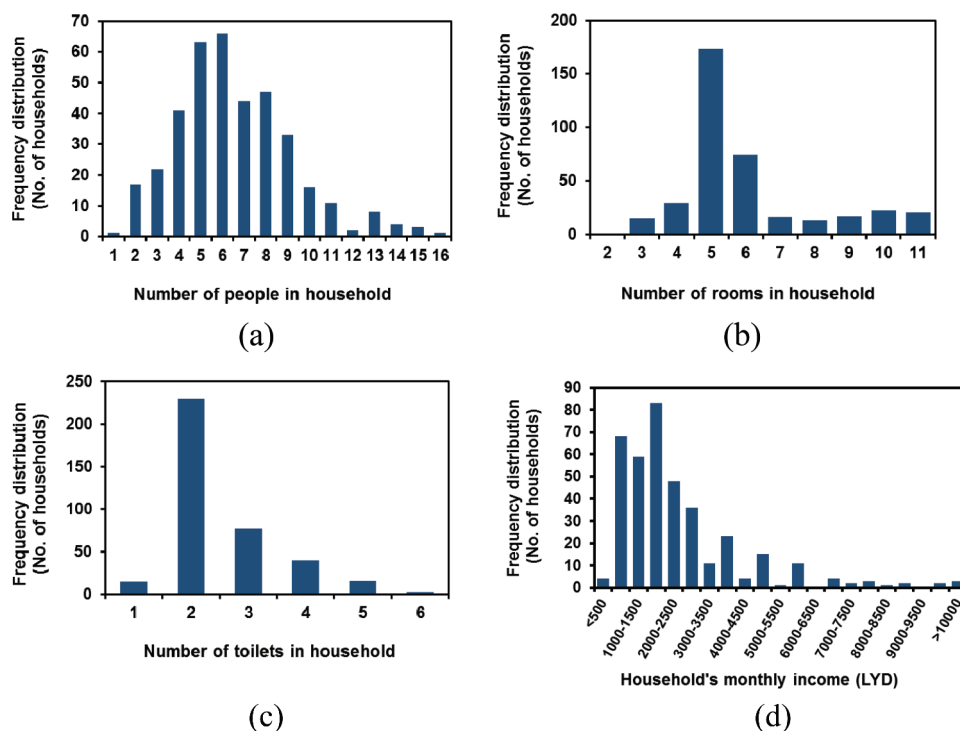


Figure 2. Frequency distribution of household characteristics.

3.2. Average per capita end-use water consumption

The analysis of surveyed data shows that the average per capita water consumption in Sirte is 255 l/p/d in the winter season. This is considerably higher than many of the developed countries (e.g. 138 l/p/d in Portugal (Jorge et al. 2015), 128 l/p/d in the UK, 143 l/p/d in the USA and 138 l/p/d in Korea (Lee, Park, and Jeong 2012) and 128 l/p/d in Australia for summer (Athuraliya, Roberts, and Brown 2012)). There seems to be considerable scope for implementing water demand management measures. The per capita water consumption was divided into end-uses which are bath, shower, hand wash basin use, toilet flushing, dishwashing, laundry, house washing, garden watering, cooking, vehicle washing and swimming pool. The daily per capita water use for all activities is a function of the frequency, the duration and the flow rate from the respective water using appliance/fitting.

Figure 3 shows the percentage and average per capita consumption for each water end-use. The figure shows that the largest consumption is attributed to hand wash basin tap use (34%), followed by toilet flushing (20%). Water consumption from taps use is much higher than reported for the developed world, (e.g. 15.7% in the USA (Mayer et al. 1999) and 16% in Australia (Athuraliya, Roberts, and Brown 2012; Beal and Stewart 2014)). High tap water use in Libya can be attributed to water consumption for ablution, a mandatory requirement before five daily prayers. The percentage of per capita water consumption for bathing and cooking are the lowest (5%). For outdoor use (watering garden and vehicle washing), per capita water consumption is less than 1%. The results suggest that in Libyan

gardening watering in winter is not frequent. Vehicle washing at home is not frequent because households tend to wash their vehicle at the services.

3.3. Impact of household characteristics on the daily average water consumption per household (l/hh/day)

The analysis of the surveyed households shows a strong positive correlation coefficient ($R^2 = 0.89$) between household water consumption and household occupancy (i.e. the number of people in the household) (Figure 4(a)). On the contrary per capita consumption tend to decrease with increased household occupancy.

It can be observed from the data that the household water consumption also increases with the increase in total household built-up area ($R^2 = 0.48$) and the number of rooms ($R^2 = 0.88$) (Figure 4(b and c)). This finding is in agreement with other studies for developing (Hussien, Memon, and Savic 2016) and developed (Cavanagh, Hanemann, and Stavins 2002) countries. For Sirte city, the garden area has no relationship ($R^2 = 0.0001$) with water consumption because many people in the city do not water their gardens. However, Hussien, Memon, and Savic (2016) found a strong relationship ($R^2 = 0.59$) between garden watering and garden area for an Iraqi city.

Moreover, the total household water consumption increases with the increase in the number of children, adult males and females, elders, number of kitchens and toilets with a very positive strong correlation coefficient ($R^2 = 0.85, 0.86, 0.69, 0.92, 0.59, 0.90$ and 0.88 , respectively). However, there is no correlation ($R^2 = 0.01$) between water

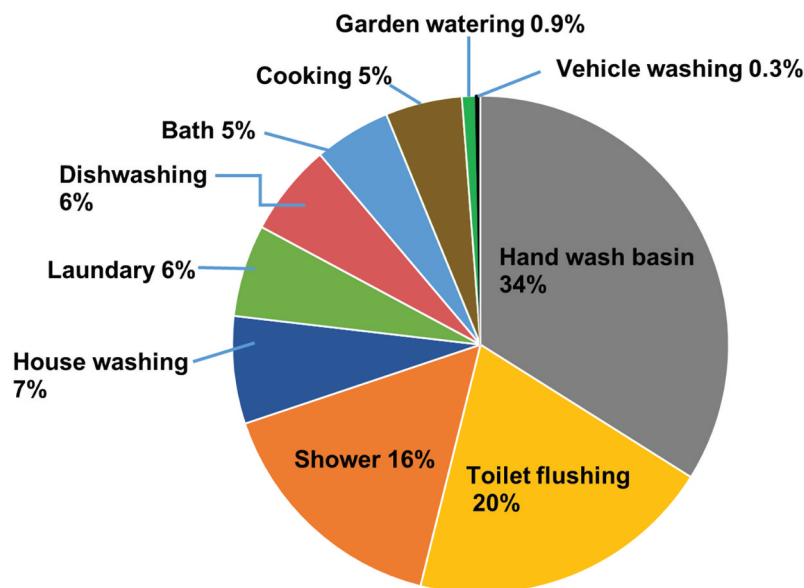


Figure 3. Characteristics of end-use water consumption.

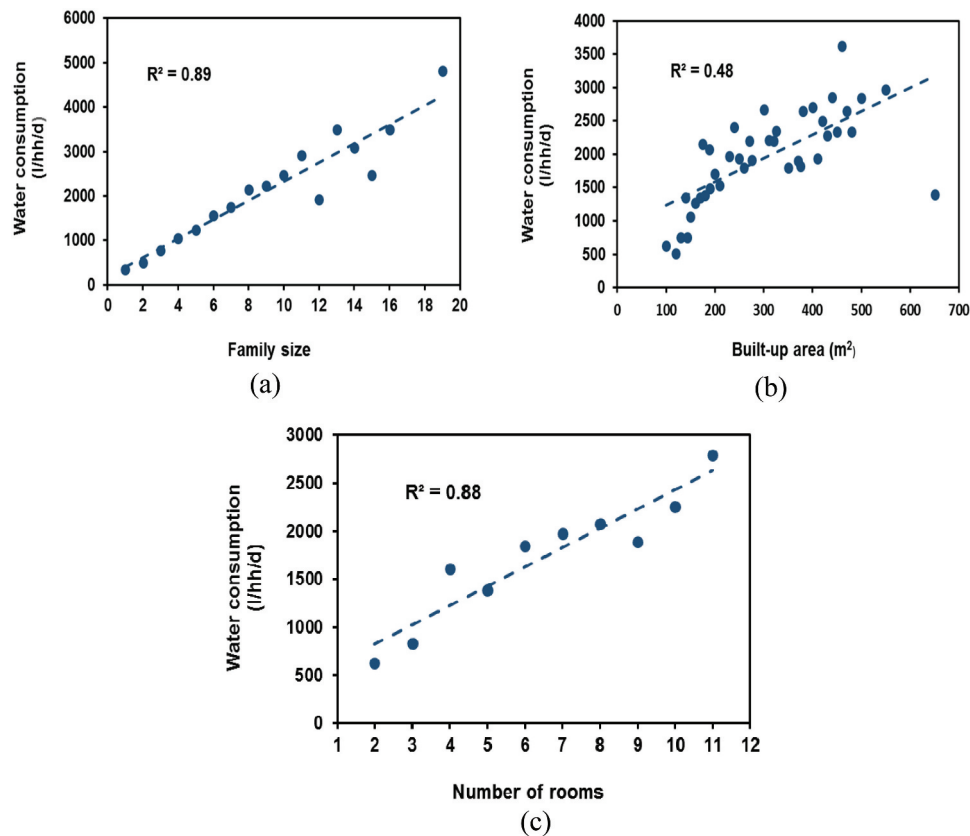


Figure 4. Relationship between household water consumption (l/hh/d) and household characteristics.

consumption and family income. This means that the total household income does not seem to affect water consumption because water is free.

