Identifying and analyzing residential water demand profile; including the impact of covid-19 and month of Ramadan, for selected developments in Dubai, United Arab Emirates

Identifying and analyzing residential water demand profile; including the impact of COVID-19 and month of Ramadan, for selected developments in Dubai, United Arab Emirates

Syed Rizvi, Rabee Rustum, Malini Deepak, Grant B. Wright and Scott Arthur

ABSTRACT

Consumption of water varies throughout the day due to the daily routines of the consumer. This pattern of daily water consumption is called the water demand profile. The initiatives to create these profiles are to improve hydraulic performance and to build energy conservation strategies for designed networks in Dubai. Therefore, the aim of the work presented here was to develop and analyze a domestic consumption profile for selected developments with socio-demographic factors including weekday/weekend variation, population, income, fasting during the month of Ramadan, and the outbreak of COVID-19. Data from more than 7000 smart meters were collected while water meters of more than 350 residential flats were examined manually. Water demand profiles generated from the data showed weekdays have more predictable peaks (morning 6–8 am and evening 5–7 pm) than weekends. During Ramadan, peak hours shifted to 7–10 am followed by 3–4 pm during workdays while peaks for low-income areas were higher due to a stricter working routine. The COVID-19 crisis has led to significant rise in observed consumption, with over a 30% increase during the month of Ramadan. The observed results, if compared with further end-use studies on more factors affecting demand profiles, can help in generating both cost and energy efficient networks.

Key words | water consumption, water demand profile, water distribution networks, water management

Syed Rizvi (corresponding author)
Rabee Rustum
Malini Deepak
Grant B. Wright
Institute for Infrastructure and Environment,
    School of Energy, Geosciences, Infrastructure
    and Society,
Heriot-Watt University,
Dubai,
United Arab Emirates
E-mail: sar32@hw.ac.uk

Grant B. Wright
Scott Arthur
Institute for Infrastructure and Environment,
    Heriot-Watt University,
Edinburgh,
UK

HIGHLIGHTS

- The paper develops a consumption profile for the unique case of COVID-19 and Ramadan.
- The paper links different socio-demographic factors to assess the position of water peak hours.
- The paper observes and develops different consumption profile for different days of the week (weekday and weekend).
- The paper produces a water profile for the first time in Dubai.
- The paper shows how culture variations can affect the consumption pattern.

ABBREVIATIONS

WDN   Water Distribution Network
WDP   Water Demand Profile
SCADA   Supervisory Control and Data Acquisition system
DEWA   Dubai Electricity and Water Authority
GA   Global Algorithm
GHG   Green House Gas
ADD   Average Daily Demand
BR   Bedroom

INTRODUCTION

A water distribution network (WDN) consists of multiple components such as reservoirs, local tanks, conduits, pumping stations, valves, and controllers. These components can be linked in computer models through various hydraulic equations that can be optimized to develop reliable, efficient, and sustainable water supply systems able to convey water with desired quality and quantity (Jamieson *et al.* 2007; Anele *et al.* 2017).

Designing and modeling WDNs is complex as the number of parameters to be considered is vast. One of these parameters is water demand, which is the water consumption by the end user plus any water leakage (Hunt *et al.* 2010). Determining water demand during the design stage is a challenge as it is affected by population and the lifestyle of the users. Accordingly, overall demand can be classified as the sum of domestic, industrial, and agricultural demand. The demand is also affected by the relative urbanization of the area, and therefore varies between rural and urban areas. Hence, future changes in demand and any new developments in an area must be considered during the design stage (Banjac *et al.* 2015; Froelich 2015).

Estimation of the time varying water demand profile (WDP) is one of the most important and difficult tasks for water supply engineers. This is due to the impact of state variables on the water distribution system, such as nodal pressure, flow velocity and water quality (Trifunovic 2008). WDPs are also used to determine the reliability of water distribution components such as water tanks and pumping stations. Typically, such data are provided through supervisory control and data acquisition systems (SCADA). These data, however, are not usually available at high temporal resolution. For instance, they may be available by month rather than hour, and hence they are often not suitable for design or modeling purposes.

This paper develops WDPs for the city of Dubai that can be used to help build energy conservative strategies for cost optimization of WDNs, which is in line with the smart city project in Dubai. Given that a significant majority of UAE residents are Muslim (76%), and observe the month of Ramadan, this paper will investigate the impact of Ramadan-related changes in life and work practices on Dubai WDPs. Finally, it has also been possible to present preliminary data showing the impact of behavior changes resulting from the COVID-19 outbreak on consumption patterns.

This paper starts by detailing the current design practice in Dubai, the impacts of WDPs and how they can be used to optimize the operation and control of WDN. Following a description of the methodology used to collect the data, the developed WDPs are discussed and conclusions made for future work.

Current practice in Dubai

In Dubai, demands are generalized using the consumption categories and peak factors based on the code of practice (rsb.gov.ae 2017). WDNs are built based on the demands that are multiplied by a peak factor of 1.25–1.30 to account for any variations in flow. Nevertheless, most networks are built with the assumption that the demand will always be high (worst-case scenario), neglecting the fact that the demand varies on an hourly basis (rsb.gov.ae 2017). Hence, WDN components such as pipes and tanks that are built with worst-case demands are oversized in scenarios where the actual demand is low or average. Furthermore, these peak factors are estimated or assigned by experience from other countries or codes rather than from local data. Thus, it is necessary to observe the variation of water demand over time in order to determine the WDP that can be used to optimize the design or operation of a WDN (Anele *et al.* 2017).

This allows the designer or the modeler to calculate and locate the peak water demand while accepting it also varies for each user, including residential, industrial, agricultural, environmental, and recreational, depending on the consumption of water in each sector. For example, a household WDP can have peaks during both the morning, when occupants ready themselves for the day, and the evening, when children to return from school and adults return from work (Koutiva & Makropoulos 2016).

