A Multi-Linear Regression Model to Predict the Factors Affecting Water Consumption in Qatar

M Alshaikhli\textsuperscript{1,a}, S Aqeel\textsuperscript{2,b}, N Valdeolmillos\textsuperscript{3,c}, F Fathima\textsuperscript{4,d} and P Choe\textsuperscript{5,e}

\textsuperscript{1}Computer Engineering Department, Qatar University, Qatar;
\textsuperscript{2}Computer Science Department, Qatar University, Qatar;
\textsuperscript{3}Architecture Engineering Department, Qatar University, Qatar;
\textsuperscript{4}Electrical Engineering Department, Qatar University, Qatar;
\textsuperscript{5}Mechanical and Industrial Engineering Department, Qatar University, Qatar

\textsuperscript{a}200753008@qu.edu.qa; \textsuperscript{b}199755081@qu.edu.qa; \textsuperscript{c}201912807@qu.edu.qa; \textsuperscript{d}201912900@qu.edu.qa; \textsuperscript{e}pchoe@qu.edu.qa

Abstract. Water scarcity is increasingly encouraging water-saving techniques and urban water management schemes committed to reducing the consumption of natural resources and the effects on the ecosystem. A comprehensive understanding of the nature of water supplies is required to design strategies for safe and effective use of water. Water management networks are complex. Consumption of water is affected by various variables, and therefore, the relationship of these variables is also complex. This study examines water consumption determinants in the State of Qatar, focusing on the factors linked to seasonal months by using a multiple linear regression model. The regression model was developed to accurately estimate the water consumption in Qatar to help the government’s plan for water usage in Qatar. The results of the model shows that the temperature-related regression coefficient is associated with an increase in water consumption per capita. In addition, an increase in population density for each unit is correlated with a decrease in water consumption per capita.

1. Introduction
Qatar is a country which is located in the Western part of Asia, occupying on North-eastern Arab Peninsula coast (latitude 25°18′N and longitude 51°31′E). It has a land area of 11,581 km\textsuperscript{2}, a population of 2.6 million in 2017. As one of the wealthy countries, the nominal GDP ranking of Qatar is 52\textsuperscript{nd} in the world in 2019, and the nominal GDP per capita is ranked 5\textsuperscript{th} in the world for the same year [1], [2].

The lack of tariffs on water schemes, along with a lack of protection knowledge, Rank Qatar among the top water consuming countries in the world. For 2013, local water consumption per capita per day had exceeded 500 Liter [3]. Sea dumping to build new towns and towers makes the area very susceptible to a saltwater path, a phenomenon which does not occur [3]. In 2008, Qatar initiated its 2030 National vision, in which one of the main aims for Qatar over the next 20 years is environmental progress. By this vision, Qatar vows to replace oil-based energy with sustainable alternatives to preserve the environment of both regional and global. Qatar landscape is mainly arid and desert-like, with high temperatures, very little rainfall, and sandstorms being very common [4].

The geographical position and climate factors such as humidity, rainfall, of Qatar have made the country at risk in terms of water security [5]. As for freshwater sources, Qatar is one of the poorest
countries [6], primarily due to a lack of annual rainfall, rivers, and lakes. Qatar depends mainly on groundwater (GW), desalted seawater (DW), and treated wastewater (WW) to meet its substantial water demands. The bulk of domestic water consumption comes from desalination plants because the groundwater resources are limited. Desalination is an energy-demanding process. With the increasing consumption patterns, much stress is put on the current desalination plants [7]. According to the National Development Strategy of Qatar between 2011–2016 (QNDS), one of its main objectives is to provide clean water and ensure its sustainable use. Further, the QNDS has highlighted its goal of “setting policies and regulations for the government to align consumption and supply over time while protecting water quality” [8], [9].

2. Literature Review
Substantial research has been done recently on factors that influence domestic water use. Economists in the United States and Australia work extensively to define the independent variables in which alternative calculations for water prices, determine the best supply strategies to regulate demand for water [10].

For example, reports have shown that the Spanish Mediterranean coast has a reverse correlation between urban density and water consumption [11], [12]. Where detached homes, water consumption rates strongly dependent on various aspects such as gardens’ size and scale. A study reported the most significant and mostly erratic use [11]. Many socio-economic and environmental variables were considered, including average monthly water supplies, population, household numbers, mean monthly temperature calculation (average monthly rainfall), and measurements of average months. The increase in the local population and the changes in temperature, household, and household income are considered [13].

The findings of Qi and Chang show that the demand for water is related to climate change, economic growth, population growth, migration, and even consumption [14]. A new model of system dynamics has indicated the connection between water demand and the macroeconomic environment, using sample estimates for long-term municipal water demand forecasts in an increasingly rising urban environment [14].