3.4. The Influence of household characteristics on the average per capita water consumption per day (l/p/d)

The analysis found that the average daily per capita water consumption is 255 l/p/d. Apartments consume slightly less (251 l/p/d) because for apartments garden-watering end-use does not exist. Figure 5 shows the distribution of daily per capita water

consumption. Approximately 3% of surveyed households consume water more than 450 l/p/d. In terms of gender, the average water consumption for females (260 l/p/d) is higher than that for males (247 l/p/d), because they stay most of the time at home and take care of the family. Further analysis shows that the increase in the number of children and elders (i.e. > 65 years), reduces average per capita water consumption with $R^2 = 0.71$ and 0.70 respectively.

In agreement with Edwards and Martin (1995) and Hussien, Memon, and Savic (2016), the analysis shows that daily per capita consumption increases with the increase in the total built-up area of the household. Daily per capita water consumption also increases with the increase in the number of floors in a household ($R^2 = 0.79$). The number of toilets in a household, in general, shows increases in the daily average per capita water consumption ($R^2 = 0.56$).

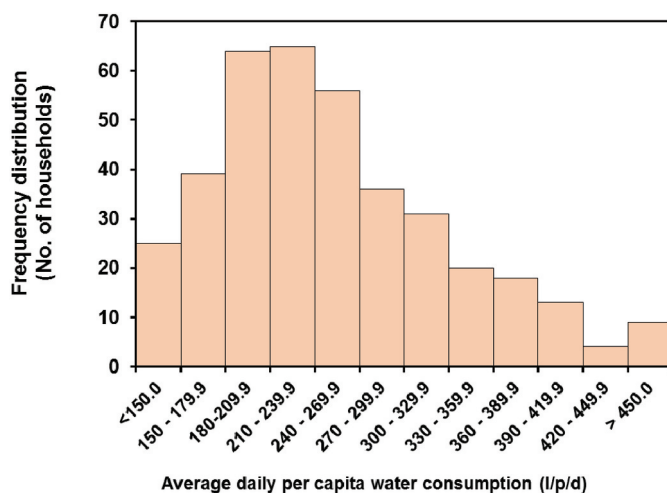


Figure 5. Frequency distribution of average per capita water consumption (l/p/d).

3.5. Water user behavior

3.5.1 Diurnal patterns

The survey data was used to extract water consumption variations over 24 hours for each water end-use per capita and household. The developed plots can help to identify the peak time(s) where a particular end-use typically occurs and its associated water consumption. Figure 6 shows that using water for toilet flushing, hand washing basin and shower starts in the morning and reaches the peak between 7 am and 9 am depending on the time when members of the household get up and prepare to go to work or school. Then, water use decreases sharply and starts to increase again after the people return to their homes.

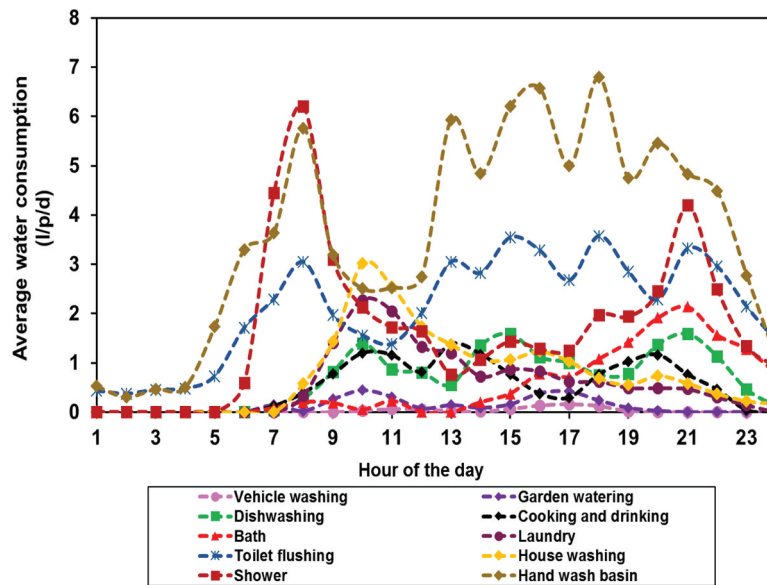


Figure 6. Time pattern for water usage for each end-use per capita per day.

The remaining water end-uses start later in the morning from 9 am. In the case of bathing, normally water use is low during day time but increases at night time when the people are back home after work and have a bath to relax. Generally, water comparison for indoor end-uses (bath, shower, toilet use, cooking, house washing, hand wash basin, dishwashing and laundry) is higher than outdoor end-use (garden watering and vehicle washing). The outdoor water consumption is very small because households prefer washing vehicles at washing services and they do not water gardens frequently. The diurnal water consumption profile in this study (Figure 6) has multiple peaks which are significantly different from typical profiles reported for the developed countries (Table 1). This difference can be attributed to several factors including cultural difference, male to female employment ratio, climate and affluence.

3.5.2. Water end-uses

The water usage behavior was investigated through the detailed analysis of frequency, duration (minute) and flow rate (liter per minute) for each end-use. The results are summarised below in Tables 2 and B2 (Appendix B).

3.5.2.1. Bath. Although bathtub is available in most surveyed households, bathing is not a common practice in Sirte but bathtubs are usually used for showering. Of the 380 households, only 129 use bathtubs for bathing. The average per capita water consumption for bathing is 13 l/p/d (Table 2). The average frequency and volume of water used for bathing are shown in Table B2 (Appendix B). The surveyed households tend to have 1 to 4 baths per week. The analysis of the time pattern for bathing shows that most of the people in the study area prefer bathing in the evening (Figure 6). This is expected and suggests bathing activity only takes place for relaxing purposes. Based on the limited use of baths as discovered in this study, any further investigations focusing on baths are unlikely to reveal any significant insights for the quantification of per capita consumption in the study area.

3.5.2.2. Shower. The results show that showering is the third largest user for water in the surveyed households. The daily average per capita water consumption for showering is 41 l/p/d (Table 2). The average daily frequency, duration and flow rate for showering are presented in Table B2 (Appendix B) which

Table 1. Summary of the diurnal water demand patterns in developed countries.

End-use	Number of peaks	Country	Reference	Comments
Irrigation, toilets, showers, clothes washers, faucets, dishwashers, baths and other domestic	2	12 North American locations	Mayer et al. 1999	The first peak in the morning at 9 am for indoor uses. However, outdoor use achieved a secondary peak in the early evening from 6 pm to 9 pm.
Washing machine, shower, bath, wash basin, kitchen sink and toilet	3	England	Butler and John 2004	The first and highest peak was in the morning between 9 and 10 am. The second was between 6 and 7 pm, while the third and not very pronounced peak occurred between 9 and 10 pm.
Irrigation, cooler, dishwasher, laundry, tap, toilet, shower and bath	2	Yarra Valley Water, Melbourne, Australia	Athuraliya, Roberts, and Brown 2012	The first peak was in the morning from 9 to 10 am and the second was in the evening from 7 to 9 pm.
Shower, laundry, tap, toilet and external	2	South East Queensland, Australia	Beal and Stewart 2014	The first peak in the morning and the second in the evening.

Table 2. Summary of average water end-uses for the surveyed household.

Water end-use	Average water consumption (l/p/d)
Bath	13.00
Showering	41.00
Toilet flushing	50.71
Hand wash basin taps	85.70
Cooking and Drinking	12.70
Dishwashing manually	15.00
Dishwashing using machine	0.71
Laundry manually	0.84
Laundry using machine	13.40
Toilets washing	13.00
Kitchens washing	1.60
Rooms washing	3.80
Vehicle washing	0.74
Garden washing	2.40
Total water consumption	255

shows that households take a lot of time showering, but the flow rate is less when compared with other research findings (Table 3). This is because most of the households seem to use showerheads with a low flow rate and power showerheads are not common, an emerging concern mainly in the developed world. The water use hourly peak for showering in the study area is 6 l/p/d at 8 am before people go to work or school. Water use for the shower is low during day times, but it is high again in the night before going to bed as presented in Figure 6.

3.5.2.3. Hand wash basin (taps). The average daily per capita water consumption for hand wash basin tap is 86 l/p/d which is the highest compared to other water end-uses (Table 2). The average usage frequency for handwash basin tap is approximately 6.87 times per day. This could be for ablution before prayers and after the use of the toilet. The average duration and flow rate of tap usage is shown in Table B2 (Appendix B). Figure 6 shows that the first peak of using hand wash basin tap is in the morning from 7 to 8 am. This is before people go to work. The other peaks are in the afternoon and evening. These peaks appear a result of the presence of all the people at home after work and school and maybe indicating water use for ablution before prayers.

3.5.2.4. Toilet use. Average daily per capita water consumption for toilet flushing is a function of the volume of water used per flushing and the frequency of toilet use. Toilet flushing is the second highest water end-use (50.71 l/p/d) in the study area (Table 2). Table B2 (Appendix B) presents the frequency and volume of water used per toilet flushing which depends on the type of the flushing toilet (i.e. cistern volume). Figure 6 shows that the average flush volume from 7 am to 9 am is around 3 l/p/d. Then, the volume of water usage decreases until 13:00 hours when people are out of their households either at work or at school. After 13:00 hours, the toilet usage starts increasing. Further investigations indicated the toilet use during off-peak hours correlates well with the number of female and elderly family members at home.