Impacts on residential WDP

WDPs for residential sectors tend to be affected by many factors. For example, in the case of a small residential house, it is difficult to predict when water is going to be used, due to the range of domestic activities such as toilet flushing, showering, cleaning, washing machine use, etc. (Trifunovic 2008; Beal & Stewart 2013; Banjac *et al.* 2015; Gurung *et al.* 2015); thus detailed surveys need to be performed to analyze the water usage. However, considering multiple demand pattern during weekday, a general or common WDP could be established based on an average scale. This is because most individuals have relatively similar and strict routines during working days which ideally is reflected in their consumption pattern. Typically, water demand tends to be higher in the morning, 6–9 am, when people wake up to go to work/school, and in the evening, 5–8 pm, when people return home from work/school. This pattern has been similar for decades, with small variations due to the geographical nature of the area and/or the socio-demographics of the population (Race & Burnell 2000; Loureiro *et al.* 2008; Aquacraft 2011; Gurung *et al.* 2015; Pretorius *et al.* 2019).

Typical weekend consumption patterns differ significantly from weekday consumption; morning peak demands tend to be higher while evening peak demands tend to be lower. In addition, the duration of weekday peaks tends to be shorter than that of weekend peaks (Pretorius *et al.* 2019). Usually, during weekends, a general WDP becomes more uneven and harder to predict due to the less predictable behavior of people, which will again differ significantly depending on socio-demographic factors of the region (Aquacraft 2011; Anele *et al.* 2017; Anang *et al.* 2019).

More generally, socio-demographic data can help develop a WDP based on specific characteristics. Examples of characteristics that have been found to influence WDPs include the following:

- Household income has a positive correlation with demand, with larger, more expensive, houses having higher water use for activities such as gardening (Coghlan & Higgs 2003; Aquacraft 2011; Anang *et al.* 2019).
- Household size has a negative correlation with per capita demand (Aquacraft 2011).
- Seasonal variations in local population have a significant impact. These include religious sites such as Mashhad in Iran (Felfelani & Kerachian 2016) and more general tourist destinations such as Greece (Voivontas *et al.* 2003), both of which have to contend with increased demand during specific periods of the year.
- Scarcity of water resources has been noted as an indirect factor as it can lead to tariffs which restrict/deter users from consuming too much water (Schleich & Hillenbrand 2019; Garrone *et al.* 2019).
- Population and climate change have been found to be linked to high level of water consumption (Voivontas *et al.* 2003; Roberts 2005).
- Educational awareness can have an impact on consumption; for example, a study by Alarcón *et al.* (2019) showcased that bringing educational strategies to school in order to conserve water, lowered consumption rates.

Models based on socio-demographic data can be very useful during the initial design stage, however they require significant and detailed statistical data. Similarly, religious festive events can alter the consumption pattern. For instance, in the month of Ramadan, many Muslims fast from morning until evening, and working hours are often reduced in order to practice such events; hence, the consumption pattern is also affected.

Usage of WDP to optimize the WDN

Previous work on WDPs have been associated with the relationship of energy and water known as embedded energy (Aquacraft 2011). This energy is the amount needed to produce, treat, and convey the water from the source to the end user. The timings of the water demand can assist the authorities with the management of energy loads; instead of supplying continuous water all the time, the WDP indicates the peak

hours at which the pump times could be matched. Besides, it can allow for conserving energy strategies by knowing the on- and off-peak demand as water supply would vary between low and high. It is important to note that up to 27% of the energy associated with the demand is utilized by pumps in water distribution networks. As a result, changes to WDPs can alter energy use by switching off some of the pumps during low demand periods (Aquacraft 2011). To add more context to these findings, research by Mkireb *et al.* (2018) used the WDP to optimize load power reduction of a pumping system using mathematical models. In their findings, they were able to use their predicted WDP to provide an optimized pumping schedule using water tanks at minimal cost. This was achieved by filling the tanks during off-peak periods when the energy tariff was low. Another strategy is the implementation of high tariffs during peak water demand period in order to reduce the peaks to discourage users from the use of water at that particular time, and hence shifting some of them to the off-peak time period of WDP (Browne *et al.* 2013).

However, it is not straightforward to establish the link between WDP and pump scheduling, and the complexities involved often mean that recourse must either be made to the use of innovative modeling techniques with readily available SCADA data, e.g. Jamieson *et al.* (2007), or installation of smart water meters to build live water demand profiles, e.g. Gurung *et al.* (2017).

Thus, WDPs can assist engineers at the design stage of WDNs, and accurate water demand estimates can help identify key network needs, such as water treatment plant capacity and the size of storage tanks (Gurung *et al.* 2015). The reduction in energy usage also helps improve the sustainability of WDNs through the reduction in greenhouse gas emissions (Stokes *et al.* 2014).

METHODOLOGY

The WDPs will be developed based on data from three case study areas carefully selected to meet the project aims.

Case studies areas

The area of Al Qusais is in Dubai and situated very close to the border region of Dubai and Sharjah, which are two major cities in the UAE. It is one of the largest and oldest communities of Dubai and has a range of social benefits such as ease of transportation service, multiple grocery stores/restaurants, outdoor parks, indoor clubs, as well as various healthcare and education services. The community is further divided into industrial and residential areas, with Al Qusais 1 being the most populated residential area. Residential buildings in the area include different types of flats such as studios and 1- or 2-bedroom (BR) apartments, which accommodate small- to medium-sized families. The community also has ease of outside access to water meters as the buildings are connected to one main water meter. The second case study community, Dubai Silicon Oasis, is a more modern community, with some areas still under development. This community covers a total area of 7.2 km^2 and offers support for residential, educational, governmental, and service sectors. The variety of residential buildings includes villas, medium-rise and high-rise flats. Unlike Al Qusais, each flat has its own water meter making it challenging to collect the data. The third case study area, Jumeirah, is a luxury community located in the center of the Dubai coast covering a total area of 6 km^2. The area contains high-rise buildings, villas, and townhouses with different architectural styles, and it is home to some of the wealthiest people living in the city.

Data recording

Multiple residential buildings of diverse floor numbers were selected from Al Qusais and Silicon Oasis, while samples were taken from SCADA for general consumption profile of Al Qusais and Jumeirah. They were selected based on their population, number of flats, types of flats (1 BR, 2 BR etc.), religious background and occupancy rate.