The lack of safe drinking water, especially in developing countries, is becoming a global problem increasingly severe. Worldwide, approximately one billion people cannot have clean water [15]. According to data from the Turkish Statistical Institute, the annual water per capita in Turkey is 1,519 m³ and is expected to decrease to 1,120 m³ by 2030. This water shortage is due to population growth. Research on the supply and demand of Arab Gulf water estimated that by 2050 almost all oil revenues were spent on fulfilling water demand [16].

Some studies showed a decrease in the number of households consumed per person [17], [18]. Many studies have shown that scale reductions are being accomplished with many household residents where cooking, dishwashing, gardening, and other household tasks are carried out and shared living atmospheres [18], [19]. Researchers have calculated the performance of three Florida systems involving the use of effective washer clothing, sinks, and toilets. No substantial results were obtained in the first year, but significant savings were made in both second and third years (15.6% for toilet recovery system) [20].

There has been little advance in technology in terms of retrofitting programmers, and researchers have received little attention on non-price related policies, especially since there has been a lack of substantial data. Most initiatives focus on technological standards to reduce expected demands [21], [22].

3. Regression Model
Regression is a technique for evaluating the statistical relationship between two or more variables when a change in a dependent variable is correlated with a change in one or more independent variables and depends on that change. Regression can be used to estimate the value of one variable, referred to as the "variable response," based on the value of other variables, referred to as the
“variables predictor”. For water consumption problems, a regression model is typically developed so that the response variable, which may otherwise be hard to obtain, can be approximated from more readily available information [23].

In this paper, the study is conducted on one dependent variable (Per Capita Water Consumption) in relationship with various independent variables (Population Density, Temperature, Humidity, Rainfall, Daylight, and Sunshine) targeting the use of Multiple Linear Regression to describe the impact of weather and population variables effect on water consumption per capita in Qatar.

3.1. Research Data
The data reported in the year 2017 for the state of Qatar collected from three sources were used in this study:

- Qatar General Electricity & Water Corporation-Kahrama [24].
- Qatar Planning and Statistics Authority [5].
- Weather Atlas [25].

The monthly measurement is taken for the year 2017:

- Per capita water consumption: The definition of water use per capita is also used to measure water usage over time or between groups of people (towns, counties, etc.) who use public water sources (e.g., city water). In general, it means the average amount of water used daily by each person in a given area, expressed as "Litres per capita per day." The data used is the monthly consumption per capita in the state of Qatar, as measured by the Qatar General Electricity & Water Corporation – Kahrama for the year 2017- as shown in Table 1.

Table 1. Water per Capita Consumption.

| Month    | Water per capita consumption (Litres/day) | Population |
|----------|------------------------------------------|------------|
| January  | 557                                      | 2576181    |
| February | 530                                      | 2673022    |
| March    | 541                                      | 2659261    |
| April    | 582                                      | 2675522    |
| May      | 614                                      | 2700539    |
| June     | 677                                      | 2545820    |
| July     | 695                                      | 2471919    |
| August   | 704                                      | 2446328    |
| September| 646                                      | 2634234    |
| October  | 629                                      | 2668415    |
| November | 609                                      | 2682596    |
| December | 583                                      | 2641669    |

- Population Density: Population density is one of the main reasons considered to have an effect on water consumption. Population density is defined as the total number of people per square kilometer. Table 1 shows the monthly population in the state of Qatar in Millions for the year 2017, as reported by Qatar Planning and Statistics Authority.
• Temperature: Environmental Technology Magazine has ranked Qatar in an article in August 2019 as the number one hottest country in the world with average summer temperatures of an incredible 42°C. Figure 1 shows monthly average temperatures in Qatar for the year 2017, as reported by Weather Atlas.

**Figure 1 Temperature Averages**

• Humidity: Humidity readings are typically given as 'relative humidity,' which is the amount of humidity in the air compared to how much humidity may occur. It is as a percentage provided. Figure 2 shows the monthly Humidity readings for the year 2017 in Qatar, as reported by Weather Atlas.

**Figure 2 Average Humidity**
• Rainfall: Is the amount of precipitation falling over a given period: it is specified in terms of the water depth which falls into the rain gauge. The average precipitation per month in Qatar in (mm) for the year 2017 is reported by Weather Atlas, as shown in Figure 3.

![Average Rainfall](image)

**Figure 3** Average Rainfall

• Daylight: Daytime is approximately the duration of the day, during which any given point in the world receives natural light from direct sunlight and is measured in hours. The data used for this research is reflected, as shown in Figure 4, as reported by Weather Atlas for the year 2017.