3.5.2.5. Dishwashing. The survey investigated whether the households use a dishwasher, manual wash, or both. Out of the 380 households, 315 wash dishes manually, 36 use machines

and 29 do both. The dishwasher ownership was found to be low and is broadly consistent with global trends including the developed world. The total average daily water consumption for dishwashing is 15.71 l/p/d (Table 2).

3.5.2.5.1. Dishwashing Manually. The average daily per capita water consumption for manual dishwashing is 14.97 l/p/d (Table 2). The average frequency, duration and flow rate for dishwashing are presented in Table B2 (Appendix B). The time pattern analysis for manual dishwashing shows that there are 3 peaks at 10 am for breakfast, at 15:00 hours for lunch and at 21:00 hours for dinner Figure 7(a). Further analysis of the manual dishwashing activities indicated that the associated water use pattern of three distinct peaks is consistent for households with a higher proportion of female members and children, eating at home mainly instead frequent out of home meals.

3.5.2.5.2. Dishwashing Machine. The average daily per capita water consumption for dishwashing by machine is 0.71 l/p/d (Table 2). This is a function of frequency and the rate of water use by the dishwashing machine. The average frequency and rate of water usage are shown in Table B2 (Appendix B).

For hourly use of dishwashing, Figure 7(b) shows that dishwashers are mainly used at night time between 20:00 and 21:00 hours. The temporal profile shows three distinct peaks correlating well with dishwashing after each of the three daily meals. A comparison of results indicates that water consumption for manual dishwashing is much higher than that for dishwashing with machines. With the deployment of more water-efficient machines, consumption can be reduced further. However, changing established practices embedded in cultural norms, space constraints in existing kitchens, uneasy access to dishwashers and lack of their wider availability in Sirte city are some of the key challenges that need addressing.

3.5.2.6. Laundry. This study investigated whether the households do their laundry manually, use a washing machine or both. Of the 380 households, 317 use washing machine only for laundry times and 63 wash their clothes both manually and by washing machines. The total average water consumption for laundry is 14.24 l/p/d (Table 2).

3.5.2.6.1. Manual laundry. The average daily water consumption is 0.84 l/p/d with average frequency, duration and flow rate as shown in Tables 2 and B2 (Appendix B) respectively. Figure 8(a) shows the hourly usage of water for laundry and suggests that households start to do their laundry in the morning between 9 am and 11 am depending on the availability of housewives or holidays.

3.5.2.6.2. Laundry by machine. The average water consumption for laundry by machine was computed as a function of the volume of water usage per washing cycle and the washing machine use frequency. From Table 2, the average daily water consumption is 13.4 l/p/d. The small volume of water consumed in this end-use is because people in the study area especially males prefer to wash and iron their clothes at paid external washing services. The average frequency of washing machine use and the volume of water used is shown in Table B2 (Appendix B). The analysis shows that the surveyed households do their laundry from 1 to more than 10 times a week, depending on the family size.

Table 3. Comparison of mean values of water end-use parameters with other studies.

End-use	Parameter	Unit	Mean	Comparison with past studies
Bath	Frequency of bath per capita per day	bath/p/d	0.08	0.044 (Blokker, Vreeburg, and Van Dijk 2010)0.004 (Hussien, Memon, and Savic 2016)
	Volume of water use in each bath	l/bath	169.0	100 (Estrela et al. 2001)132.00 (Hussien, Memon, and Savic 2016)20.70 (Ibrahim, Memon, and Butler 2021)
Shower	Frequency of showering per capita per day	shw/p/d	0.66	0.73 (Athuraliya, Roberts, and Brown 2012) 0.49 (Hussien, Memon, and Savic 2016) 0.52 (Ibrahim, Memon, and Butler 2021)
	Duration of each shower	min/shw	16.61	8.64 (Hussien, Memon, and Savic 2016) 3.28 (Ibrahim, Memon, and Butler 2021)
	Flow rate	l/min	4.36	9.02 (Hussien, Memon, and Savic 2016) 6.93 (Ibrahim, Memon, and Butler 2021)
Hand wash basin taps	Frequency of using taps per capita per day	tpu/p/d	6.87	10.46 (Hussien, Memon, and Savic 2016) 3.07 (Ibrahim, Memon, and Butler 2021)
	Duration of tap use	min/tpu	5.00	6.66–8.33 ((Roberts 2005) 2.73 (Gato 2006) 1.81(Hussien, Memon, and Savic 2016) 1.00 (Ibrahim, Memon, and Butler 2021)
	Flow rate	l/min	2.49	8.14 (Hussien, Memon, and Savic 2016) 2.65 (Ibrahim, Memon, and Butler 2021)
Toilet flushing	Frequency of toilet use per capita per day	fl/p/d	6.19	4.20 (Roberts 2005) 4.65 (Hussien, Memon, and Savic 2016) 3.05 (Ibrahim, Memon, and Butler 2021)
	Water use in each flush	l/fl	8.07	9.5 (OFWAT 1997) 5.51(Hussien, Memon, and Savic 2016)
Cooking	Frequency of running water for cooking	cok/d	2.97	-
	Volume of water per each cooking	l/cook/p	4.23	13.66 (Hussien, Memon, and Savic 2016) 12.11(Ibrahim, Memon, and Butler 2021)
Dishwashing manually	Frequency of washing dishes per day	wsh/ d	3.10	-
	Duration of running water in each wash	min/wsh	8.14	-
	Flow rate	l/min	2.88	-
Dishwashing machine	Frequency of washing dishes by machine per day	wsh/d	0.24	-
	Volume of water per washing load	l/wsl	14.98	-
Laundry manually	Frequency of laundry manually per day	wsh/d	0.06	0.26 (Ibrahim, Memon, and Butler 2021)
	Duration of each wash	min/wsh	3.02	-
	Flow rate	l/min	0.82	-
Laundry machine	Frequency of laundry per day	wsh/d	0.79	16.50 (Ibrahim, Memon, and Butler 2021)
	Volume of water per washing load	l/wsh	72.11	80 (Estrela et al. 2001) 167.32 (Hussien, Memon, and Savic 2016)
Kitchens washing	Frequency of kitchens washing per day	wsh/d	0.24	-
	Duration of each wash	min/p/d	10.00	-
	Flow rate	l/min	2.43	-
Rooms washing	Frequency of rooms washing per day	wsh/d	0.17	-
	Duration of each wash	min/p/wsh	11.10	-
	Flow rate	l/min	1.54	-
Toilets washing	Frequency of toilets washing per day	wsh/d	1.83	-
	Duration of each wash	min/p/wsh	5.58	-
	Flow rate	l/min	3.13	-
Vehicle washing	Frequency of vehicles washing per day	wsh/d	0.04	0.07 (Hussien, Memon, and Savic 2016)
	Duration of each wash	min/wsh	5.74	1.39 (Hussien, Memon, and Savic 2016)
	Flow rate	l/min	1.16	10.2 (Marinoski et al. 2014) 12.82 (Hussien, Memon, and Savic 2016)
Swimming pool	Frequency of filling swimming pool per day	No./d	0.00	0.001(Hussien, Memon, and Savic 2016)
	Volume of water provided to fill the swimming pool	m ³	0.00	36.00 (Hussien, Memon, and Savic 2016)
Garden watering	Frequency of garden watering per day	wtr/d	0.14	0.40 (Roberts 2005) 0.13 (Hussien, Memon, and Savic 2016)
	Duration of each watering	min/wtr	10.99	13.01(Hussien, Memon, and Savic 2016)
	Flow rate	l/min	1.91	11.67 (Hussien, Memon, and Savic 2016)

Note: L = liter, p = person, d = day, min = minute, shw = shower, tpu = tap use, fl = flushes, wsh = washes, wsl = washing load, wtr = watering, cok = cooking

Figure 8(b) shows the hourly use of water for this end-use. It shows that laundry is mostly done in the morning time between 9 am and 11 am.

3.5.2.7. House washing. About 7% of the total water consumption is used for house washing (Figure 3). The total average daily water consumption for house washing is 18.3 l/p/d (Table 2). House washing activities include washing of room,

toilets and kitchens floors. Households in Sirte city, tend to wash the floor of their toilets every day depending on the number of people occupying the house. However, kitchen washing is not as regular as toilets because people cover the kitchen floor with carpet which is the same for rooms. For this reason, the households were asked questions for each part (toilets, kitchens, and rooms) separately in terms of the frequency, duration, flow rate and the time that they use water

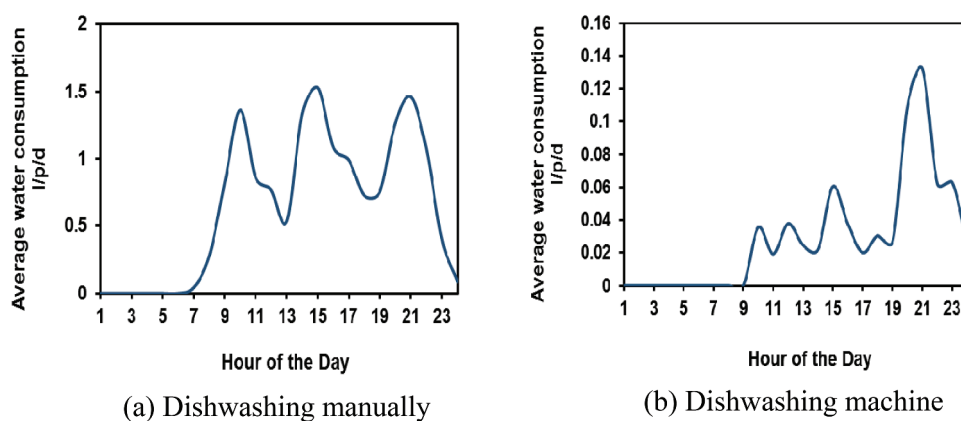


Figure 7. Time pattern for water usage for dishwashing per capita per day.