For the area of Al Qusais, water consumption for selected buildings was recorded for 1 week during the month of May 2019 (2nd to 9th). These buildings are categorized in Table 1. The month of May was selected as it is the beginning of summer season and hence consumption is typically high, and it was also the start of the fasting month, Ramadan. The data were recorded on an hourly basis from the buildings' main water meter. Subsequently the data were also taken for the following weeks for a total of 4 weeks after 9 May to account for any variations. Similarly, for the period of COVID-19, the observed water readings were taken manually

Table 1 | Characteristics of residential buildings

| Name | Al Qusais | | | | | Dubai Silicon Oasis |
	A	B	C	D	E	F
No. of floors	G + 3	G + 3	G + 4	G + 12	G + 11	G + 8
No. of flats (1 BR)	–	24	16	48	60	–
No. of flats (2 BR)	38	12	16	48	66	80
No. of tenants	195	160	140	400	500	320
Occupancy rate (P/F)	5.1	4.44	4.38	4.17	3.97	4

from 13 April to 1 May 2020. Moreover, the event of Ramadan started from 26 April 2020, which allowed to evaluate the pandemic of COVID-19 during the holy month and observe its effects.

For Dubai Silicon Oasis, 24 hour usage data were taken for 1 week from the individual flow meters placed at each floor in building F. As access to some meters was restricted, permission was sought from the flat owners themselves; although only one building volunteered access, the similarity in building layout meant that the measured WDP could be used as a good proxy for a typical building. Each profile for individual flats was then analyzed to remove irregularities, such as unoccupied flats, and then the demand multipliers (ratio of hourly demand to average daily demand) were also used to compare factors other than population.

Finally, data from SCADA was obtained from the live feed of smart water meters in Al Qusais and Jumeirah, to investigate the impact of different socio-economic factors; property prices in Jumeirah are significantly higher than in Al Qusais (Stevens *et al.* 2016). In total, more than 7000 smart meters were selected for both areas on the same days. Once the information was received, graphical comparison was made between the two areas using the demand multipliers to ensure fair comparison, as the population density is different in both areas.

The obtained WDPs for the selected buildings in Dubai were then further examined to check the differences in peak water demand periods by population, working days (weekends and weekdays) and socio-economic factor of fasting and income.

RESULTS AND DISCUSSION

The daily consumption for each building was determined to find the maximum, minimum and average demand per capita (Table 2). When compared with the design value of 250–350 liters per capita, it shows that there is a vast difference between the actual consumption and the design consumption. This is primarily because the design consumption accounts for future rises in water demand, to ensure that no failure occurs within the network.

WDP vs population:

Results were obtained for the different building types in Al Qusais for both weekdays and the weekend.

Weekday

Figure 1(a) indicates the WDP for the residential buildings during weekdays. As expected, less water is used during the night (midnight to 5 am), after which there are periods of high consumption (6–9 am), medium consumption (9 am to 1 pm) and high consumption (from ~6 pm). As shown, higher-rise buildings (D and E) tend to have higher consumption, again confirming that the population of the building is directly related to water consumption.

The peaks generated in Figure 1(b) show the peak hourly demand with respect to the average daily demand. While the fluctuations in each building are the same as Figure 1(a), the differences between the buildings are lower as average daily demand increases with population, which numbs down the peak water consumption for buildings with high population. These types of graphs are very

Table 2 | Statistical data of water consumption

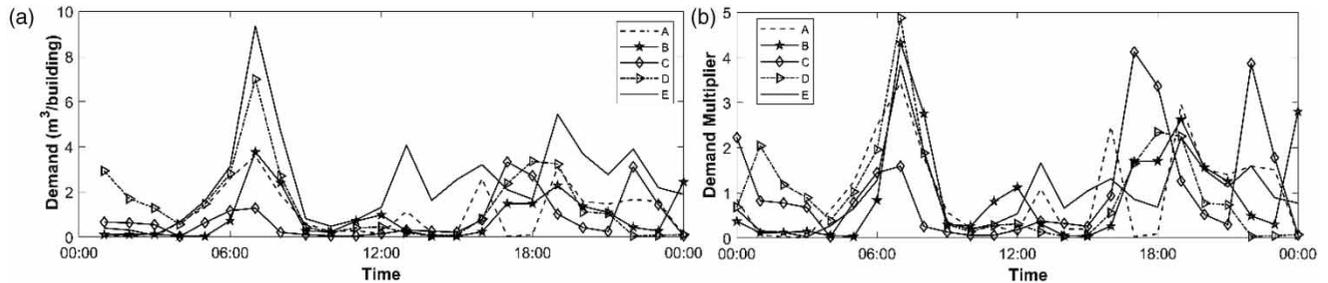| Residential buildings	Maximum (l/d/capita)	Average (l/d/capita)	Minimum (l/d/capita)
A	170	155	135
B	180	158	140
C	200	171	150
D	133	129	120
E	140	136	125
F	–	165	–

Figure 1 | (a) WDP for different residential buildings during weekday in terms of consumption volume. (b) The same profile generated in terms of demand multiplier.

useful from an engineering standpoint as they give values for demand multipliers that could be integrated into buildings with similar characteristics. Based on the results from Figure 1(b), the graph does not necessarily link a pattern with population, as the highest demand multiplier was for building D followed by building B. To understand why, it is important to recall the design of the local storage tanks used in Dubai. The relevant code of practice (rsb.gov.ae 2017) stipulates that the capacity of each tank must equal the average water demand of an entire building for a period of 24 hours, hence translation and attenuation of peak flows occur; these processes are more marked in large buildings, and are magnified by the allowable range of design per capita demand (250–350 liters) and the regular specification of the tanks.

Figure 1(b) also shows how the marked similarity in morning demand multipliers for different buildings is not replicated after mid-afternoon. This is because, while most people start work within a similar time period (7.30–9.30 am), the private sector nature of work in Dubai allied to significant traffic congestion, can result in variations on when people arrive home from work.

Weekend

In Dubai, weekends consist of Friday and Saturday, with the latter constituting a semi-working day for most of the private sector. Hence, WDP was established for both the days.

Figure 2(a) shows water consumption for different residential building types on a Friday. As shown, consumption is again higher in both highly populated buildings (D and E) when compared to buildings with lower populations (A, B and C). However, the demand multipliers shown in Figure 2(b) indicate that fluctuations during the weekend do not show a similar pattern as that observed during weekdays. This is primarily because, in the absence of structure provided by work, people's behavior is more individualistic during the weekend than during the week, hence resulting in less simultaneous water use within the same building. As different buildings attract different types of households, this less structured water use also varies between building type.