![Daylight/Sunshine](image)

**Figure 4** Daylight/Sunshine

• Sunshine: Sunshine period is typically measured in hours per year or (average) hours per day and allows the comparison of sunshine at the same location in different seasons. The data used for this research is reflected, as shown in Figure 4, as reported by Weather Atlas for the year 2017.
4. Analysis and Results

Prior to performing the multiple linear regression analysis, normality, and equal uniformity of the data were tested. Correlations were examined to avoid multicollinearity between the different independent variables, as shown in Figure 5.

| Correlation: Total (Liter/day, population, temperature, humidity, rainfall, daylight, sunshine) |
|---------------------------------------------------------------|
| population | Total (Liter/day) | population | temperature | humidity |
| -------- | ----------------- | ---------- | ----------- | ------- |
| population | -0.706 | 0.010 |
| temperature | 0.819 | -0.499 |
| humidity | -0.627 | 0.310 |
| rainfall | -0.924 | 0.420 |
| daylight | 0.000 | 0.174 |
| sunshine | 0.020 | 0.161 |
| rainfall | 0.082 | -0.901 |
| daylight | 0.082 | 0.000 |

**Figure 5** Correlation Result

The results from Figure 5 indicated that:
- There is a strong positive correlation between Water Consumption per Capita and the factors: Temperature, and Sunshine
- There is a strong negative correlation between Water Consumption per Capita and the factors: Population Density and Rainfall
- There is a moderate correlation between Water Consumption per Capita and the Daylight factor as a positive correlation and with Humidity factor as a negative correlation
- Temperature, Rainfall, Daylight, and Sunshine are highly correlated positively or negatively

Given the above results, the factor Population Density is identified to be included in the intended multiple linear regression model. However, it is a negative correlation for the fact that Water per Capita is calculated based on population, unlike moderate correlation factors of Humidity and Daylight, which were identified to be discarded from the intended multiple linear regression model. Factors showing multicollinearity were tested separately in a linear regression model against the dependent variable to decide on the factor to include in the intended multiple linear regression model, as shown in Figures 6, 7, and 8.

Comparing the results, it is evident that the Temperature and Rainfall factors have higher $R^2$ parameters than the Sunshine factor. Nevertheless, given the fact that the Rainfall is not an element strongly related to the Qatari atmospheric agents in comparison to Temperature, it is decided to include the factor Temperature in the linear regression model.

After analyzing the data for assumption satisfaction, the Multiple Linear Regression analysis was run through Minitab 17 between the dependent variable (Water Consumption per Capita) and the two independent variables (Population Density, Temperature) at an $\alpha = 0.05$.

The null and alternative hypotheses for testing were defined as below:
- $H_0$: There is no significant relationship between water per capita consumption and population and temperature.
- $H_1$: There is a significant relationship between water per capita consumption and population and temperature.
The multiple linear regression test outcome analyzed as that for the test results, the p-Values suggest that there is a significant relationship between Water Consumption per Capita in Qatar and the factors Population Density and Temperature rejecting the null hypothesis at α = 0.05.

The $R^2$ for the conducted analysis in this research is evaluated by Minitab to be 92.63%, whereas the Adjusted $R^2$ value is 91.00% and high predictability with Predicted $R^2$ value 89.11%. The resulting coefficients show the high impact of temperature in comparison to the population with a regression equation:

$$\text{Total (Liter per Day)} = 1027 - 0.0006 \times \text{population} + 6.523 \times \text{temperature}$$  \hspace{1cm} (1)

The result of the regression equation can be interpreted as below:

As the value of the coefficient represents the mean change in the response given a change of one unit in the predictor. The temperature-related regression coefficient is 6,523; each one-unit temperature increase is associated with an increase in water consumption per capita of 6,523 litres. In addition, an increase in population density for each unit is correlated with a decrease in water consumption per capita of 0.000226 litres.

5. Conclusion and Future Plans

Our study aimed at understanding the combined effect of several influences on domestic water use in Qatar. Despite the inclusion of socio-demographic variables, our regression model results show the climate factor of temperature, as a significant influencer on urban water demand.

However, we acknowledge the shortcomings of the analysis mainly due to the absence of available data on the transient population and its residence period. Nevertheless, it is essential to know that knowledge of water consumption in Qatar is not currently available, and data collection is challenging. The transient population should be measured because this aspect has a higher environmental effect on water consumption. This was assessed by some researchers measuring factors such as months of use of water or solid waste production from extensive analyses within the municipality [26]. These relationships should be considered at a local level by water policies. Municipal governments must enable non-conventional methods, such as rainwater storage and greywater recycling schemes, to be introduced in residential buildings in order to deal with water shortages.

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