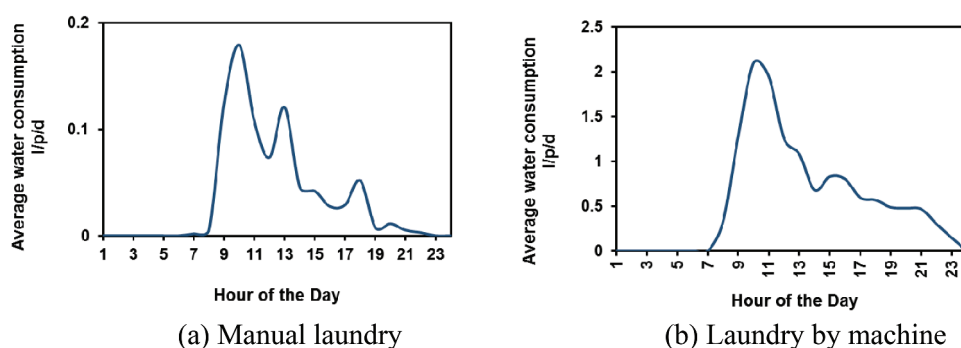


Figure 8. Time pattern for water usage for laundry per capita per day.

for each end-use for house washing (Table B2, Appendix B). The total time pattern for house washing is shown in Figure 6 which shows that the majority of households (housewives) prefer to wash their houses from 9 am to 11 am with the peak at 10 am.

3.5.2.7.1. Toilet washing. The average daily water consumption for toilet washing is 12.94 l/p/d with an average frequency of 1.83 per day (Tables 2 and B2, Appendix B). Depending on the number of toilets in the house, households tend to wash toilet floors every day between 1 to 4 times a day depending on the number of people who occupy the house and their availability.

The frequency, duration and flow rate are shown in Table B2 (Appendix B). Most households use water for toilet washing and cleansing between 9 am and 11 am which results in the highest peaks of 2.1 l/p/d at 10 am as shown in Figure 9(a).

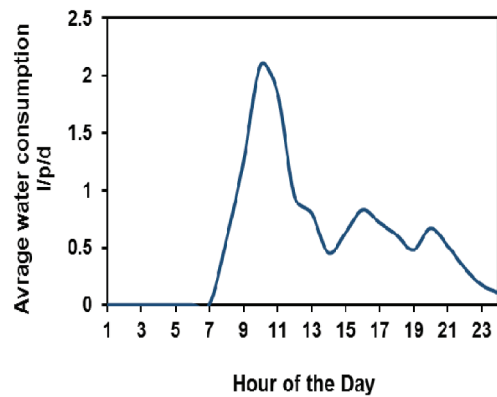
3.5.2.7.2. Kitchen washing. The average daily water use for kitchen washing is 1.60 l/p/d (Table 2) The average frequency, duration and flow rate of water usage are shown in Table B2 (Appendix B). Households tend to wash kitchen floors between 1 to 4 times per week. Around 3.2% of the households do not wash kitchen floors during the week because the floor is covered to keep the kitchen warm. The duration of using the tap for washing kitchens varies depending on the size and number of kitchens in the house and the attitude of households in terms of water usage. Most of the households tend to wash the floors of their kitchens after finishing dishwashing after lunch time around 15:00 hours Figure 9(b).

3.5.2.7.3. Rooms washing. The average household water consumption for washing rooms is 3.81 l/p/d (Table 2) and the average frequency, duration and flow rate are shown in Table B2 (Appendix B). The duration of water usage for washing rooms depends on the number and the size of rooms in the house and also the attitude of the households on water consumption. The 24 hours time pattern for water usage for washing rooms Figure 9(c) shows that households start using water for washing between 10 am and 12 noon.

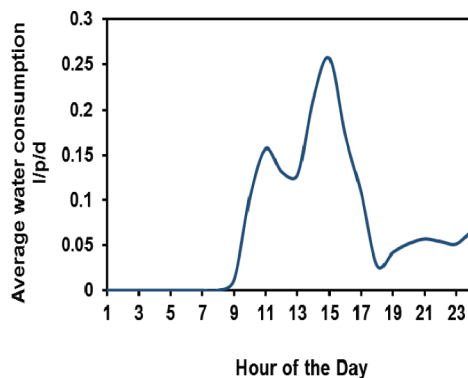
3.5.2.8. Cooking. The volume of water used for cooking includes water for preparing food (washing vegetables, meat, and fruits) and water used for drinking or preparing coffee, tea or juice. The average water consumption is 12.7 l/p/d (Table 2). The average frequency and volume of water required for cooking are shown in Table B2 (Appendix B). The analysis shows that the whole family consumed water for cooking less than 10 l/hh to more than 40 l/hh depending on the family size and family members' availability in the household.

Figure 6 shows the hourly usage of water for food preparation and indicates that there are 3 peaks in the pattern, between 9 am and 11 am, 13:00 and 14:00 hours and 19:00 and 20:00 hours corresponding to breakfast, lunch and dinner times respectively.

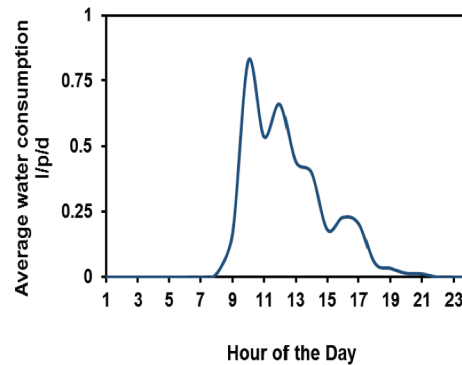
3.5.2.9. Garden watering. The average water consumption for garden watering is 2.4 l/p/d as shown in Table 2. The average frequency, duration and flow rate per day are shown



(a) Water consumption for toilet washing



(b) Water consumption for kitchen washing



(c) water consumption for rooms washing

Figure 9. Time pattern for water usage for house washing per capita per day.

in Table B2 (Appendix B). The results show that about 217 (57%) of the households do not water gardens. Some of these have gardens while others do not have. About 18% of the households water their gardens twice per week. 33% of the households take between 20 and 30 minutes to water their gardens and 22% water their gardens for 10 to 20 minutes. Watering gardens is in the morning from 9 am to 11 am and in the afternoon between 16:00 and 18:00 hours (Figure 6).

3.5.2. 10. Vehicle washing. Water usage for vehicle washing is the lowest (0.74 l/p/d) compared to other end-uses as shown in Table 2. This is because households 276 (73%) in Sirte city prefer washing their vehicles at car wash service stations. The average frequency, duration of water use and flow rate for vehicle washing is shown in Table B2 (Appendix B). For households that wash their vehicles at home Figure 6, they mostly wash their vehicles at home in the afternoon from 16:00 to 18:00 hours The morning peak (between 10 am and 12 pm) is at the weekend and holidays.

The comparison of frequency, duration and flow rates for all end uses discussed in this study with past studies are summarised in Table 3. The table suggests there is a considerable variation in the magnitude of water used for different end uses. This is not surprising, since the reported studies represent different countries, contexts and cultural shades and to some extent predominant climatic and socio-economic conditions

including demographic compositions. Consequently, although households in Sirte use devices with very low flow rates for all end uses, water consumption is high because of the long duration and high frequency of water use. These may be related to households habits, lack of knowledge to use water efficiently or because the water is free.

3.7 Performance of the statistical models

Using the calibration data set, the relationship between the household characteristics (independent variables) and households water consumption (dependent variable) is investigated and the values of the correlation coefficient (R) are obtained (Table 4). From the table, it can be seen that the strongest relationship of household consumption is with the family size followed by the number of adult females and the number of adult males in the house.

Three different models for calculating household water consumption were developed using demographic (Model 1), physical (Model 2) and combined demographic and physical characteristics (Model 3) as shown in Table 5. These models were statistically significant (at $p < 0.05$). The performance of these models was evaluated by plotting the collected household water consumption data against the predicted values by the three models. The investigated households based on demographic characteristics, physical characteristics and both

Table 4. Correlation coefficients between household characteristics and household water consumption.

Household water consumption (l/hh/d)*	Correlations of demographic characteristics						
	Family size	No. of children	No. of adult males	No. of adult females	No. of elders		
	0.730	0.157	0.460	0.542	0.192		
	Correlations of physical characteristics						
	No. of rooms	No. of kitchens	No. of toilets	No. of floors	Total built-up area	Garden area	Income
	0.363	0.266	0.421	0.242	0.388	0.138	0.177

Table 5. Models and coefficients of determination (R^2) using multiple linear regression method (STEPWISE).