Figure 3(a) and 3(b) show water consumption and demand multipliers for different residential building types on a Saturday. As Saturday is a semi-working day for most
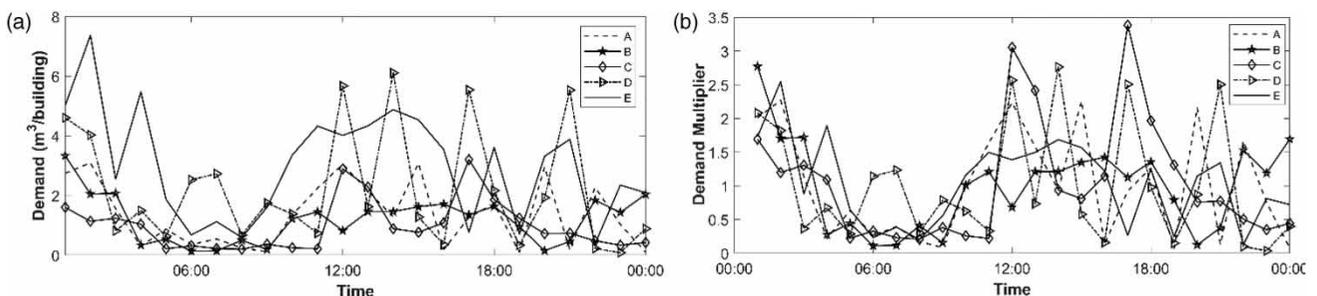

Figure 2 | (a) Different WDPs generated for weekend (Friday) in terms of actual volume. (b) The same profile generated in terms of demand multiplier.
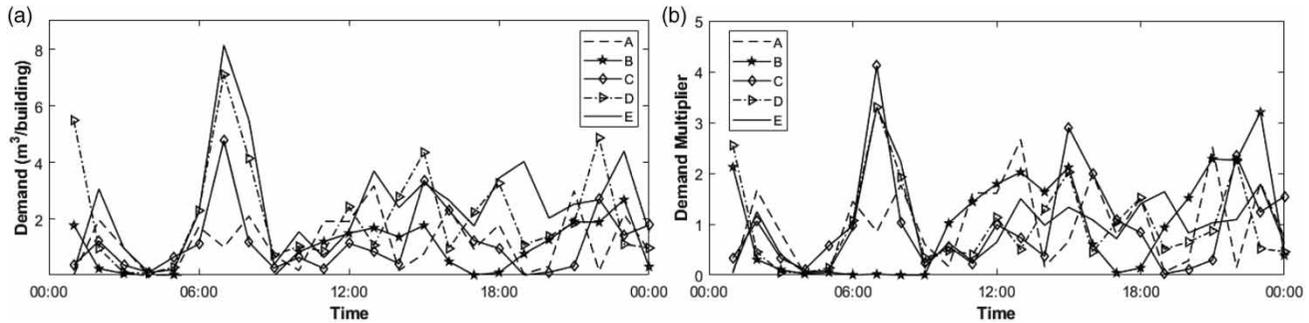
Figure 3 | (a) Volumetric WDPs for weekday during Saturday. (b) Demand multiplier-based WDPs for the same day.

people, the patterns shown exhibit characteristics from both weekday and Friday-weekend WDPs. The peak is observed in the morning session for most of the buildings between 6–9 am as some people set out for work and others simply go out for leisure activities, particularly evident when comparing the curves for buildings B and D.

The hourly peak factor was also found to be high, between 4–5, for high populated buildings during the normal weekdays at 7 am. The current code of practice suggests a peak factor of 1.25–1.3, however, this factor is based on the daily flow (rsb.gov.ae 2017). This result confirms results from previous studies, based on the established pattern (Aquacraft 2011; Banjac *et al.* 2015). Yet, the demand multipliers are quite high, hence, justifying the establishment of local tanks in each building. Another important matter is that the code of practice suggests the average day demand (ADD) to be in the range of 250–350 liters/day per capita whereas the actual rates differ. Taking example of building A, usage was found to be 135–170 liters/day per capita. The maximum observed value was 200 liters per capita per day which is still considerably below the value suggested by the code. However,

the current design practice also considers yearly rise in water demand based on the forecasting trend (Maceda 2015). Hence, this justifies the high range suggested by the code of practice.

Fasting

The WDPs illustrated in Figure 4 were obtained during the month of Ramadan during weekdays.

As shown in Figure 4(a) and 4(b), the impact of Ramadan is evident, with fasting people waking earlier leading to increases in the normally low nighttime consumption. In addition, peaks tend to start from 3 pm as working times typically reduce from 8 hours to 6 hours during Ramadan; therefore, most people return home between 2–4 pm rather than the usual 7–9 pm. Another observation from both Figure 4(a) and 4(b) is the lack of consistent patterns shown in weekday WDPs (Figure 1(a) and 1(b)), along with lower morning peaks and higher evening peaks. This highlights that the multicultural makeup of Dubai means that not everyone is observing Ramadan, and hence people of different faiths are now behaving differently; this
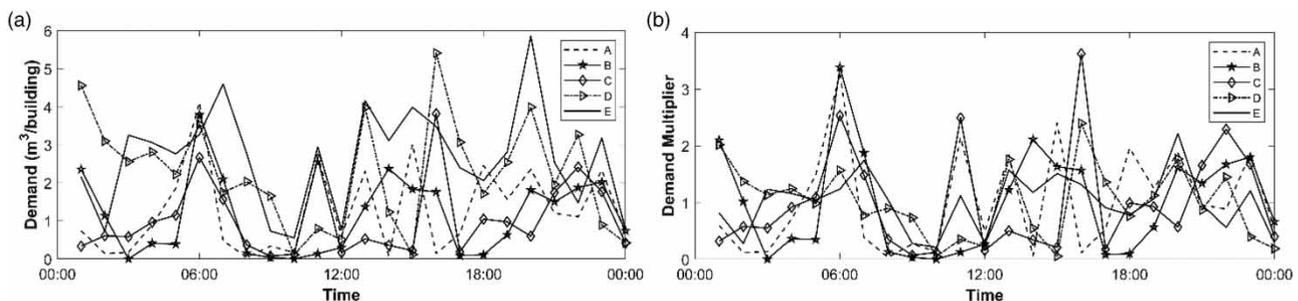

Figure 4 | (a) Weekday WDP during the month of Ramadan. (b) Demand multiplier-based WDPs for the same month.

change is similar to that observed between weekdays and weekends with Ramadan. This is particularly evident in the more distributed peak hourly demand for buildings D and E, whose larger population automatically leads to a more diverse religious mix and hence more diverse behavior during Ramadan.

To reflect the effect of Ramadan, the area of Dubai Silicon Oasis was further studied using data from individual property water meters. This allowed an in-depth comparison of the complex routine of people that are fasting against those who are not.

Figure 5(a) indicates the change in activities during the period of Ramadan during normal working days. As shown, differences start to appear at night where there is a small peak between 3–4 am, highlighting fasting people having small meals to cope with the rest of the day without eating. The dynamic tends to stay the same for the morning peak just as on normal working days as people go to work and becomes distributed throughout the day as mentioned previously. The consumption increases gradually after 6 pm as people that are fasting can start eating and hence a peak is observed along with high usage of water until midnight. As these comparisons draw out the behavior during the weekdays for the people that are fasting and not, it is also informative to study their routine during the weekends where the consumption per day is the highest.

As shown in Figure 5(b), there are notable difference between those fasting during the week and at weekends, particularly 7–9:30 am and 12–2 pm, mirroring the change in behavior during the weekend even for those fasting. Another finding is that people tend to stay awake later during weekends, presumably to eat, as indicated by the peaks around 2–3 am. However, this pattern does showcase the changes in peak times, which allows the engineers to assess the situation when embedding it with the timings of the distribution pumps.

The pump scheduling is based on filling up the local tanks during off-peak hours, particularly midnight to 6 am. As is common practice, few supply pumps are switched OFF at night (during weekdays) to fill up the local tanks due to minimal consumption rate. However, during Ramadan, the off-peak hours differ to those observed on normal weekdays, due to increased consumption at night. With the data provided, pump operations can be rescheduled during Ramadan to ensure that all tanks are filled before use, for better energy conservation strategy. Similarly, the patterns in Ramadan also indicate a shift in peak from morning to evening, which means that the pumps schedule should be setup to ensure that the local tanks are filled before the high consumption period. However, this change in scheduling is only applicable if most of the dwellings within the network are fasting which would affect the overall consumption pattern.
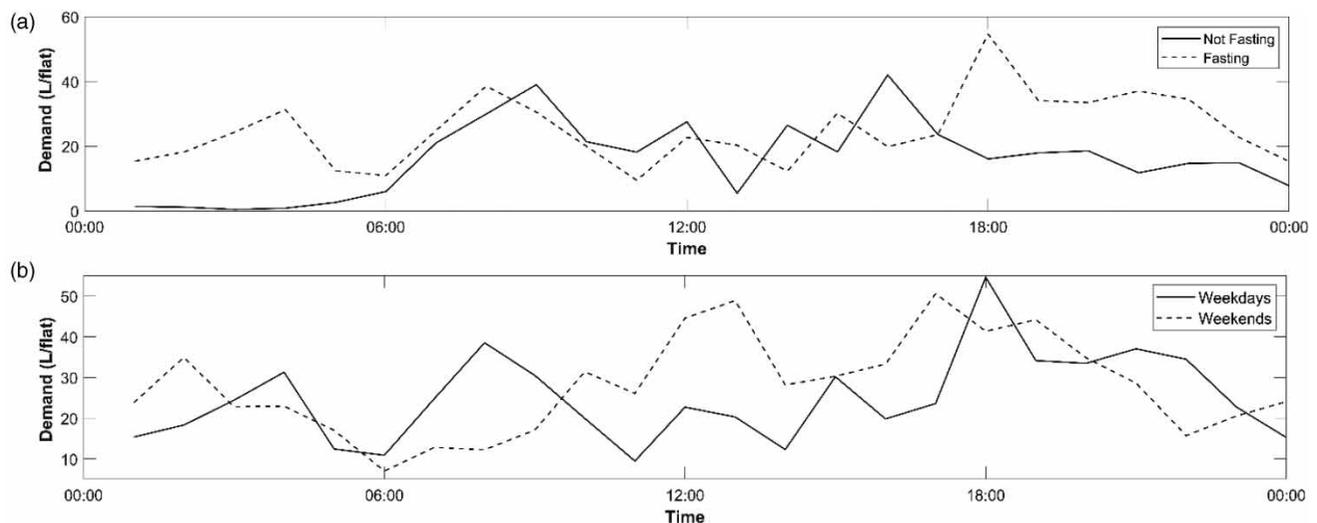

Figure 5 │ (a) Contrasting the profiles with people fasting and those that are not fasting. (b) Changes in profile during weekdays and weekends for people that are fasting.

Impact of income

The influence of income on water consumption patterns was investigated for two major populated areas of Al Qusais (low income) and Jumeirah (high income), as shown below, in Figure 6.

The profile patterns for both areas differ extensively in terms of both time and magnitude of peak consumption. As shown in Figure 6, the low-income area of Al Qusais has a high peak during the morning session, which shows that many residents have similar work start times, and presumably work in similar sectors. For the other area of Jumeirah, the peak in the morning is lower but more dispersed, indicating a different lifestyle of the people; people working in these areas often have a lucra-tive role up the hierarchy or own their own businesses, both of which afford less strict work hours. For the area of Al Qusais, people tend to have a longer shift (leaving early in the morning) and would require more extensive use of water such as bathing, flushing etc. at early morning or late evening. To understand completely these patterns of income, a more detailed and microscopic research needs to be conducted to analyze the instruments where water is being used.

Impact of COVID-19

The impact of the ongoing COVID-19 pandemic has affected water consumption in all the study areas, as shown in Figure 7.

As shown, daily consumption in most buildings has increased, both due to greater daytime occupancy resulting from the 'Stay Home, Stay Safe' campaign in the country (people are restricted to their homes and are only allowed to leave for urgent needs) and increased cleaning (personal and household).