Model	R^2	
	Training set.	Testing set.
Model 1: based on demographic characteristics of the household $TW_w = 67.920 + 241.997 \times F_s$ (1)	0.53	0.60
Model 2: based on physical characteristics of the household $TW_w = 629.242 + 404.759 \times N_T$ (2)	0.18	0.21
Model 3: based on (demographic and physical characteristics) of the household $TW_w = -19.111 + 233.142 \times F_s + 275.486 \times N_T - 93.968 \times N_R$ (3)	0.56	0.60

*Where: TW_w = daily household water consumption (l/hh/d), F_s = family size, N_T = number of toilets in a household, N_R = number of rooms in a household.

for the three models. However, Model 3 was found to have the highest R^2 values indicating the improvement in the model performance when both demographic and physical characteristics were incorporated.

The three models developed in STEPWISE were compared using R^2 values (Table 6). The R^2 values suggest that the demographic characteristics have a relatively strong influence on household water consumption and improve the accuracy of the model and eliminating household physical characteristics are unlikely to influence the model predictions radically. This is an important inference suggesting that any future studies may mainly focus on investigating user behaviour and associated influencing factors and the role of physical household characteristics is broadly insignificant.

The study also investigated the sensitivity of the developed models. All input parameters were tested using three values (i.e. average, average + standard deviation and average - standard deviation). The average and standard deviation statistics (Table B2, appendix B) were used to calculate

demographic and physical characteristics are presented in Figure 10(a–c), respectively. Figure 10 shows that the trend lines of the household water consumptions obtained from the calibration data are almost identical to those of the testing data

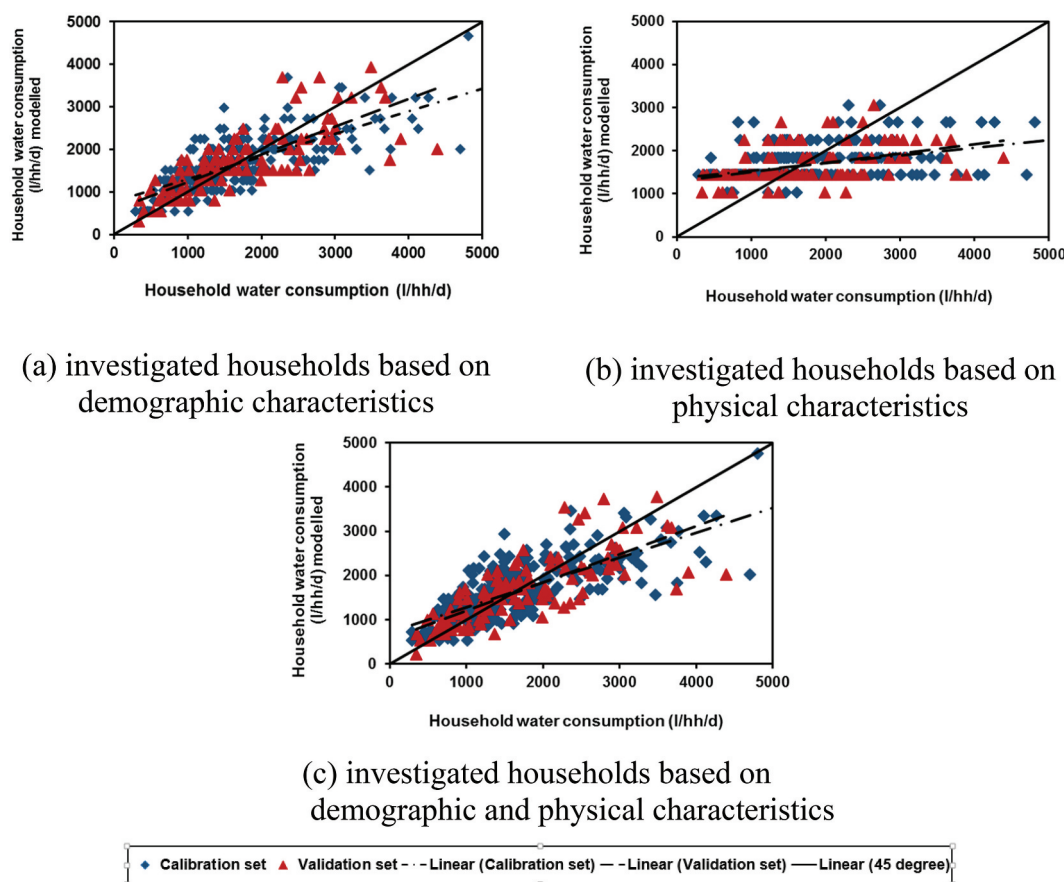
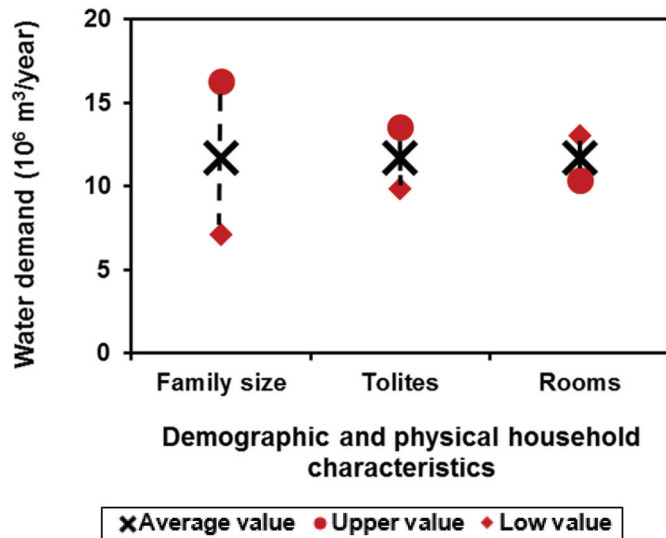


Figure 10. Relationship between actual and predicted daily per capita water consumption using STEPWISE method.

Table 6. Coefficients of determination (R^2) of the final regression model.

Relationship of household water consumption with	Coefficient of determination (R^2)		
	Demographic characteristics	Physical characteristics	Demographic and Physical characteristics
Surveyed households	0.73	0.42	0.75

**Figure 11.** Sensitivity analysis of input parameters for STEPWISE based domestic water demand prediction models for Sirte city.

the low and high values of each household characteristic. The calculated upper and lower values of each household characteristic were used with the STEPWISE developed models to estimate the annual total water demand for households in Sirte city as shown in Figure 11. The figure shows that the developed models are very sensitive to the family size.

4. Limitations

The study faced some significant limitations which might affect the accuracy of the determined average per capita water consumption. The first limitation is that there are no available previous research studies on the study area in terms of water consumption and diurnal patterns for end uses to develop confident comparisons. Secondly, due to the massive loss of documents in 2011 as a result of the war, there is no social-economic data for households characteristics in Sirte city. Therefore, there is no existing information in the city that can be compared with the finding of this study. Thirdly, because of missing meters to measure the duration and flow rates of water consumption, the study developed a method to collect data. However, the accuracy of the flow rates and durations could not be validated by measured data. The end-use water consumption data are a result of a questionnaire, so they may be dependent on the ability and sensitivity of subject in measuring and /or replying.

5. Conclusion

The paper studied the domestic water consumption at the end-use level in Sirte city, Libya. The effect of household characteristics (demographic and socio-economic) on per capita water consumption was investigated using a comprehensive questionnaire survey. The collected data was analysed using IBM SPSS Statistics software package Version 25 to obtain daily per capita water consumption of each end-use as a function of household characteristics. The average daily water consumption was calculated as a function of the frequency of water use, duration of running water from taps and flow rate of water for all end-uses. The study obtained the 24 hours time pattern for all end-uses. The multiple linear regression (STEPWISE) technique was used to develop regression models from which the best fit model was selected which can be used to predict future per household water consumption.

The results revealed that the average daily per capita water consumption is 255 l/p/d for the winter season. The number of toilets for households in the study area is high compared with other developing countries. It ranged between 1 and 6 toilets depending on the type and size of the house. The same situation exists for the kitchens. Some houses have more than one kitchen. The increase in the number of toilets and kitchens leads to increased water consumption and has a strong positive correlation coefficient. In addition, the results indicated that there is a strong positive correlation between household water consumption and household occupancy, total household built-up area, number of children, adult males and females, elders. However, there is no correlation between per capita water consumption and the total household income because the water is free. The result showed that the frequency and duration of hand wash basin tap use are much higher than the case is in developed countries. This could be because of additional water use activities (e.g. ablution) via the hand wash basin tap.

In terms of the diurnal water consumption profile, the results indicated that the time patterns for all end uses have multiple peaks which are significantly different from typical profiles for the developed countries reported in the literature. For the statistical models, the analysis revealed that the demographic characteristics provide more accurate predictions of per household water consumption than the predictions resulting from the use of physical characteristics of the investigated households.

The study findings provide information that can be used to improve water demand forecasts and management. Moreover, the information will be useful to those designing and operating water supply and sewer systems. Specifically, the data collected and analysed (average water consumption and diurnal patterns) will serve as input to software tools such as EPANET and Stormwater Management Model (SWMM) for analysing the water supply and sewer systems respectively.

The high household water consumption was found to be a result of the long duration of running water for particular end-uses. This provides the basis for developing policies and programs aimed at creating awareness and improving water consumption behaviour. These will help to increase the adoption

of techniques such as rainwater harvesting and greywater reuse for non-potable water uses. These have the potential not only to reduce household water consumption but also sewer systems flooding.

Note

1 £1 = 1.89 LYD

Acknowledgements

The funding for this research has been provided by the Ministry of Higher Education and Scientific Research in Libya which is thankfully acknowledged.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

- Abdelrhem, I.M., K. Raschid, and A. Ismail. 2008. "Integrated Groundwater Management for Great man-made River Project in Libya." *Eur. J. Sci. Res* 22 (4): 562–569.
- Abderrahman, W. A. 2000. "Urban Water Management in Developing Arid Countries." *International Journal of Water Resources Development* 16 (1): 7–20. doi:10.1080/07900620048536.
- Abufayed, A. A., and M.K.A. El-Ghuel. 2001. "Desalination Process Applications in Libya." *Desalination* 138 (1–3): 47–53. doi:10.1016/S0011-9164(01)00243-0.
- Al-Rashed, M.F., and M. M. Sherif. 2000. "Water Resources in the GCC Countries: An Overview." *Water Resources Management* 14 (1): 59–75. doi:10.1023/A:1008127027743.
- Arnell, N. W. 2004. "Climate Change and Global Water Resources: SRES Emissions and socio-economic Scenarios." *Global Environmental Change* 14 (1): 31–52. doi:10.1016/j.gloenvcha.2003.10.006.
- Athuraliya, A, P Roberts, and A Brown. 2012. *Residential Water Use Study Volume 2-Summer 2012*. Melbourne: Yarra Valley Water.
- Beal, C. D., R. A. Stewart, and K. Fielding. 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. doi:10.1016/j.jclepro.2011.09.007.
- Beal, C.D., and R.A. Stewart. 2014. "Identifying Residential Water End Uses Underpinning Peak Day and Peak Hour Demand." *Journal of Water Resources Planning and Management* 140 (7): 04014008. doi:10.1061/(ASCE)WR.1943-5452.0000357.
- Bhatti, A. M., and S. Nasu. 2010. "Domestic Water Demand Forecasting And Management Under Changing Socio: Economic Senario." *Society for Social Management Systems (SSMS-2010)* 6 (1): 1–8.
- Bindra, S. P., S. Abulifa, A. Hamid, H.S. Al Reiani, and H. K. Abdalla. 2013. "Assessment of Impacts on Ground Water Resources in Libya and Vulnerability to Climate Change." *Scientific Bulletin of The "Petru Maior" University of Targu Mures* 10 (2): 63.
- Blokker, JME, JGH Vreeburg, and JC Van Dijk. 2010. "Simulating Residential Water Demand with Stochastic end-use Model." *Journal of Water Resources Planning and Management* 136 (1): 19–26. doi:10.1061/(ASCE)WR.1943-5452.0000002.
- Butler, D., and W. John. 2004. *Urban Drainage*. 2nd ed. London and New York: Taylor & Francis Group.
- Cavanagh, S., W.M. Hanemann, and R.N Stavins. 2002. "Muffled Price Signals: Household Water Demand under increasing-block Prices." Available at SSRN 317924 40: 1–45.
- Cevik, A. 2007. "Unified Formulation for Web Crippling Strength of cold-formed Steel Sheeting Using Stepwise Regression." *Journal of Constructional Steel Research* 63 (10): 1305–1316. doi:10.1016/j.jcsr.2007.01.001.
- Davies, K., C. Doolan, R. van den Honert, and R. Shi. 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. doi:10.1002/2014WR015812.
- Domene, E., and D. Saurí. 2006. "Urbanisation and Water Consumption: Influencing Factors in the Metropolitan Region of Barcelona." *Urban Studies* 43 (9): 1605–1623. doi:10.1080/00420980600749969.
- Duarte, R., V. Pinilla, and A. Serrano. 2013. "Is There an Environmental Kuznets Curve for Water Use? A Panel Smooth Transition Regression Approach." *Economic Modelling* 31: 518–527. doi:10.1016/j.econmod.2012.12.010.
- Edwards, K., and L. Martin. 1995. "A Methodology for Surveying Domestic Water Consumption." *Water and Environment Journal* 9 (5): 477–488. doi:10.1111/j.1747-6593.1995.tb01486.x.
- Estrela, T, Dimas Menéndezm, M Leonard, Ovesen INB J, NJ Fehér, and V Consult. 2001. *Sustainable Water Use in Europe*. Denmark: Office for Official Publications of the European Communities.
- Gato, S (2006) "Forecasting Urban Residential Water Demand." PhD thesis, RMIT University
- GMRWUA. 2005. "Great Man-Made River Water Utilization Authority Report."
- GMRWUA. 2006. "Great Man-Made River Water Utilization Authority Report."
- Gregory, G. D., and M. D. Leo. 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. doi:10.1111/j.1559-1816.2003.tb01949.x.
- Hussien, W. A., F. A. Memon, and D. A. Savic. 2016. "Assessing and Modelling the Influence of Household Characteristics on per Capita Water Consumption." *Water Resources Management* 30 (9): 2931–2955. doi:10.1007/s11269-016-1314-x.
- Ibrahim, A, S., F.A Memon, and D. Butler. 2021. "Seasonal Variation of Rainy and Dry Season per Capita Water Consumption in Freetown City Sierra Leone." *Water* 13 (4): 499. doi:10.3390/w13040499.
- Jorge, C., P. Vieira, M. Rebelo, and D. Covas. 2015. "Assessment of Water Use Efficiency in the Household Using Cluster Analysis." *Procedia Engineering* 119: 820–827. doi:10.1016/j.proeng.2015.08.945.
- Kenney, D. S., C. Goemans, R. Klein, J. Lowrey, and K. Reidy. 2008. "Residential Water Demand Management: Lessons from Aurora, Colorado." *JAWRA Journal of the American Water Resources Association* 44 (1): 192–207. doi:10.1111/j.1752-1688.2007.00147.x.
- Larson, B, B Minten, and R Razafindralambo. 2006. "Unravelling the Linkages between the Millennium Development Goals for Poverty, Education, Access to Water and Household Water Use in Developing Countries: Evidence from Madagascar." *Journal of Development Studies* 42 (1): 22–40. doi:10.1080/00220380500356258.
- Lee, D. J., N. S. Park, and W. Jeong. 2012. "End-use Analysis of Household Water by Metering: The Case Study in Korea." *Water and Environment Journal* 26 (4): 455–464. doi:10.1111/j.1747-6593.2011.00304.x.
- Loh, M., and P. Coghlan. 2003. "Domestic Water Use Study in Perth." In *Western Australia*, 1998–2001. Perth: Water Corporation.
- Madanat, S, and F Humplick. 1993. "A Model of Household Choice of Water Supply Systems in Developing Countries." *Water Resources Research* 29 (5): 1353–1358. doi:10.1029/93WR00126.
- Marinoski, A, A Vieira, A Silva, and E Ghisi. 2014. "Water end-uses in low-income Houses in Southern Brazil." *Water* 6 (7): 1985–1999. doi:10.3390/w6071985.
- Mayer, Peter W., William B. DeOreo, Eva M. Opitz, Jack C. Kiefer, William Y. Davis, Benedykt Dziegielewski, and John Olaf Nelson. 1999."
- McKenzie, H.S., B.O. Elsaiah, and PARKMAN. 1994. "The Libyan Great MAN-MADE River Project." *PAPER 1. PROJECT OVERVIEW.(WINNER OF 1995 PARKMAN MEDAL)*. *Proceedings OF the Institution OF Civil Engineers-Water Maritime and Energy* 106 (2): 103–122.

- Mu, X, D Whittington, and J Briscoe. 1990. "Modeling Village Water Demand Behavior: A Discrete Choice Approach." *Water Resources Research* 26 (4): 521–529. doi:10.1029/WR026i004p00521.
- Nasar, M.N. 2015. "Survey of Sustainable Development to Make Great Man-Made River Producing Energy and Food." *Current World Environment* 10 (3): 758–763. doi:10.12944/CWE.10.3.05.
- Nauges, C., and D. Whittington. 2009. "Estimation of Water Demand in Developing Countries: An Overview." *The World Bank Research Observer* 25 (2): 263–294. doi:10.1093/wbro/lkp016.
- OFWAT. 1997. *International Comparison of the Demand for Water: A Comparison of the Demand for Water in Three European Countries: England and Wales, France and Germany*. UK: WRC.
- PCSC, 2003. "Planning Committee of Sirte City Report."
- Pim, R.H., and A. Binsariti. 1994. "The Libyan Great MAN-MADE River Project. Paper 2. The Water Resource." *Proceedings of the Institution of Civil Engineers-Water Maritime and Energy* 106 (2): 123–145. doi:10.1680/iwtme.1994.26389.
- Roberts, P. 2005. *Yarra Valley Water: 2004 Residential end-use Measurement Study*. Melbourne: Yarra Valley Water.
- Simukonda, K., R. Farmani, and D. Butler. 2018. "Intermittent Water Supply Systems: Causal Factors, Problems and Solution Options." *Urban Water Journal* 15 (5): 488–500. doi:10.1080/1573062X.2018.1483522.
- Slavíková, L., V. Malý, M. Rost, L. Petružela, and O. Vojáček. 2013. "Impacts of Climate Variables on Residential Water Consumption in the Czech Republic." *Water Resources Management* 27 (2, January 1): 365–379. doi:10.1007/s11269-012-0191-1.
- SMP., (2018) "Sirte Ministry of Planning Report."
- Syme, G. J., Po. M. ShaoQ, and E. Campbell. 2004. "Predicting and Understanding Home Garden Water Use." *Landscape and Urban Planning* 68 (1): 121–128. doi:10.1016/j.landurbplan.2003.08.002.
- Willis, R.M., R.A. Stewart, D.P. Giurco, M.R. Talebpour, and A. Mousavinejad. 2013. "End Use Water Consumption in Households: Impact of socio-demographic Factors and Efficient Devices." *Journal of Cleaner Production* 60: 107–115. doi:10.1016/j.jclepro.2011.08.006.
- World Health Organization WHO, UNICEF. (2019) "Water Supply, sanitation and Hygiene Monitoring." https://www.who.int/water_sanitation_health/monitoring/
- WWCI. (2019). "World Weather and Climate Information." <https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Sirte,Libya>
- Yasar, A., M. Bilgili, and E. Simsek. 2012. "Water Demand Forecasting Based on Stepwise Multiple Nonlinear Regression Analysis." *Arabian Journal for Science and Engineering* 37 (8): 2333–2341. doi:10.1007/s13369-012-0309-z.