However, the consumption has significantly reduced for building B, due to the reduced number of occupants in the building because of the return to their home country as shown in Figure 7. Although the observed peak demand is still highest in the morning (7–9am), as many residents are working remotely or still going to work, smaller peaks can be seen during lunchtime, evening and night time where the usage of water has increased for cleaning purpose. During the month of Ramadan, the demand increased by up to 37% for building A, 31% for building C and 27% for building D. Again, due to the reduction of tenants in build-ing B, the observed peaks are lower and shorter. The trend of consumption is very similar to that of Ramadan, however,
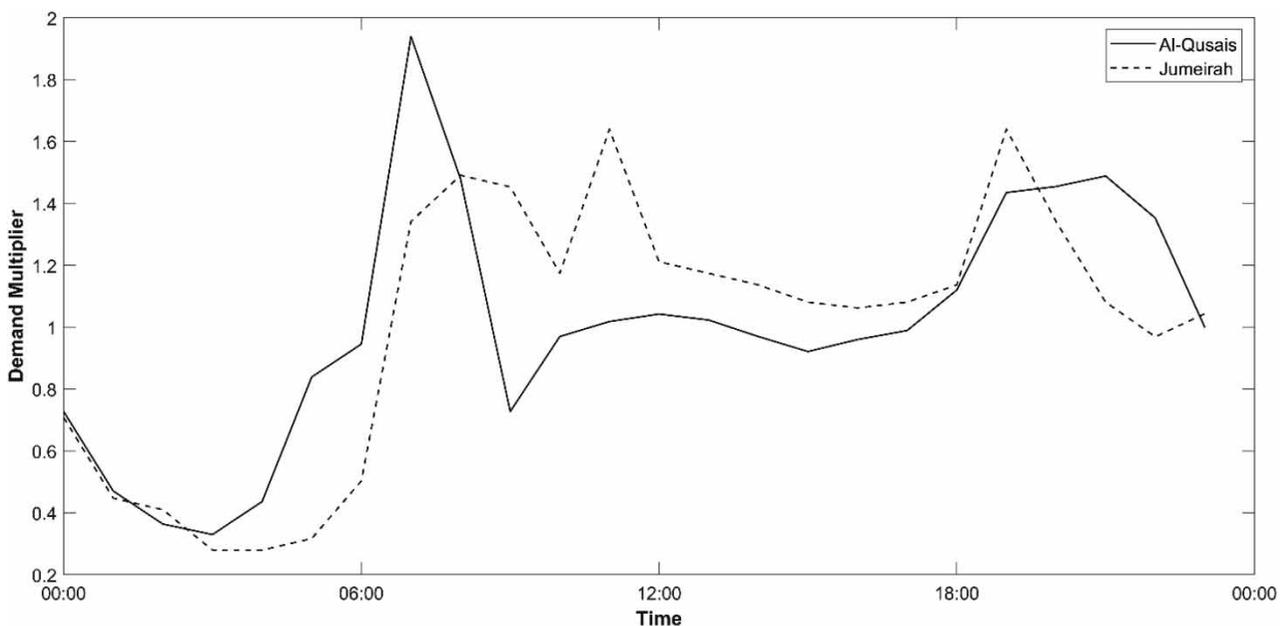

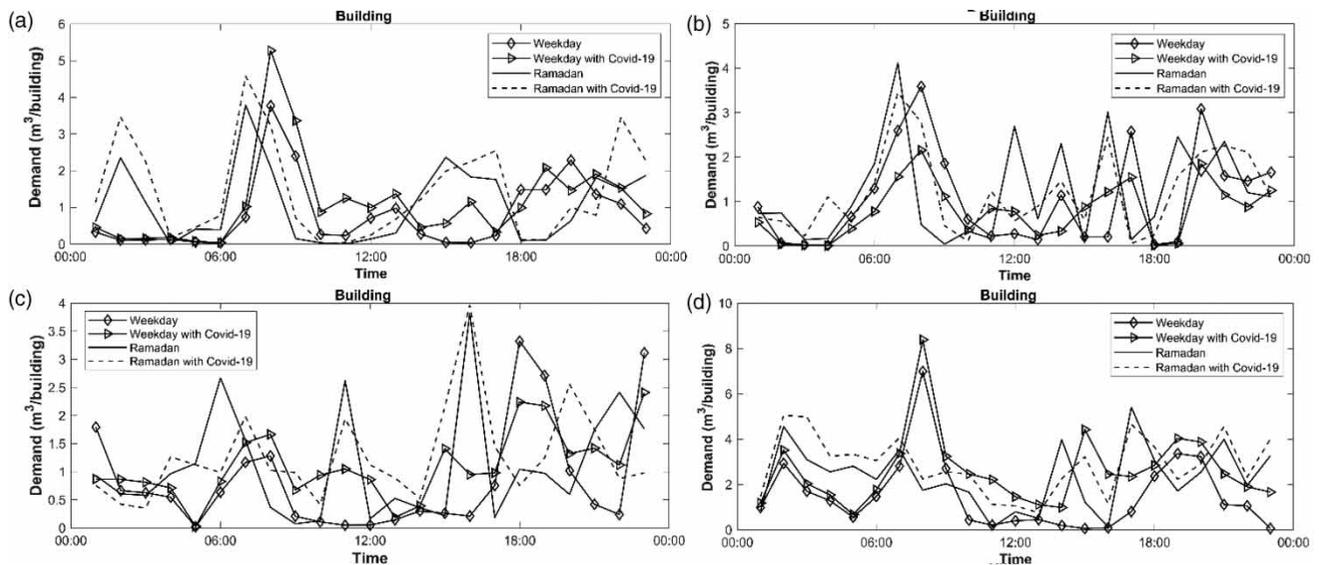**Figure 6** │ WDP comparison for Al Qusais and Jumeirah during weekday.

Figure 7 | Water demand profile during COVID-19 crisis (weekday, Ramadan) for buildings A, B, C and D (a–d, respectively).

with the added danger of COVID-19, the peaks have increased as more people are motivated to increase their water usage to keep themselves safe. Graphical comparison, of weekends with the pandemic and normal weekends, is not provided as the obtained WDPs were very similar. This similarity is the result of people staying at home during weekends due to different social activities for these specific buildings. It could vastly differ if people were going out frequently during weekends. Overall, during the pandemic, the frequency of water usage has become more regular due to the self-isolation.