APPENDIX A: Household Water Consumption Survey Sirte, Libya (winter season)

This survey is carried out as a part of a research project to collect and analyse the information on water use patterns in the residential areas of Sirte. The information provided by you will be used anonymously and solely for educational and research purposes. This survey will not take more than **Thirty minutes**. Please tick the relevant box.

Participant **Area and Street** **Date**

Demographic characteristics of household:

Gender of the person filling this form	Male		Female		
How many people live in your household?	2	3	4	5	Other (specify)
How many children under 15 live in your household?	0	1	2	3	Other (specify)
How many adult males (15- 65years) live in your household?	0	1	2	3	Other (specify)
How many adult females (15- 65 years) live in your household?	0	1	2	3	Other (specify)
How many people above 65 years live in your household?	0	1	2	3	Other (specify)

Socio-economic characteristics of the household

How many rooms are there in your household?	1	2	3	4	Other (specify)
How many kitchens are there in your household?	1	2	3	4	Other (specify)
How many toilets are there in your household?	1	2	3	4	Other (specify)
How many floors/storeys in your household?	1	2	3	4	Other (specify)
What is your household type ?	House	Apartment	Clay/cane		Other (specify)
What is the total area of all floors in m ² of your household?	250–300	300–35	350–40	400–50	Other (specify)
What is the garden area in m ² of your household?	0	1–30	30– 60	60–100	Other (specify)
How much is the total monthly income of your household (i.e. all family members)? Libyan Dinar (LD/month)				

1) Bath

1.1 How many times do you have a bath every day?	N/ A	0	1	2	3	Other (specify)
1.2 At what times during the day do you have a bath?	1	First time at	Clock			
	2	Second time at	Clock			
	3	Third time at	Clock			
	4	Fourth time at	Clock			
	5	Fifth time at	Clock			
1.3 How much is the volume of water use for each bathing in a litre?	1–40	40–80	80–120	120–160	160–200	Other (specify)

2) Shower

1.4 How many showers do you take per day	1	2	3	4	5	6	7	Other (specify)	
1.5 How many minutes do you run the water for each shower?	<5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	Other (specify)
1.6 At what times do you take a shower during the day?	1	First time at	Clock						
	2	Second time at	Clock						
	3	Third time at	Clock						
	4	Fourth time at	Clock						
	5	Fifth time at	Clock						
2.4 How much is the shower flow rate in litres/minute?	>1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	Other (specify)

3) Bathroom sink (Tooth brush, hand and face washing, ablution, etc.)

3.1 How many times do you use a bathroom sink (tap) for washing per day?	<=5	6.....	7.....	8.....	9.....	10.....	11.....	12...	13.....	Other (specify).....	
3.2 How many seconds/minutes does water run in each use (e.g. hand and face washing, tooth brushing and ablution)?	1-3...	3-5.....	5-7.....	7-9.....	9-11.....	11-13.....	13-15.....	Other (specify).....			
3.3 At what time do you have a hand, face and feet washing every day?	1	First time at Clock									
	2	Second time at Clock									
	3	Third time at Clock									
	4	Fourth time at Clock									
	5	Fifth time at Clock									
3.4 How much is the average flow rate of each tap use in litres/minute?	<1.....	1-2.....	2-3.....	3-4.....	4-5.....	5-6.....	Other (specify).....				

4) Toilet

4.1 How many times a day do you use a toilet?	1.....	2.....	3.....	4.....	5.....	Other (specify).....					
4.2 At what time do you use toilet every day?	1	First time at Clock									
	2	Second time at Clock									
	3	Third time at Clock									
	4	Fourth time at Clock									
	5	Fifth time at Clock									
4.3 How much is the volume of water use in each flush in litres? litres										

5) Dishwashing

5.1 Manually	5.1.1 How many times does your family wash dishes per day?	0.....	1.....	2.....	3.....	4.....	Other (specify).....					
	5.1.2 How many minutes does water run in each wash?	1-5.....	5-10.....	10-15...	15-20.....	20-25....	Other (specify).....					
	5.1.3 How many times do you wash dishes every day?	1	First time at Clock									
		2	Second time at Clock									
		3	Third time at Clock									
4		Fourth time at Clock										
5	Fifth time at Clock											
5.1.4 How much is the flow rate of washing tap in litres/minute?	<1.....	1-2.....	2-3.....	3-4.....	4-5.....	5-6.....	Other (specify).....					
5.2 Machines	5.2.1 How often do you use a dishwasher per day?	N/A.....	0.....	1.....	2.....	3.....	Other (specify).....					
	5.2.2 At what time do you wash dishes every day?	1	First time at Clock									
		2	Second time at Clock									
		3	Third time at Clock									
		4	Fourth time at Clock									
5	Fifth time at Clock											
5.2.3 What is the brand of dishwashing machine?											
5.2.4 What is the model of dishwashing machine?											
5.2.5 What is the capacity of each wash in kilogram? kilogram											

7) Garden watering

7.1 How many times a week do you water the garden?	N/ A	0	1	2	3	Other (specify)		
7.2 How many minutes does the water run in each watering session?	1- 10.....	10-20...	20-30...	30-40...	40-50...	Other (specify)		
7.3 At what time do you water your garden per week ?	1	First time at Clock						
	2	Second time at Clock						
	3	Third time at Clock						
	4	Fourth time at Clock						
	5	Fifth time at Clock						
7.4 How much is the flow rate in litres/minute for irrigating the garden?	1-2.....	2- 3.....	3- 4.....	4- 5.....	5- 6.....	6- 7.....	7- 8.....	Other (specify)

8) Drinking and Cooking

8.1 How many times does your family cook per day?	1.....	2.....	3.....	4.....	5.....	Other (specify).....		
8.2 At what time do you cook and drink every day?	1	First time at Clock						
	2	Second time at Clock						
	3	Third time at Clock						
	4	Fourth time at Clock						
	5	Fifth time at Clock						
8.3 How much is the volume of water use in each cooking session (including washing) of each type of cereal, vegetables, fruits and meat per day in litres ? litres							

9) House washing

9.1 Rooms washing floor	9.1.1 How many times a week do you wash your rooms?	1..... 2..... 3..... 4..... Other (specify)
	9.1.2 At what time do you wash your rooms per week ?	1 First time at Clock 2 Second time at Clock 3 Third time at Clock 4 Fourth time at Clock 5 Fifth time at Clock 1-4 4-8 8-12 12-16 16-20 Other (specify) <1..... 1-3..... 3-5..... 5-7..... Other (specify) 1..... 2..... 3..... 4..... Other (specify)
	9.1.3 How many minutes does the water run each time?	1-4 4-8 8-12 12-16 16-20 Other (specify)
	9.1.4 How much is the flow rate in litres/minute for rooms washing?	<1..... 1-3..... 3-5..... 5-7..... Other (specify)
9.2 Toilets washing floor	9.2.1 How many times a week do you wash your toilets?	1..... 2..... 3..... 4..... Other (specify)
	9.2.2 How many times do you wash your toilets per day ?	1 First time at Clock 2 Second time at Clock 3 Third time at Clock 4 Fourth time at Clock 5 Fifth time at Clock 1-3 3-5 5-7 7-9 9-11 Other (specify) 1-2 2-3 3-4 4-5 Other (specify) 1..... 2..... 3..... 4..... Other (specify)
9.3 Kitchens washing floor	9.2.3 How many minutes does water run for toilets washing?	1-3 3-5 5-7 7-9 9-11 Other (specify)
	9.2.4 How much is the flow rate in litres/minute for toilets washing?	1-2 2-3 3-4 4-5 Other (specify)
	9.3.1 How many times a week do you wash your kitchens?	1..... 2..... 3..... 4..... Other (specify)
	9.3.2 At what time do you wash your kitchens per week ?	1 First time at Clock 2 Second time at Clock 3 Third time at Clock 4 Fourth time at Clock 5 Fifth time at Clock 1-5 5-10 10-15 15-20 20-25 Other (specify) <1..... 1-2 2-3 3-4 4-5 Other (specify) 1..... 2..... 3..... 4..... Other (specify)
	9.3.3 How many minutes does water run for kitchens washing?	1-5 5-10 10-15 15-20 20-25 Other (specify)
	9.3.4 How much is the flow rate in litres/minute for kitchens washing?	<1..... 1-2 2-3 3-4 4-5 Other (specify)
9.4 Driveways washing	9.4.1 How often do you wash your paths, garage, and driveways per week ?	1..... 2..... 3..... 4..... Other (specify)
	9.4.2 At what times do you wash your paths, garage, and driveways per week ?	1 First time at Clock 2 Second time at Clock 3 Third time at Clock 4 Fourth time at Clock 5 Fifth time at Clock 1-4 4-8 8-12 12-16 16-20 Other (specify) <1..... 1-2 2-3 3-4 4-5 Other (specify)
	9.4.2 How many minutes does the water run each time?	1-4 4-8 8-12 12-16 16-20 Other (specify)
	9.4.3 How much is the flow rate in litres/minute ?	<1..... 1-2 2-3 3-4 4-5 Other (specify)