In terms of design, each model allows the designer to implement a WDP more suitable to the area they are developing and the conditions (income). Models with the associated COVID-19 epidemic and Ramadan event could help the engineers to adjust the extra water demand within the current network design as a part of water forecast (demand increasing yearly). Overall, the significance of each models could help bridge the gap between the performance of actual network and design model. A summarized water demand profile is presented in Figure 8 to showcase the overall consumption pattern in residential buildings.

Finally, it is worth pointing out the limitations observed from the paper. Starting with the income, it was assumed that the consumers living in higher rental areas have higher income than people living in lower rental areas. However, this is limitation of the research, as it is quite

hard to investigate all the consumer characteristic for each live water meter. Secondly, the results obtained for COVID-19 were taken in a very restricted environment. The trendline observed each day differed quite vastly due to various restrictions implemented. Hence, the built WDP could differ vastly as the condition have started to change in the region (travel restriction removed). Moreover, some readings were missed within the hour mark due to restrict travelling in COVID-19, however that missed time span was given more attention for the following day to interpolate a trendline for the previous day.

CONCLUSION

The built WDP has been analyzed and the weekday routine has been established, with the highest peak being observed during morning session. The impact of fasting has effectively moved the peaks to a different time. This suggests that engineers should review the pumping schedule for this period. This is similar with the case of water demand during the widespread virus of COVID-19 which has equally increased the load on the water resource to fulfill customer needs. Additionally, the impact of income has shown that the peak demand for low-income areas is higher than those with high income. Moreover, the results showed the difference between the actual consumed demand compared to
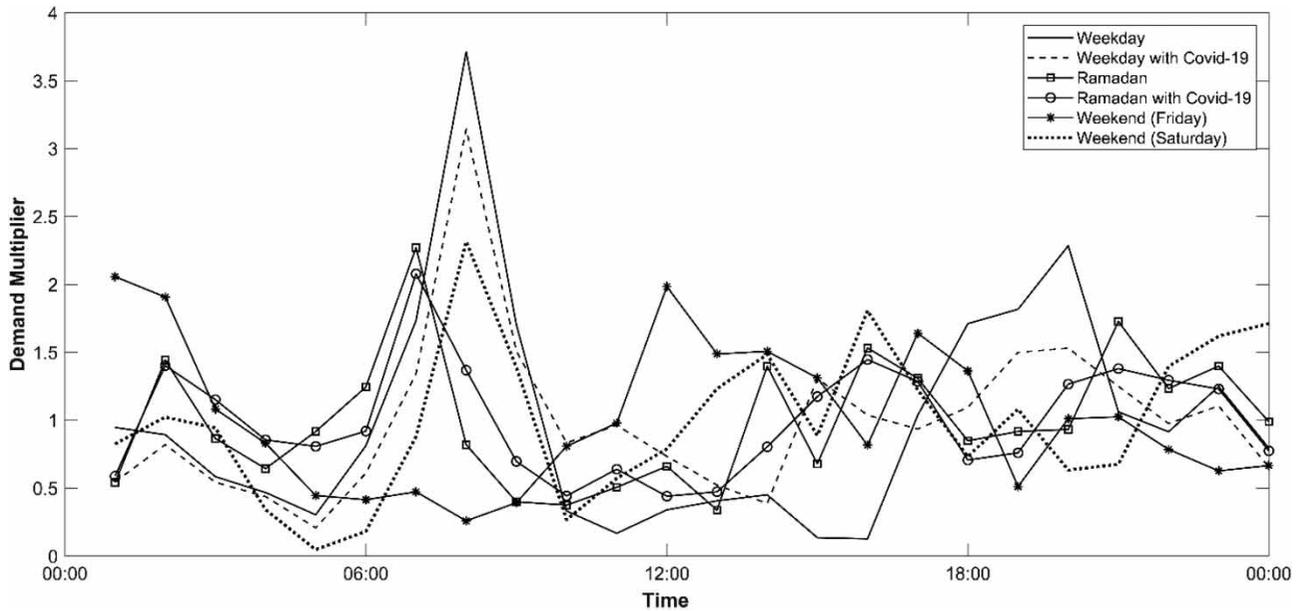
Figure 8 | Overall water demand profile generated to represent High-rise buildings for different conditions.

the ones that are provided by the region's code of practice. Furthermore, it has been examined that the curve during weekend is the least predictable as the behavior varies from person to person, which makes it essential for an urbanized city like Dubai that has lots of high-rise infrastructure and multiple functionalities to establish it. It would serve in design, reduction in cost (substantiality), hydraulic relief and an accurate representation of water usage by embedding it with the pump timings of a network. For future references, this study would be vital for new structures to be developed and prediction of WDP. One recommendation for future research is the relation between end-use appliances with the demand in this region.

DECLARATION

I, Syed Abbas Hussain Rizvi, hereby declare that this research paper titled 'Identifying and Analyzing Residential Water Demand Profile; Including the impact of COVID-19 and month of Ramadan for selected Developments in Dubai, United Arab Emirates', represents our own studied work with significant contribution from our Co-authors Rabee Rustum, Malini Deepak, Grant Wright and Scott Arthur. The manuscript has not been published in part or

in full elsewhere and is not under consideration for publication elsewhere. Moreover, each of the sections below is answered to my best knowledge and understanding.

AVAILABILITY OF DATA AND MATERIAL (DATA TRANSPARENCY)

We declare that our research included parts of information that were restricted and required external permission and authorization to obtain them.

CODE AVAILABILITY

Not applicable in this research.

AUTHOR CONTRIBUTION

We declare that all authors contributed on this paper's conception and design. Initial concept was proposed by Rabee Rustum after which the methodology that included data collection and analysis were performed by Syed Abbas Hussain Rizvi and Malini Deepak. The initial draft of the manuscript was written by Syed Abbas Hussain Rizvi and all authors commented on previous versions of the manuscript and made the necessary changes. Finally, each author read and approved the final paper.

CONFLICT OF INTEREST

We declare that we have no significant competing financial, professional or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

REFERENCES

Alarcón, R. A., Rodríguez, J. P. & Kua, H. W. 2019 Voluntary management of residential water demand in low and middle-low income homes: a pilot study of Soacha (Colombia). *Water (Switzerland)* **11**, 216.

Anang, Z., Padli, J., Rashid, N. K. A., Alipiah, R. M. & Musa, H. 2019 Factors affecting water demand: macro evidence in Malaysia. *Jurnal Ekonomi Malaysia* **53**, 17–25.

Anele, A., Hamam, Y., Abu-Mahfouz, A. & Todini, E. 2017 Overview, comparative assessment and recommendations of forecasting models for short-term water demand prediction. *Water (Switzerland)* **9**, 887.

Aquacraft (2011) *Embedded Energy in Water Studies Study 3: End-use Water Demand Profiles*. CA. Available at: http://www.aquacraft.com/wp-content/uploads/2015/10/CIEE-Water-Demand-Profile-Study.pdf (accessed 11 February 2020).

Banjac, G., Vašak, M. & Baotić, M. 2015 Adaptable urban water demand prediction system. *Water Science and Technology: Water Supply* **15**, 958–964.

Beal, C. D. & Stewart, R. A. 2013 Identifying residential water end uses underpinning peak day and peak hour demand. *Journal of Water Resources Planning and Management* **140**, p. 04014008.

Browne, A. L., Medd, W. & Anderson, B. 2013 Developing novel approaches to tracking domestic water demand under uncertainty-A reflection on the 'Up scaling' of social science approaches in the United Kingdom. *Water Resources Management* **27**, 1013–1035.

Coghlan, P. & Higgs, C. 2003 Domestic water use study. In Perth, Western Australia 1998–2001. *Hydro 2000: Interactive Hydrology*, 36 pp.

Felfelani, F. & Kerachian, R. 2016 Municipal water demand forecasting under peculiar fluctuations in population: a case study of Mashhad, a tourist city. *Hydrological Sciences Journal* **61**, 1524–1534.

Froelich, W. 2015 Dealing with seasonality while forecasting urban water demand. *Smart Innovation, Systems and Technologies* **39**, 171–180.

Garrone, P., Grilli, L. & Marzano, R. 2019 Price elasticity of water demand considering scarcity and attitudes. *Utilities Policy* **59**, p.100927.

Gurung, T., Stewart, R., Beal, C. & Sharma, A. 2015 Smart meter enabled water end-use demand data: platform for the enhanced infrastructure planning of contemporary urban water supply networks. *Journal of Cleaner Production* **87**, 642–654.

Gurung, T., Stewart, R., Beal, C. & Sharma, A. 2017 Reprint of: smart meter enabled informatics for economically efficient diversified water supply infrastructure planning. *Journal of Cleaner Production* **163**, S138–S147.

Hunt, J. F., Honeycutt, C. W. & Yarborough, D. 2010 Water demand. *International Journal of Fruit Science* **10**, 390–415.

Jamieson, D. G., Shamir, U., Martinez, F. & Franchini, M. 2007 Conceptual design of a generic, real-time, near-optimal control system for water-distribution networks. *Journal of Hydroinformatics* **9**, 3–14.

Koutiva, I. & Makropoulos, C. 2016 Modelling domestic water demand: An agent based approach. *Environmental Modelling & Software* **79**, 35–54.

Loureiro, D., Coelho, S. T., Machado, P., Santos, A., Alegre, H. & Covas, D. 2008 Profiling Residential Water Consumption. *Water Distribution Systems Analysis Symposium* **2006**, 1–18.

Maceda, C. 2015 UAE electricity consumption to grow 'more rapidly' | energy – Gulf News. *Gulf News*. Available at: https://gulfnews.com/business/energy/uae-electricity-consumption-to-grow-more-rapidly-1.1569200 (accessed 19 May 2020).

Mkireb, C., Dembele, A., Jouglet, A. & Denoeux, T. 2018
Energy-efficient operation of water systems through
optimization of load power reduction in electricity markets.
Journal of Electronic Science and Technology **16**,
304–315.

Pretorius, D., Crouch, M. L. & Jacobs, H. E. 2019 Diurnal water
use patterns for low-cost houses with indigent water
allocation: a South African case study. Journal of Water
Sanitation and Hygiene for Development **9**, 513–521.

Race, J. & Burnell, D. 2000 Water distributions systems analysis:
analysis of domestic demand patterns. In: Building
Partnerships. Reston, VA: American Society of Civil Engineers,
pp. 1–10.

Roberts, P. 2005 Yarra Valley Water 2004 Residential End Use
Measurement Study, pp. 1–77. Available at: http://www.
manuelectronics.com.au/pdfs/YarraValleyWater2004REUMS.
pdf (accessed 5 January 2019).

rsb.gov.ae 2017 Guide to Water Supply Regulations-Issue 3. Dubai.
Available at: http://rsb.gov.ae/assets/documents/191730/
guide_to_the_water_supply_regulations_issue_3_(2017).pdf
(accessed 9 February 2020).

Schleich, J. & Hillenbrand, T. 2019 Residential water demand
responds asymmetrically to rising and falling prices. Applied
Economics **51**, 4973–4981.

Stevens, J., Allen, J., McCauley, S., Weidling, J., Alvi, Z. & Joughin, J.
2016 A Historic Review and Outlook of Dubai's Real Estate
Sector From 2008 to 2016. Available at: https://www.asteco.
com/application/files/9314/8757/7030/20170115_astrep833_
q4report_dubai.pdf (accessed 3 September 2019).

Stokes, C. S., Simpson, A. R. & Maier, H. R. 2014 The cost–
greenhouse gas emission nexus for water distribution systems
including the consideration of energy generating
infrastructure: an integrated conceptual optimization
framework and review of literature. Earth Perspectives.
Springer Berlin Heidelberg **1** (1), 9.

Trifunovic, N. 2008 Introduction to Urban Water Distribution.
Taylor & Francis/Balkema. https://doi.org/10.1201/
9780203964699.

Voivontas, D., Arampatzis, G., Manoli, E., Karavitis, C. &
Assimacopoulos, D. 2003 Water supply modeling towards
sustainable environmental management in small islands: the
case of Paros, Greece. Desalination **156** (1–3), 127–135.