10) Other water consumption

10.1 Vehicle washing	10.1.1 How many cars are washed at your household per week ?	0 1 2 3 4 Other (specify)
	10.1.2 How many minutes does water run for washing each car?	5-10... 10-15... 15-20... 20-25... 25-30... 30-35... 35-40... Other (specify)
	10.1.3 At what time do you wash your vehicle per week ?	1 First time at Clock 2 Second time at Clock 3 Third time at Clock 4 Fourth time at Clock 5 Fifth time at Clock 1-2..... 2-3..... 3-4..... 4-5..... 5-6..... 6-7..... 7-8..... Other (specify) Yes No
10.2 Swimming pool	10.1.4 How much is the flow rate in litres/minute for washing car?	1-2..... 2-3..... 3-4..... 4-5..... 5-6..... 6-7..... 7-8..... Other (specify)
	10.2.1 Do you have a swimming pool in your household?	Yes No
	10.2.2 If the answer to question 8.3.1 is yes , how many times a year does your household replace water in a swimming pool?	N/A 0 1 2 3 Other (specify)
	10.2.3 How many cubic metre of water are provided to fill the swimming pool? m³

Appendix B: Summary of survey results

Table B1 Summary of household (hh) characteristics in Sirte, Libya.

Household characteristics	Unit	Mean	Median	Standard deviation	variance	Minimum	Maximum	Skewness	Kurtosis	Confidence interval (95%)
Number of People in household	No./hh	6.58	6.00	2.76	7.61	1.00	19.00	0.883	1.42	0.08
Number of children (<15 years)		1.86	2.00	1.72	2.96	0.00	6.00	0.372	- 1.10	0.17
Number of adult males (15–65 years)		2.10	2.00	1.47	2.17	0.00	7.00	0.865	0.116	0.14
Number of adult females (15–65 year)		2.32	2.00	1.61	2.58	0.00	9.00	1.19	1.43	0.13
Number of adult (>65)		0.33	0.00	0.60	0.37	0.00	2.00	1.63	1.50	0.31
Total area m ² of house	m ² /hh	226.69	190.0	89.28	7972.0	100	650.0	1.56	1.88	0.08
Garden area in m ² in the household		31.45	0.00	96.17	9249.0	0.00	1500.0	10.55	148.0	0.47
Number of kitchens in the household	No.	1.60	2.00	0.667	0.446	1.00	5.00	0.983	1.44	0.08
Number of toilets in the household		2.53	2.00	0.942	0.888	1.00	6.00	1.31	1.46	0.07
Number of rooms in the household		6.00	5.00	1.998	3.992	2.00	11.00	1.198	0.125	0.06
Number of floors in the household		1.21	1.00	0.447	0.200	1.00	3.00	1.927	0.125	0.07
Monthly family income/ household	LYD/ month	2524.1	2000.0	1931.0	3,729,611	300.0	15,000.0	2.415	8.429	0.14
Household type	%			Houses (77%)					Apartments (23%)	

Where No: number, hh: household, LYD: (LYD, Libyan Dinar).

Table B2 Summary of water end–uses parameters for surveyed households (380 households).

End–use	Parameter	Unit	Mean	Median	Std. deviation	Variance	Minimum	Maximum	Skewness	Kurtosis	Confidence interval (95%)
Bath	Frequency of bath per capita per day	bath/p/d	0.08	0.00	0.12	0.02	0.00	0.57	1.61	1.87	0.28
Shower	Volume of water use in each bath	l/bath	169.0	180.0	41.53	1725.0	0.00	220.0	-0.84	0.88	0.08
	Frequency of showering per capita per day	shw/p/d	0.66	0.57	0.32	0.10	0.14	2.00	1.16	2.39	0.09
	Duration of each shower	min/shw	16.61	12.50	10.16	103.23	1.50	55.0	1.70	3.10	0.12
Hand wash basin taps	Flow rate	l/min	4.36	4.00	1.53	2.34	1.50	8.00	0.33	-0.75	0.07
	Frequency of using taps per capita per day	tpu/p/d	6.87	6.00	2.33	5.43	2.00	18.0	0.91	1.29	0.07
	Duration of tap use	min/tpu	5.00	5.00	1.24	1.55	2.00	10.0	0.89	2.34	0.05
Toilet flushing	Flow rate	l/min	2.49	2.00	1.01	1.00	0.50	6.00	1.00	1.11	0.08
	Frequency of toilet use per capita per day	fl/p/d	6.19	6.00	2.18	4.75	3.00	16.0	1.14	1.71	0.07
Cooking	Water use in each flush	l/fl	8.07	7.00	2.66	7.09	1.00	15.0	0.13	0.69	0.06
	Frequency of running water for cooking	cok/d	2.97	3.00	0.35	0.13	1.00	4.00	-0.80	6.83	0.02
	Volume of water per each cooking	l/cook/p	4.23	4.00	0.99	0.98	2.00	8/00	0.38	0.87	0.05
Dish washing manually	Frequency of washing dishes per day	wsh/ d	3.10	3.00	1.34	1.79	0.00	6.00	-0.73	0.58	0.08
	Duration of running water in each wash	min/wsh	8.14	8.00	3.94	15.53	0.00	27.50	0.03	1.50	0.09
Dish washing machine	Flow rate	l/min	2.88	3.00	1.38	1.91	0.00	6.00	-0.27	0.20	0.09
	Frequency of washing dishes by machine per day	wsh/d	0.24	0.00	0.63	0.40	0.00	3.00	2.81	7.24	0.19
	Volume of water per washing load	l/wsl	14.98	15.00	5.54	30.69	0.00	30.0	1.08	2.66	0.16

(Continued)

Table B2 (Continued).

End-use	Parameter	Unit	Mean	Median	Std. deviation	Variance	Minimum	Maximum	Skewness	Kurtosis	Confidence interval (95%)
Laundry manually	Frequency of laundry manually per day	wsh/d	0.06	0.00	0.15	0.02	0.00	0.86	2.50	5.78	0.40
	Duration of each wash	min/wsh	3.02	0.00	7.86	61.72	0.00	50.0	2.87	8.21	0.42
	Flow rate	l/min	0.82	0.00	1.93	3.72	0.00	7.00	2.10	2.80	0.38
Laundry machine	Frequency of laundry per day	wsh/d	0.79	0.86	0.30	0.09	0.14	1.70	-0.23	-0.10	0.07
	Volume of water per washing load	l/wsl	72.11	63.0	26.55	703.1	43.0	204.0	1.59	4.86	0.07
Kitchens washing	Frequency of kitchens washing per day	wsh/d	0.24	0.14	0.13	0.02	0.00	0.57	0.97	0.27	0.10
	Duration of each wash	min/p/d	10.00	8.00	6.30	39.72	2.00	30.0	1.14	0.62	0.12
	Flow rate	l/min	2.43	2.00	1.14	1.31	0.00	6.00	0.64	0.32	0.09
Rooms washing	Frequency of rooms washing per day	wsh/d	0.17	0.14	0.10	0.01	0.00	0.57	1.72	4.57	0.12
	Duration of each wash	min/p/wsh	11.10	10.00	6.61	43.74	0.00	37.5	0.60	0.46	0.11
Toilets washing	Flow rate	l/min	1.54	1.25	1.15	1.31	0.00	6.00	1.08	1.23	0.14
	Frequency of toilets washing per day	wsh/d	1.83	2.00	0.83	0.69	1.00	4.00	0.61	-0.58	0.09
	Duration of each wash	min/p/wsh	5.58	6.00	2.28	5.20	2.00	20.0	1.07	3.40	0.08
Vehicle washing	Flow rate	l/min	3.13	3.00	1.00	0.99	1.40	6.00	0.71	0.15	0.06
	Frequency of vehicles washing per day	wsh/d	0.04	0.00	0.07	0.01	0.00	0.29	1.48	1.40	0.29
	Duration of each wash	min/wsh	5.74	0.00	10.22	104.42	0.00	45.0	1.55	1.14	0.30
Swimming pool	Flow rate	l/min	1.16	0.00	2.01	4.06	0.00	8.00	1.44	0.74	0.30
	Frequency of filling swimming pool per day	No./d	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Volume of water provided to fill the swimming pool	m ³	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Garden watering	Frequency of garden watering per day	wtr/d	0.14	0.00	0.18	0.03	0.00	0.86	1.02	0.02	0.23
	Duration of each watering	min/wtr	10.99	0.00	15.96	254.50	0.00	87.5	1.59	2.38	0.26
	Flow rate	l/min	1.91	0.00	2.36	5.57	0.00	8.00	0.73	-0.89	0.22

Note: L = liter, p = person, d = day, min = minute, shw = shower, tpu = tap use, fl = flushes, wsh = washes, wsl = washing load, wtr = watering, cok = cooking.